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COMPARATIVE BASEFLOW HYDROCHEMISTRY OF VARIOUS SEPTIC SYSTEM DENSITY GROUPS WITHIN THE YELLOW RIVER WATERSHED, GWINNETT COUNTY, GEORGIA

by

ROBERT CARL NEURATH

Under the Direction of Seth Rose

ABSTRACT

Baseflow water chemistry between different septic system density groups was analyzed to understand how septic system usage impacts the water quality of the Yellow River Watershed located in Gwinnett County, Georgia. Seventy water samples were collected at baseflow conditions in the summer of 2006. The samples were analyzed for the abundance and distribution of chlorides, sulfates, nitrates, and specific conductance. Geographic Information Systems were used to determine sample collection sites, assign samples into density groups, and spatially analyze and display the results. Statistical methods were used to compare the results of each density group with all others, and to find any correlation of the anions with respect to specific conductance. Regression coefficient values between nitrate and specific conductance in all groups average 0.77 and the elevated nitrate concentrations in group four suggest a limited relationship between septic system density and baseflow water quality. INDEX WORDS: Baseflow Water chemistry, Geographic Information, Systems, Septic systems.

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by

Robert Carl Neurath

A Thesis Submitted in Partial fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in the College of Arts and Science

Georgia State University

2007

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Robert Carl Neurath
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by

Robert Carl Neurath

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Committee: W. Crawford Elliott
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Office of Graduate Studies
College of Arts and Sciences
Georgia State University
August 2007

Dedication

I dedicate this thesis to my wife, Susan Neurath, for her love and support during this project.

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I would like to thank my advisor Dr. Seth Rose for his guidance and his sharing of his extensive knowledge of the subject during this thesis, his advisement went way above my expectations. Thanks also to my other committee members, Dr. W. Crawford Elliott for his penetrating questions and detailed review of my thesis drafts, and to Dr. C. Virginia Lee for coming aboard on short notice and allowing me the time to complete this project.

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Chapter 1 – Introduction

The purpose of this thesis is to analyze the baseflow inorganic chemistry of member streams in the Yellow River Watershed located in Gwinnett County, Georgia and relate the occurrence of the chemical variation of the nitrate, chloride, and sulfate anions, and specific conductance measurements to septic system density. It is important to find out if there is a significant difference in the baseflow water chemistry between different septic system density groups in order to understand how septic system usage impacts the water quality of those streams through the baseflow. The working hypothesis is that high concentrations of sulfates, chlorides, nitrates, and specific conductance are directly related to septic system density. To test this hypothesis, water samples were taken from the watershed during baseflow conditions and the samples were analyzed for the abundance and distribution of chlorides, sulfates, nitrates concentrations, and specific conductance. Statistical techniques were applied to determine if there is a significant difference in the water chemistry among the different septic system density groups. Finally the results were displayed using geographic information system software to derive a visual depiction of how septic system usage impacts the water quality of the Yellow River Watershed.

Chapter 2 – Background

Septic Systems and the Water District

Septic systems are an issue of local concern in the Metropolitan North Georgia Water Planning District, an assembly of 16 counties surrounding and including the city of Atlanta, Georgia (Figure 1). In 2003, the Water District adopted a Long-Term Wastewater Management Plan which began a district-wide discussion on septic systems and their management. Throughout the Water District, over half of the stream lengths were found to not fully support their designated use (Jordan J. Goulding, 2003). Water District Health Department Officials have noted non-point source pollution as the major cause of water quality impairment with failing septic systems identified as one possible source of the contamination (MNGWPD, 2005).

The Water District recognized that there are few programs or requirements in place and very little data available to determine the exact pollutant contribution to the streams from septic systems (MNGWPD, 2006). In an effort to fill that gap, the Atlanta Regional Commission in 2005, under the guidance of the Long Term Wastewater Management Plan, was tasked to create a survey and interview the Environmental Health Officers of the Water District. The purpose of the survey was to gather information to summarize the current usage of septic systems, practices, problems, and suggestions for improvement in their respective counties.

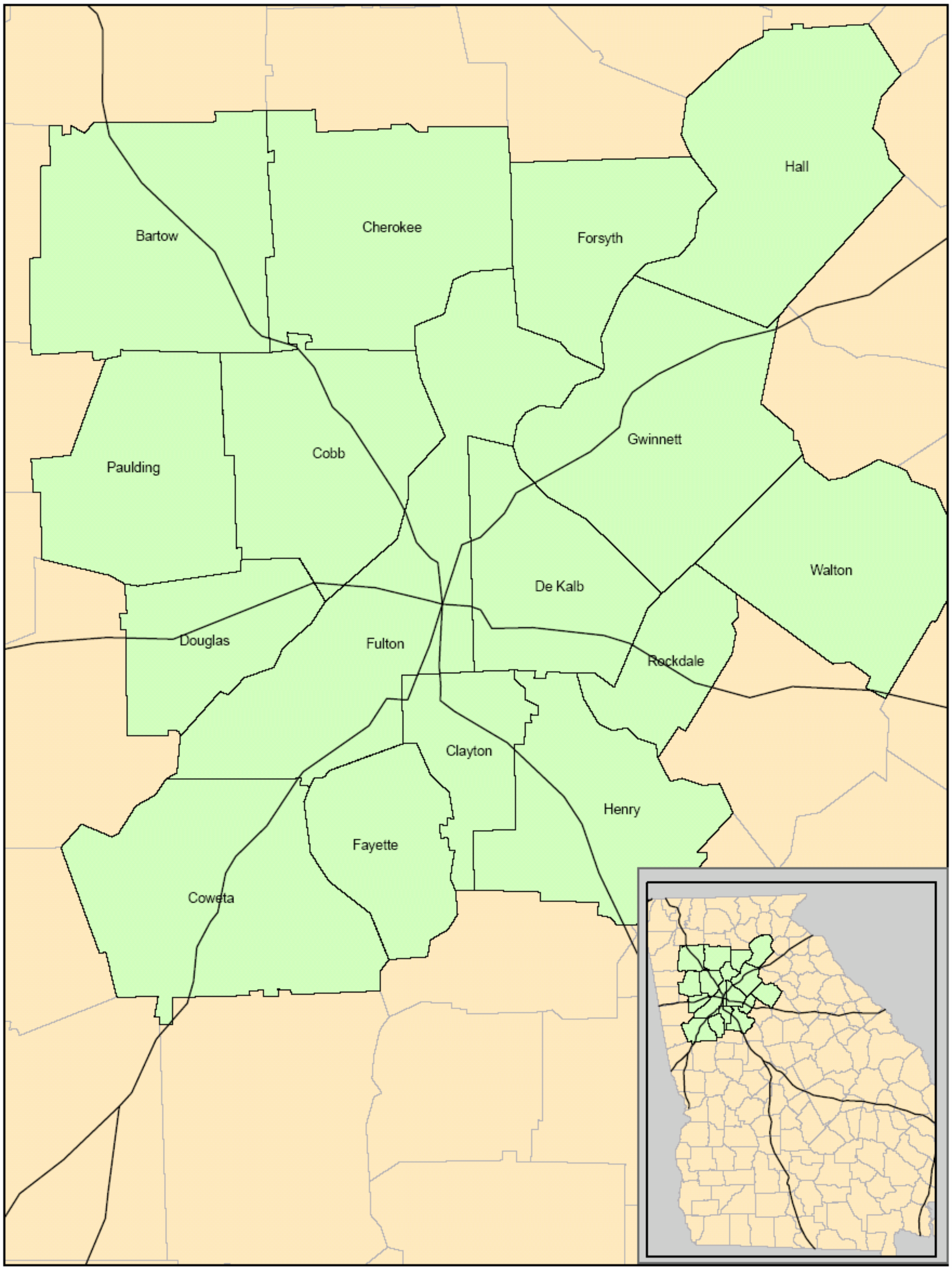


Figure 1 - Metropolitan North Georgia Water Planning District MNGWPD

The results of the survey estimated that the number of septic systems in the Water District is to be greater than half a million systems with over 12,000 septic systems being added per year due in part by the rapid expansion of the population into the outlying suburban counties (GDHR, 2006). Approximately two percent or about 4000 septic systems in the Water District fail per year (MNGWPD, 2005). The main cause of septic system failure in the Water District is that the systems are installed in unsuitable soils and locations (Figure 2). "Unsuitable soils" is a regulatory term that attempts to classify soils by their ability to receive and process effluent, which is based on the characteristics of an individual drainfield. Seventy four percent of the soils within the Georgia Piedmont are deemed unsuitable for conventional septic systems. Three characteristics are shallow bedrock or other impervious surfaces, drainfield slope, and low permeability (GDHR, 2006).

The survey did not determine an exact pollutant contribution to the streams from septic systems. Previous studies indicate specifically that septic systems do affect the health and usability of streams and wells (Arnade, 1999; Hem, 1989; Khayat, 2006; Peck, 1994; Robertson, 2000; Sinton, 1982; USEPA, 2002). The US Environmental Protection Agency states that septic system densities in some groups exceed the capacity of even suitable soils to assimilate the contaminants found in the effluent. In addition, many systems are located too close to ground water or surface waters and others, particularly in rural groups with newly installed public water lines, are not designed to handle increasing wastewater flows (USEPA, 2002).

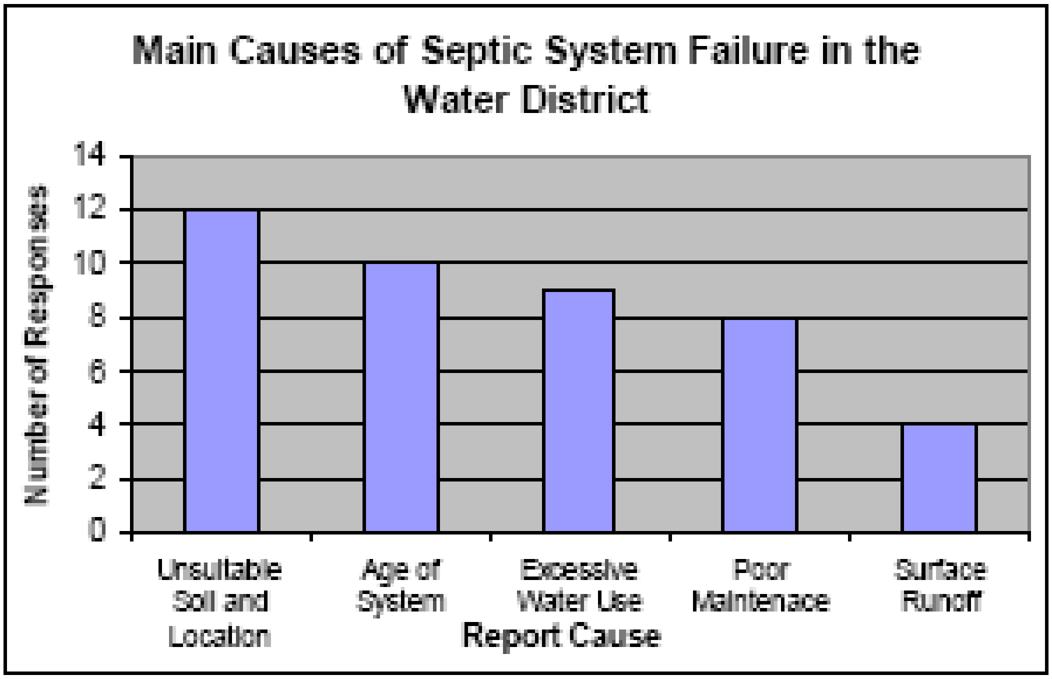


Figure 2 - Main Causes of Septic System Failures in the MNGWPD (from MNGWPD, 2005)

At one time, the Water District considered septic systems as a temporary solution to wastewater treatment until sewer lines could be extended. Currently it appears that sewers will not be installed to some portions of the Water District (MNGWPD, 2005), which guarantees that more septic systems will be installed causing a greater septic system density in certain groups. Consequently, Water District counties are concerned that the volume of in-place septic systems along with the growing installation of septic systems could significantly impact the overall health of their watersheds and streams (MNGWPD, 2005).

To summarize, the goal of this thesis is to address some of these concerns by testing the hypothesis that high septic system density groups tend to yield high concentrations of sulfates, chlorides, nitrates, and specific conductance measurements while low septic system density groups tend to yield lower concentrations and measurements of those constituents.

CHAPTER 3 - Septic Systems Overview

Wastewater contains many substances that if left untreated are potentially harmful to the public health and the environment if introduced to streams via failing septic systems. Data collected since 1981 indicates that approximately half of the water borne disease outbreaks were attributed to contaminated ground water (Borchardt et al., 2003). Present in wastewater are significant concentrations of bacteria, infectious viruses, organic matter, toxic chemicals, and excessive nitrogen and phosphorus. To protect the public and the environment from these, the wastewater must be treated and disposed of in a safe and effective manner (GDHR, 2006). Septic systems that are properly installed and maintained have proven to perform as well as centralized sewer systems (USEPA, 2002).

Septic systems within the Piedmont Province of Georgia are typically located in the vadose zone of the regolith and effluent is discharged into the ground water system via a septic tank and a drainfield, (Figure 3). The function of the septic tank is to separate solids from liquids and to promote the partial breakdown of the solids by microorganisms naturally present in the wastewater.

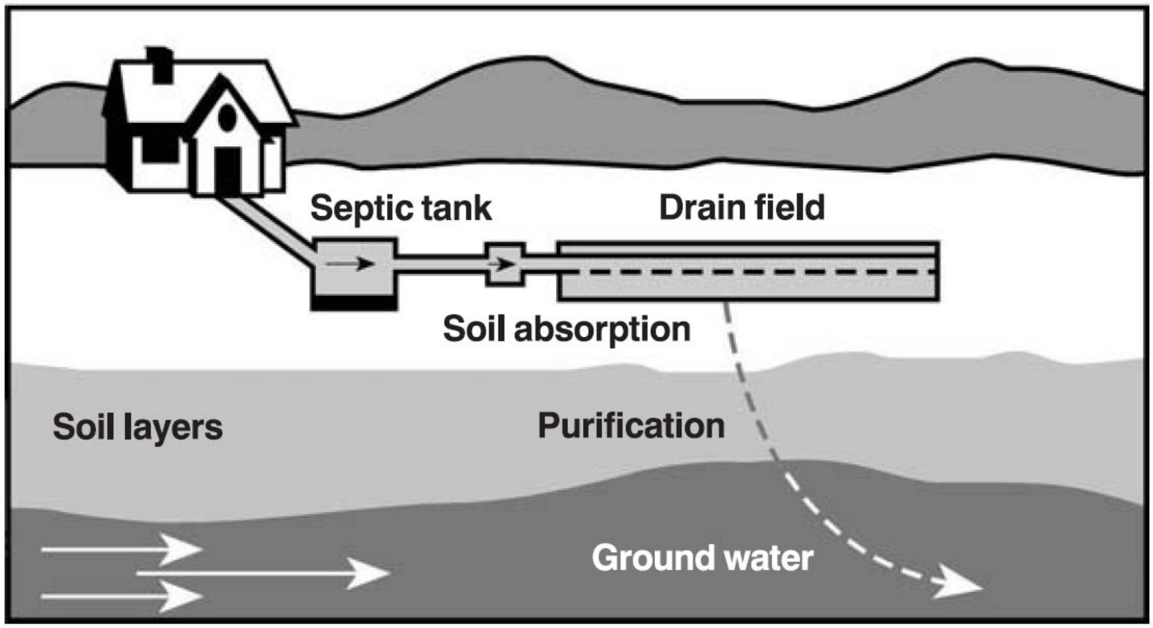


Figure 3 - Typical Septic System Layout (from USEPA, 2002)

The drainfield further treats the effluent by biological processes, sorption, filtration, and infiltration (Evans, 1999).

The Septic Tank

The septic tank represents an anaerobic environment where the concentration of dissolved oxygen is low and the concentration of organic matter is high. Normal household sewage enters the septic tank at a rate of approximately 160 liters/person/day via a pipe from the residence that contains toilet, bath, kitchen, and laundry wastes (Wilhelm et al., 1994). Approximately 99% of the sewage is liquid while the remaining 1% is solids. It is this small percent of the solid material that is mainly responsible for causing health hazards. Two-thirds of this 1% of solids are organics while the remainder

is inorganic. The organic compounds in sewage are divided into three groups, proteins, carbohydrates, and fats. The protein group contains all the proteins, amino acids, and urea, the carbohydrate group contains sugars, starches, and cellulose, and the fat group contains the fats, oils, grease, and soaps (GDHR, 2006).

Microorganisms that are present in the wastewater and the septic tank obtain their energy from fermentation and anaerobic reduction of organic matter. The microorganisms first hydrolyze large organic molecules found in the waste water and sludge into simpler molecules such as amino acids, sugars, and fatty acids as shown in Equation 1a,b,c - Organic Molecule Hydrolysis (Wilhelm et al., 1994).

Proteins + H_2O → Amino acids [Equation 1a]

Carbohydrates + H_2O →Simple sugars [Equation 1b]

Fats + H_2O → Fatty acids and glycerol [Equation 1c]

The amino acids and simple sugars produced in equations 1a and 1b undergo fermentation, in which the organic carbon is both oxidized and reduced. This produces intermediate organic acids, acetate, and water as shown in Equation 2 – Amino Acids and Simple Sugars Fermentation (Wilhelm et al., 1994).

Amino acids, simple sugars →
H_2O, acetate ($CH_3\ OO^-$), and other organic acids [Equation 2]

The urea and amino acids that are a component of the protein group react with water to produce ammonium, carbon dioxide and organics as shown in Equations 3a,b – Ammonium Release (Wilhelm et al. et al., 1994).

$$\text{Urea } [CO(NH_3^+)_2] + H_2O \rightarrow 2\ NH_4^+ + CO_2 \qquad \text{[Equation 3a]}$$

$$\text{Amino acids} + H_2O \rightarrow 2\ NH_4^+ + \text{Organics} \qquad \text{[Equation 3b]}$$

The fatty acids and intermediate organic acids produced in Equations 1c and Equation 2 undergo anaerobic oxidation. This process forms CH_3OO^- (acetate) and H_2 as shown in Equation 4 – Fatty Acids Anaerobic Oxidation (Wilhelm et al., 1994).

$$\text{Fatty acids} + H_2O \rightarrow H_2,\ CH_3OO^- \qquad \text{[Equation 4]}$$

In addition, if SO_4^{2-} is available, microorganisms will use it as an electron acceptor to oxidize organic carbon (CH_2O) to produce CO_2 and hydrogen sulfide H_2S as shown in Equation 5 – Sulfate Reduction (Wilhelm et al., 1994).

$$SO_4^{2-} + 2\ CH_2O + 2\ H^+ \rightarrow H_2S + 2CO_2 + 2H_2O \qquad \text{[Equation 5]}$$

In the final steps of anaerobic digestion, methanogenic bacteria produce methane CH_4 as shown in Equation 6a,b - Methanogensis (Wilhelm et al., 1994). Acetate and CO_2 are the reactants.

$$CH_3OO^- + H^+ \rightarrow CH_4 + CO_2 \qquad \text{[Equation 6a]}$$

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O \qquad \text{[Equation 6b]}$$

These above reactions have been confirmed by the presence of their products in septic-tank gases. Gas bubbles collected within five septic tanks consisted on average of 73% CH_4 , 12% CO_2 , 13% N_2 , and trace amounts of H_2S, O_2 , and H_2 (Wilhelm et al., 1994).

The chemical breakdown of the proteins, carbohydrates, and fats also results in a physical breakdown of the solids. The fats are lighter than water and float to the top of the tank forming a layer of scum. The remaining solids are divided into settled, soluble, and suspended solids. The suspended and settled solids undergo the bacterial decomposition as previously discussed and sink to the bottom of the tank. This leaves a volume of solubles comprising a middle layer of clarified wastewater between the fat group and the settled solids. It is this middle layer that is discharged to the drainfield. The remaining fats and solids should be pumped out of the tank at recommended regular intervals every 3 – 5 years (GDHR, 2006).

The Drainfield

Whereas the septic tank represents an anaerobic environment, the drainfield represents in general an aerobic environment. The drainfield is where the effluent undergoes its most significant oxidizing geochemical changes. The effluent is discharged to the drainfield via pipes and a distribution box at a typical flow rate of 1 to 5 cm/day. The drainfield is typically lined with aggregate that promotes percolation and aerobic conditions. How well the drainfield removes or immobilizes the effluent is dependant upon the physical properties of the drainfield that include the seasonal ground water height, the height below the drainfield of the bedrock or other impervious strata, if the

drainfield contains any back filled soil, the grading, the slope, and the drainage patterns of the drainfield (GDHR, 2006). Other properties that need to be considered are the thermodynamic instability of organic matter, the nitrogen cycle, and the availability of O_2 within the drainfield (GDHR, 2006; Wilhelm et al., 1994).

Before a septic system is built, a soil survey evaluates the physical properties of the drainfield to their effectiveness of removing or immobilizing the effluent to acceptable levels before discharge to baseflow. Once a survey has passed then a permit to build a septic system is approved. Within the Georgia Piedmont only 26% of the soils have the appropriate properties that are suited for a high-quality septic system drainfield that is capable of renovating the effluent (GDHR, 2006).

Within the aerobic conditions of the drainfield, the microorganisms are capable of almost completely oxidizing the reduced components present in the effluent. These components are ammonium NH_4^+, hydrogen sulfide H_2S, and organic matter CH_2O. The organic carbon is oxidized as shown in Equation 7 – Organic Matter Oxidation and the organic sulfide is oxidized as shown in Equation 8 – Sulfide Oxidation (Wilhelm et al., 1994).

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad \text{[Equation 7]}$$

$$H_2S + 2\ O_2 \rightarrow SO_4^{2-} + 2H^+ \qquad \text{[Equation 8]}$$

The nitrogen cycle which began in the septic tank continues in the drainfield. The ammonium that escapes adsorption by the soils is oxidized into nitrite Equation 9 –

Nitrification (Weismann, 1994) followed by the oxidation of these nitrites into nitrates Equation 10 – Oxidation of Nitrogen (Weismann, 1994).

$$NH_4^+ + 2\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+ \quad \text{[Equation 9]}$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \quad \text{[Equation 10]}$$

Bacteria, such as the *Nitrosomonas* species can change ammonia to nitrite while the *Nitrobacter* species can change nitrite to nitrate (Watson et al., 1981).

Denitrification is an anaerobic process that requires a source of carbon. This process Equation 11 - Denitrification (Wilhelm et al., 1994) reduces some of the nitrates in the soil to nitrogen gas (N_2).

$$5\ CH_2O + 4\ NO_3^- + 4\ H^+ \rightarrow 2\ N_2 + 5\ CO_2 + 7\ H_20 \quad \text{[Equation 11]}$$

The bacteria species *Paracoccus denitrificans* aids in the denitrification process. The soluble nitrate that escapes the denitrification process has the ability to enter the baseflow and evidently surface waters.

Chapter 4 – Study Suite of Constituents

Disposal of wastewater through a septic system creates a plume that contains elevated concentrations of nitrate, sulfate, and chloride which are three reliable septic indicators of domestic wastewater in baseflow (USGS, 2000). Conceptually, most of the bacteria, infectious viruses, organic matter, toxic chemicals, excessive nitrogen, and phosphorus present in the effluent are removed or immobilize to acceptable levels before discharge to baseflow. However the worst case scenario occurs when the effluent is no longer in contact with favorable environmental conditions resulting in a failure. Two examples of a failure are: 1) when the plume is mixing with the water table; and; 2) second the soils are overwhelmed with effluent and the soils can not properly remove or immobilize the effluent (Evans et al., 1999). At this point, the effluent plume will move in response to the prevailing hydraulic gradient and this movement can lead ultimately to contamination of lakes, rivers, streams, wetlands, coastal areas, or ground water (USEPA, 2002).

Several studies indicate a positive linear relationship between baseflow nitrate concentrations and housing densities in unsewered groups, meaning that when the housing density increases so does the nitrate concentrations (Sinton, 1982; USGS, 2000). Nitrification is unavoidable in septic systems; however NO_3^- might not undergo the denitrification process and enter baseflow. Wilhelm et al., (1994) cited a study about mixing models of septic systems; where the NO_3^- that escaped denitrification was modeled to mix with the ground water to dilute the NO_3^- concentration. The study

concluded that this approach is questionable in high population density groups and geological environments as fractured bedrock where high NO_3^- concentration plumes are found at considerable distances from the source (Wilhelm et al., 1994).

The least degree of treatment of the effluent occurs when O_2 is limited in the drainfield and oxidation does not occur. This anoxic condition may lead to an increase of organic carbon and NH_4^+ that is sorbed to the drainfield sediments, and plumes of dissolved organic carbon and NH_4^+ may form in the baseflow. Further solid organic carbon may clog the drainfield sufficiently and prevent the percolation of the effluent. The effluent might pool in the drainfield and enter the surface waters as untreated sewage through run-off (Wilhelm et al., 1994).

Above background concentrations of nitrate, chloride, sulfate, and specific conductance measurements have been noted as possible indications of septic system failure. The USGS used nitrate, sulfate, and chloride, among other constituents, to identify and characterize the quality of ground water contributions to surface waters within the Croton watershed New York (USGS, 2000). They concluded that both nitrate and sulfate concentrations could be predicted in small streams from the density of septic systems (USGS, 2000). Burns et al. (2005) studied the same watershed and concluded that the nitrate and sulfate baseflow concentrations in the high and medium residential densities were greater than the undeveloped groups and specifically cites septic systems as a likely contributor to this increase (Burns et al., 2005). Nizeyimana, (1996) cites several sources that have concluded that ground water contaminated with nitrate is

strongly correlated with population and septic system densities (Nizeyimana, 1996). Chloride concentrations > 28 mg/L were used as a septic indicator and possible presence of fecal contamination of wells down gradient of septic system drainfields (Borchardt et al., 2003).

Nitrate (NO_3^-)

Nitrogen in its nitrate form is a significant ground water pollutant. The Maximum Contaminant Level (MCL) for nitrate is 10 mg/L. Nitrate is a water soluble anion and does not sorb to soils or evaporate. Because of this solubility, nitrates have a high potential to migrate into baseflow and eventually enter surface waters and wells (USEPA, 1997). Nitrate has been detected in urban and rural ground waters throughout the United States and in some places the levels exceed the USEPA drinking water standard of 10 mg/L as nitrogen – N (Hem, 1989). Water ingested with these high levels of nitrate could cause potential human health problems. For example the conversion of nitrate to nitrite (NO_2^-) by the body can lead to methaemoglobinemia in human infants. This potentially fatal syndrome interferes with the oxygen-carrying capacity of the blood resulting in shortness of breath and blue skin. Long term exposure can result in diuresis, an increase of starchy deposits and hemorrhaging of the spleen (USEPA, 2006).

Surface waters that contain excessive levels of nitrate could lead to eutrophication which causes excessive algal growth called algal blooms. The bloom will eventually die and sink to the bottom. The blooms decay causes the depletion of dissolved oxygen, which usually results in the disappearance of aquatic insect species and fish (Smith et al.,

1999). Figure 4 illustrates the chemical processes of ammonification, nitrification, and denitrification and how nitrate species can enter baseflow and eventual the surface waters via septic systems as discussed in the "Septic System Overview" section.

The following study is summarized to illustrates what might occur if the drainfield soils can not treat or immobilize the effluent and is a testament of the cycle and solubility of nitrogen. Leblanc (1984) observed nitrogen in the form of ammonia up to 5,000 feet in the center of a sand aquifer plume. Overlying the plume is a thin zone of ground water containing more than 1 mg/L nitrate in the center of the plume. Between 5,000 feet and 8,000 feet from the origin, nitrogen in the plume changes from ammonia to nitrate. Nitrate was detected farther than 8,000 feet from the origin (Leblanc, 1984).

The observed change in the species of nitrogen in the plume as the contaminated ground water moves away from the origin is the result of oxidation of ammonia to nitrite in the presence of dissolved oxygen. In the center of the plume, within 5,000 feet of the origin, dissolved oxygen is absent and most of the nitrogen is in the form of ammonia, and nitrate is absent.

Ammonia is oxidized to nitrate in the thin boundary zone along the top and sides of the plume within 5,000 feet of the origin. In this zone, ground water outside the plume which contains as much as 11 mg/L dissolved oxygen mixes with the contaminated ground water that contains elevated levels of ammonia. The oxidation of ammonia to nitrate also occurs in the center of the plume between 5,000 and 8,000 feet from the origin as the contaminated and uncontaminated ground water mix. Both ammonia and

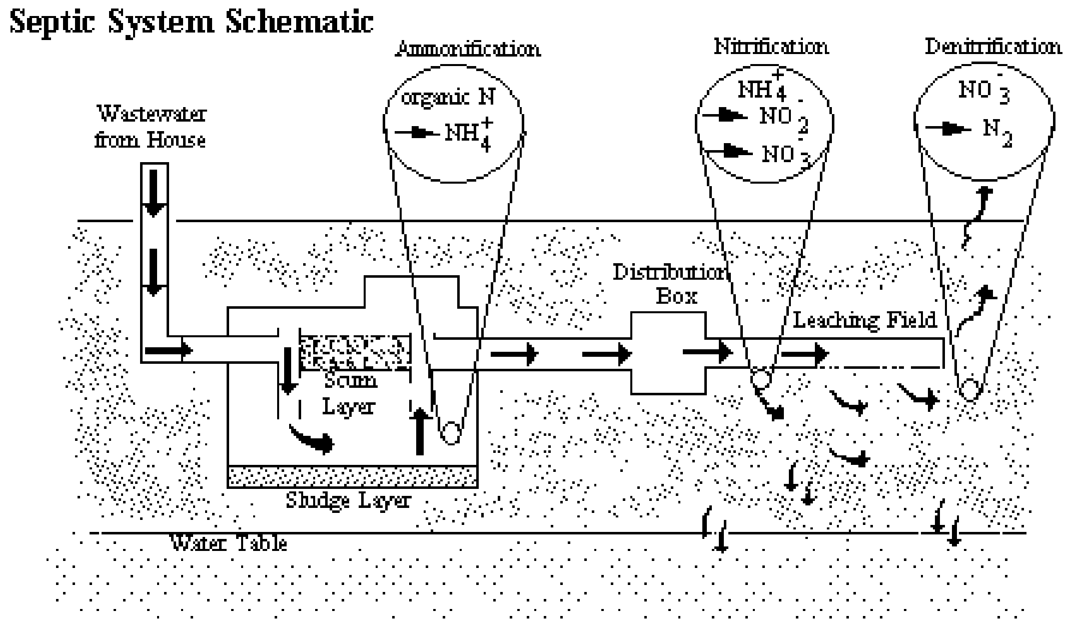


Figure 4 - Nitrogen Cycle within a Septic System (from Ecosystems, 2006)

nitrate are present at concentrations greater than 1 mg/L at this site. The oxidation of ammonia was essentially complete 8,000 feet down gradient of the origin (Leblanc, 1984).

Chloride (Cl^-)

Chloride is present in all natural waters in low concentrations. In most surface streams, chloride concentrations are lower than those of sulfate or bicarbonate. However, studies have shown that streams that receive a source of high-chloride ground water, or industrial wastewater or those experiencing salt water intrusions have chloride concentrations elevated above sulfate or bicarbonate (Sherwood, 1989). The primary

source of chloride is from rainwater that experiences a cycle that begins and ends in the oceans. Evaporated water precipitates as rain over land and then the runoff enters the streams and eventually flows back to the oceans (Hem, 1989).

The MCL for chloride is 250 mg/L and was established primarily for aesthetic reasons (USEPA, 2006). The concentration at which the average person can taste chloride in water is at 250 mg/L. A very high chloride level can lead to corrosiveness of pipes and heating equipment. High levels are typically associated with high sodium levels which could lead to health problems if ingested. Anthropogenic elevated chloride concentrations may be caused by sewage contamination, run-off from road salting, or an improperly maintained water softener (USEPA, 1988). The presence of chloride in septic system effluent is from the human diet and human wastes (LeBlanc, 1984). Chloride can leach into the ground water because of its high solubility (USEPA, 2002). This high level of mobility together with the fact that chloride ions result from a wide range of human activities makes chloride an ideal ion for monitoring the anthropogenic influences on natural freshwater systems (Sherwood, 1989).

Sulfate (SO_4^{2-})

Sulfate occurs naturally in Piedmont drinking waters. High concentrations greater than 100 ppm are primarily a result of the weathering products of gypsum, while the breakdown of organic matter both natural and human waste contribute to low background concentrations. High concentrations of sulfate have been noted in previous studies downstream from wastewater treatment plants (Burns, 2005). The USEPA in

conjunction with the Centers for Disease Control and Prevention (CDC) concluded in a study that there is a weak increase (not statistically significant) of diarrhea cases in the population that when accustomed to low concentrations ingested water with the higher concentrations of sulfate (USEPA, 1999). The MCL of sulfate is 250 mg/L.

The sulfur compounds in the sewage are decomposed to hydrogen sulfide under the anaerobic conditions in the septic tank. In the aerobic drainfield the sulfur bacteria oxidize these compounds first to sulfates and then to sulfites. However if the drainfield is experiencing anaerobic conditions and consequently failing, the sulfates are reduced to sulfides. Ferrous sulfide is associated with a failing septic system and an indication that the drainfield is lacking sufficient oxygen to immobilize the effluent (GDHR, 2006).

Specific Conductance

Specific Conductance is a measure of a waters ability to transmit an electrical current. Electrical conductivity in water is the reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature. Because conductance is the reciprocal of resistance, the units in which specific conductance are shown as the reciprocal ohms, or mhos. Natural waters have specific conductance measurements much less than 1 mho. Under the International System of Units (SI) the measurement units for specific conductance are the “siemens.” Specific conductance measurements are reported in this thesis in microsiemens per centimeter μS/cm (Hem, 1985).

Specific conductance measurements are proportional to the amount of dissolved solids in the water. Total dissolved soilds or TDS are the presence of dissolved solids in water such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution (Hem, 1989). If an anion or a cation is dissolved in water and can pass through a 0.45 micron membrane then it is considered a dissolved solid. Specific conductance is used an indirect measure of the total dissolved solids. The concentration of TDS in mg/L, or ppm is about 65 percent of the specific conductance measurement μS/cm. This relation is not constant from stream to stream, and it may vary in the same stream with changes in the composition of the water (BASIN, 2005). Factors that contribute to varying specific conductance measurements are the area geology and soil, the presence of acid mine drainage, agriculture runoff, road runoff, and the location of wastewater treatment plants, and septic system locations within the watershed (BASIN, 2005). Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

Chapter 5 – The Study Area

General Information

The Yellow River Watershed (YRW) is located in Gwinnet County ~ 30 miles northeast of Atlanta, Georgia (Figure 5). The YRW is the largest of the six watersheds within the county draining 162 square miles of southwestern Gwinnett and a small portion of eastern DeKalb County. The YRW is part of the larger Ocmulgee River watershed. The average discharge of the YRW measured at USGS gage station number 02207120 located where GA 124 crosses the Yellow River is 316.52 feet ^{3} per second with the average runoff of 26.5 inches per year. Rainfall amounts in the Piedmont are on average 50 inches per year (Plummer, 1983). Land use from 1998 is shown in Figure 6 for the portion of the watershed located within Gwinnett County (USGS, 2002). The dominate land use is low-to-medium density residential. Commercial and industrial developments are concentrated along the major transportation corridors. Four waste water treatment facilities discharge into the watershed (USGS, 2002).

Hydrogeology of the Yellow River Watershed

The Yellow River Watershed is located geologically in the Piedmont Province of Georgia and represents a typical Piedmont watershed. Piedmont aquifers are mostly small ground water units confined to small watersheds with perennial streams (LeGrand, 1988). In simplest terms the Piedmont can be described as a thick regolith layer overlying fractured crystalline and metamorphosed sedimentary rocks, both of which are the water-bearing units.

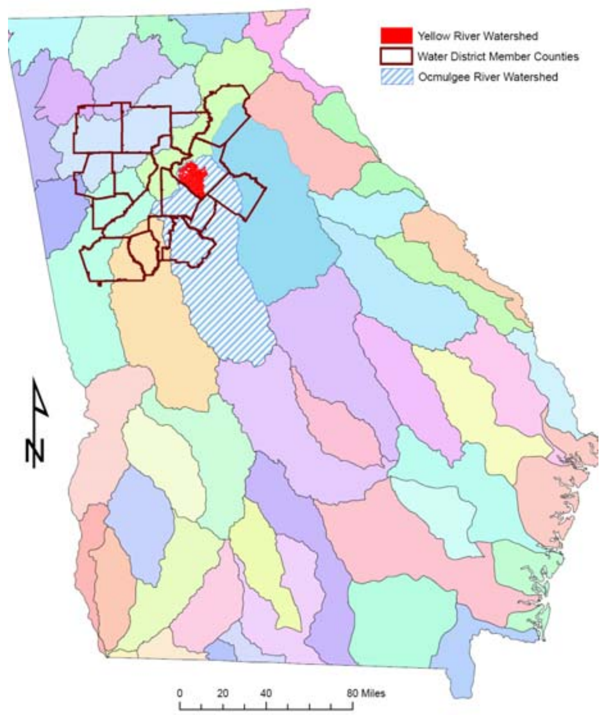


Figure 5 - The Location of the study area in Relation to the MNGWPD and other Georgia watersheds.

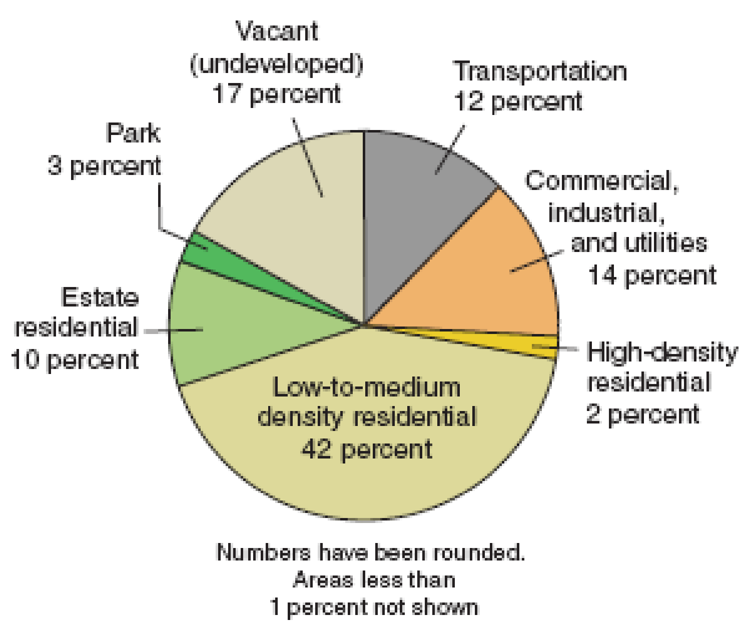


Figure 6 - 1998 Landuse of the study area (from USGS, 2002).

The rocks are of Precambrian and older Paleozoic age that have undergone intense structural deformation that includes thrust faulting, large-scale folding and faulting, partial melting, and intrusion of granitic bodies. While these igneous and metamorphic rocks have low permeability, and a fracture and joint system gives the rocks secondary permeability and porosity (Cressler et al.,1983). Figure 7 illustrates the surface geology of the study area and nearby surrounding area.

In situ weathering of the bedrock produces the overlying layer of regolith. The regolith layer varies in thickness from approximately 2 – 20 meters but can be absent in some places and thicker than 20 meters in other places. Figure 8 shows the regolith thickness as a function of the topography of the area. Regolith is typically thin on ridges and hilltops and thicker in valleys and draws (USGS, 1990). The porosity of the regolith is on average between 20 -30% and the average hydraulic conductivity is between 0.001 – 1 meter per day (Heath, 1984).

Figure 9 represents the typical Piedmont landscape. The water table follows the topography of the watershed, but with less relief while the regolith provides storage and the fractures provides secondary porosity. Recharge occurs primarily by rain that falls on the areas above the flood plains of streams. The precipitation percolates into the vadose zone of the regolith then moves as baseflow into and through the saturated zone to discharge points represented as surface depressions and streams (Heath, 1984). The residence time for shallow ground water comprising of baseflow in the Piedmont is

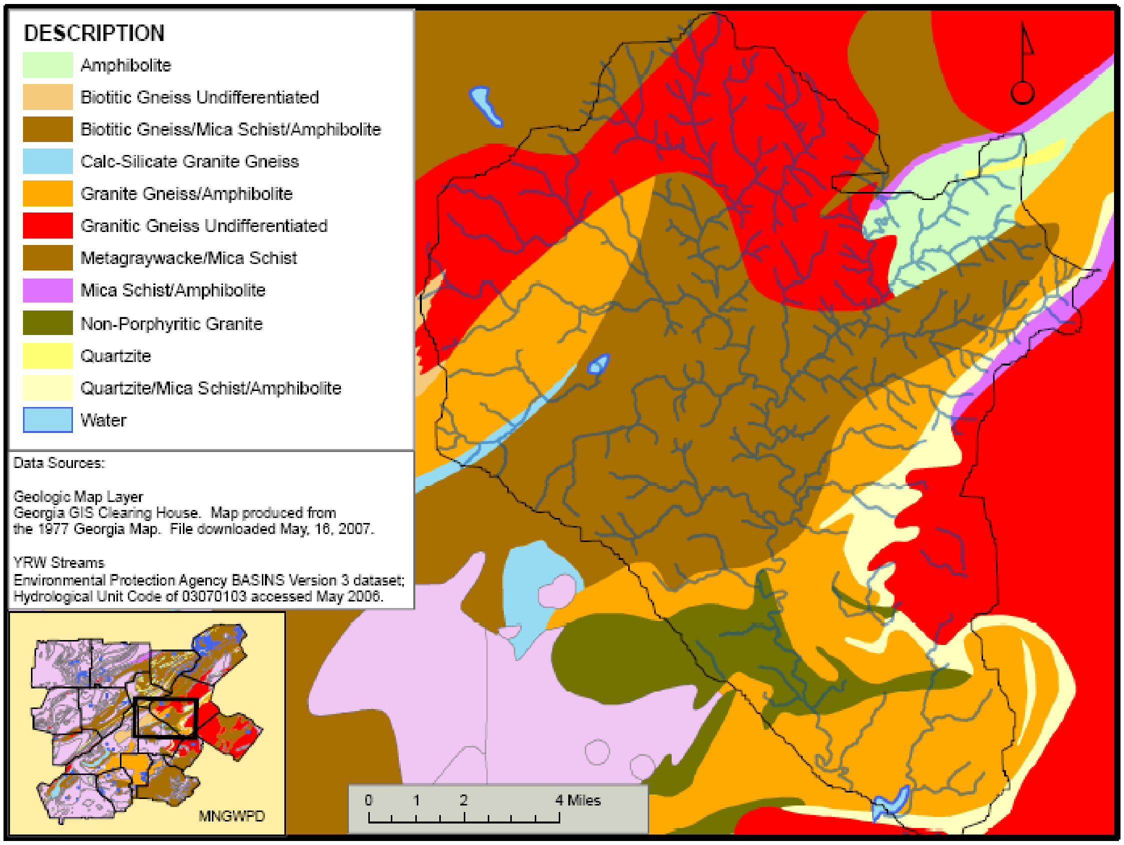


Figure 7 - Geological map of the study area (after GDNR, 1999)

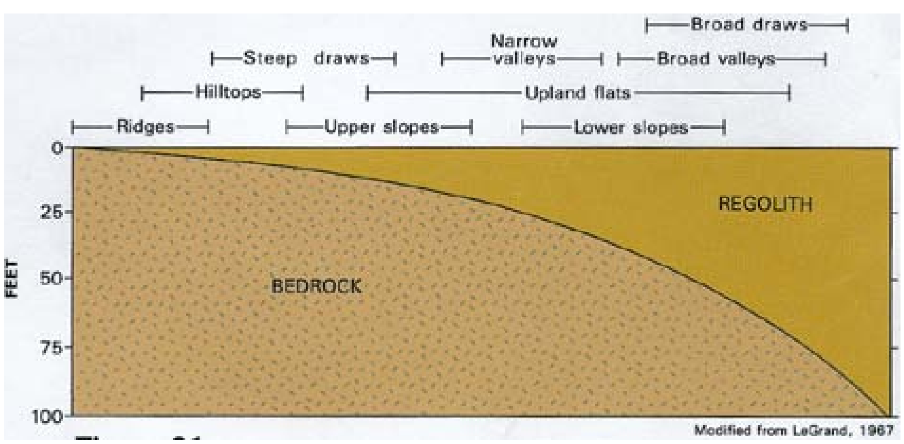


Figure – 8 Factors effecting regolith thickness (from USGS, 1990).

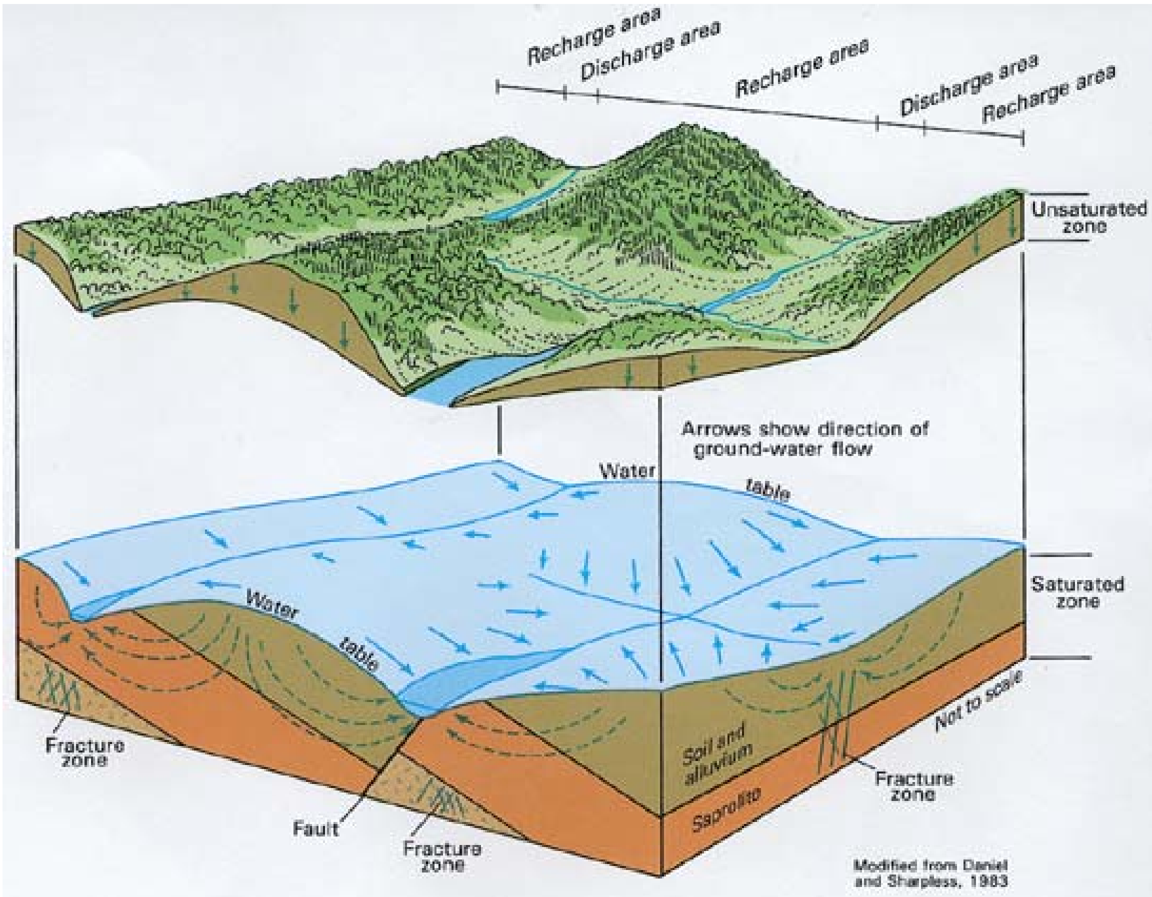


Figure 9 - Typical Piedmont Watershed showing topography, water flow, regolith and fracture zones, (from USGS, 1990).

between 14 and 18 years (Rose, 2007). This calculation was done by Rose, 2007 in a model that used multiple baseflow tritium measurements taken from one location coupled with regional tritium precipitation concentrations spanning several decades.

Baseflow

Collecting samples during baseflow conditions is critical to this thesis. Baseflow is the portion of the streamflow that comes from ground water and not surface runoff. Figure 10 illustrates a yearly cycle of streamflow and baseflow within the YRW between

the years 1998 and 2001. Baseflow yield and flow varies little while stormflow yield and flow varies greatly through out the year (USGS 2002). Stormflow chemistry varies with the rise and fall of the storm surge (Rose, 2002), while baseflow chemistry is more stable (USGS 2002).

As septic system effluent percolates through the vadose zone it could find a pathway into baseflow and eventually into the streams. The chemical quality of baseflow gives an indication of the composite quality of the ground water within the basin (USGS 2000). Therefore, baseflow makes for a reliable and convenient method of sampling and determining constituent concentrations.

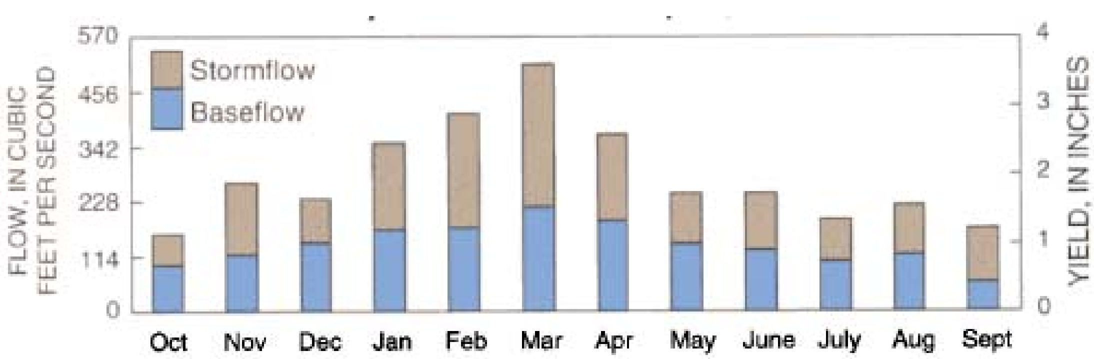


Figure 10 - Monthly mean flow and water yield, 1998 – 2001, (from USGS, 2002).

Piedmont Water Chemistry

The water chemistry of the Piedmont is derived from the weathering and erosion of the Piedmont rocks in contact with the water. The Piedmont rocks are divided into two groups with each group producing their own distinct water chemistry. The first group of rocks includes granite, granite gneiss, mica schist, slate, and rhyolite flows and

tuffs. The second group includes diorite, gabbro, hornblende gneiss and andesite flows and tuffs. The geology of the YRW is composed of the first or granite group that yields a soft, slightly acidic water that is low in total dissolved solids usually less than 100 mg/L (LeGrand, 1988).

Chapter 6 – Methods and Procedures

Geographic Information Systems

Geographic Information Systems were used in this project to create a basemap from which all other maps were derived. Environmental Systems Research Institute (ESRI) commercially available desktop software, ArcGIS 9.2, was used as the platform for the creation of the maps used in this project. ESRI was founded in 1969 as a privately held consulting firm that specialized in landuse analysis projects. The worldwide headquarters of ESRI are located in Redlands, California (ESRI, 2007). The maps were used to divide the watershed into density groups, to locate suitable sample collection sites, to calculate the average distances between sub-basins within the watershed, and to give a spatial dimension to the results.

The digital base map was created first and then appropriate layers were added to create the individual maps. The basemap was created by obtaining four digital USGS topographical quadrangles (Snellville, Stone Mountain, Norcross, and Luxomni). These were imported into the ESRI Geographic Information System and projected at WGS 1984 UTM Zone 16N Transverse Mercator. This layer provided a large scale view of the study area that includes the buildings, powerlines, streams, elevation contour lines, and the transportation network. All these features are used to locate the sample collection site on the map and in the study area.

Added to the quadrangles is a polygon representing the Yellow River Watershed drainage basin boundary that was obtained from the USGS Water-Resources

Investigations Report 02-4281 USGS (2002), and the Environmental Protection Agency BASINS Version 3 Hydrological Unit Code of 03070103 (USEPA, 1998). The BASINS attributes designate member streams of the Yellow River, the location of USGS gage stations, and wastewater treatment plants. This dataset also includes the 1990 census tract data that contains the attributes of census tract location, population, number of households within the census tract, where these households obtain their water and sewer services, and if the household is using a septic system. The drainage basin boundary and the BASINS dataset were both processed in the GIS program using the clip tool to create a geographic subset of the BASINS dataset that excludes all but the study area as defined by the drainage basin boundary.

The watershed was divided into septic system density groups that are defined as the number of households using a septic system per total number of households in a given census tract. The density groups were calculated and added to the attribute field of the BASINS dataset. The resultant percents are grouped into four septic density groups representing the < 25%, 26-50%, 51-75%, and 76-100% households on septic systems for a given census tract. A fifth group was created that represents those samples collected downstream from a wastewater treatment plant.

To aid in selecting sample sites, three northeast trending transects were plotted on the base map to minimize any anomaly of the sample caused by an increase or decrease in the constituents present in baseflow. The possible increase or decrease could come from discharges into the stream i.e. the draining of a swimming pool or effluent pooling

in the drainfield and runoff into the stream prior to sample collection. Since the transects are plotted across all the septic density groups, the sample collection sites where chosen so all septic density groups are represented in each day of sampling. All sample sites were located in a stream crossed by a bridge.

ArcGIS was used in the computation of 14 randomly selected distances that represent the distance in a sub - basin from a hill to a stream within the YRW. The previously created base map was used with the Environmental Protection Agency BASINS Version 3 Hydrological Unit Code of 03070103 EPA BASINS dataset and the four digital USGS topographical quadrangles. The drawing tool was used to draw lines between hill tops and first and second order streams. The measure tool was used to measure that distance in miles.

Figure 11 shows the digital base map of the Yellow River Watershed displaying the road and stream network, septic system density groups, wastewater treatment plants, and gage stations. A summary list of all the map titles, a list the layers used to create the maps, a description of the layers, and their references are provided in Appendix A.

Sample Collection

A total of 70 stream water samples were collected during baseflow conditions from May 25, 2006 to July 13, 2006. Figure 12 shows the sample locations by density group. A summary table of sample location, the density group it is in and the stream the sample was collected from may be found in Appendix A. Upon arrival at the proposed sample location a visual survey was conducted to insure safety and the correct execution of the

sampling protocol. Samples were collected by lowering a polyethylene one gallon sample collection device into the center of stream flow as determined by visual inspection. Between 2 – 3 liters of stream water was collected at each location. All test equipment and final collection bottles were acid rinsed prior to collection then rinsed with the collected stream water prior to in-field testing of nitrates, specific conductance, and water temperature. Between one half and one liter of stream water was then placed in a DI and stream water rinsed collection bottle. The bottle was labeled with the sample identifier that included the date and sample number in the format of month day year and sample count of the day. The sample identifiers are located on Figure 12. The sample location was marked on a paper map with the sample identifier and the location and ID later transferred to GIS software and the database. At the end of the day all of the sample bottles were refrigerated locally until transported to Georgia State University and placed in a refrigerator until the time for laboratory analysis.

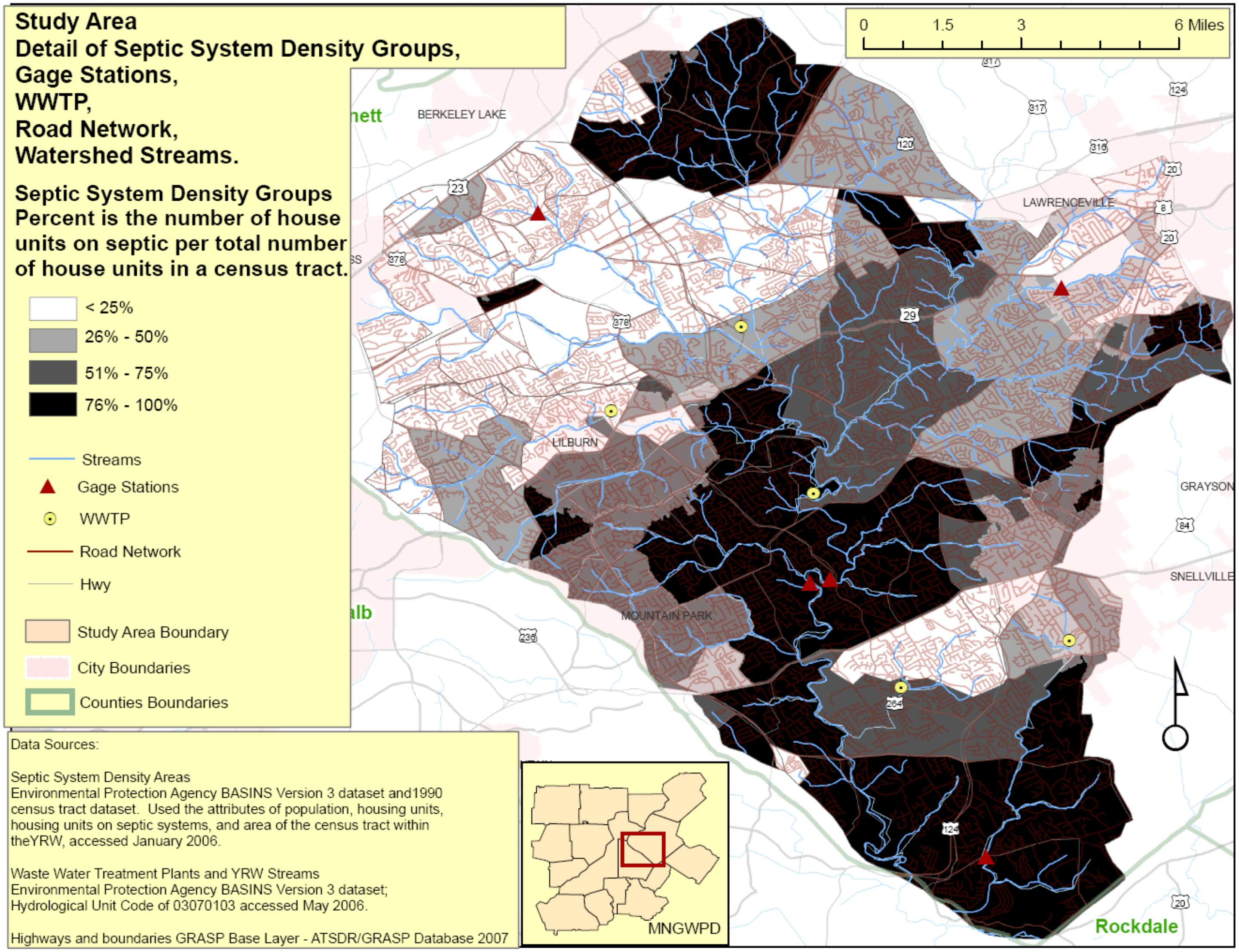


Figure 11 - The Yellow River Watershed Study Area

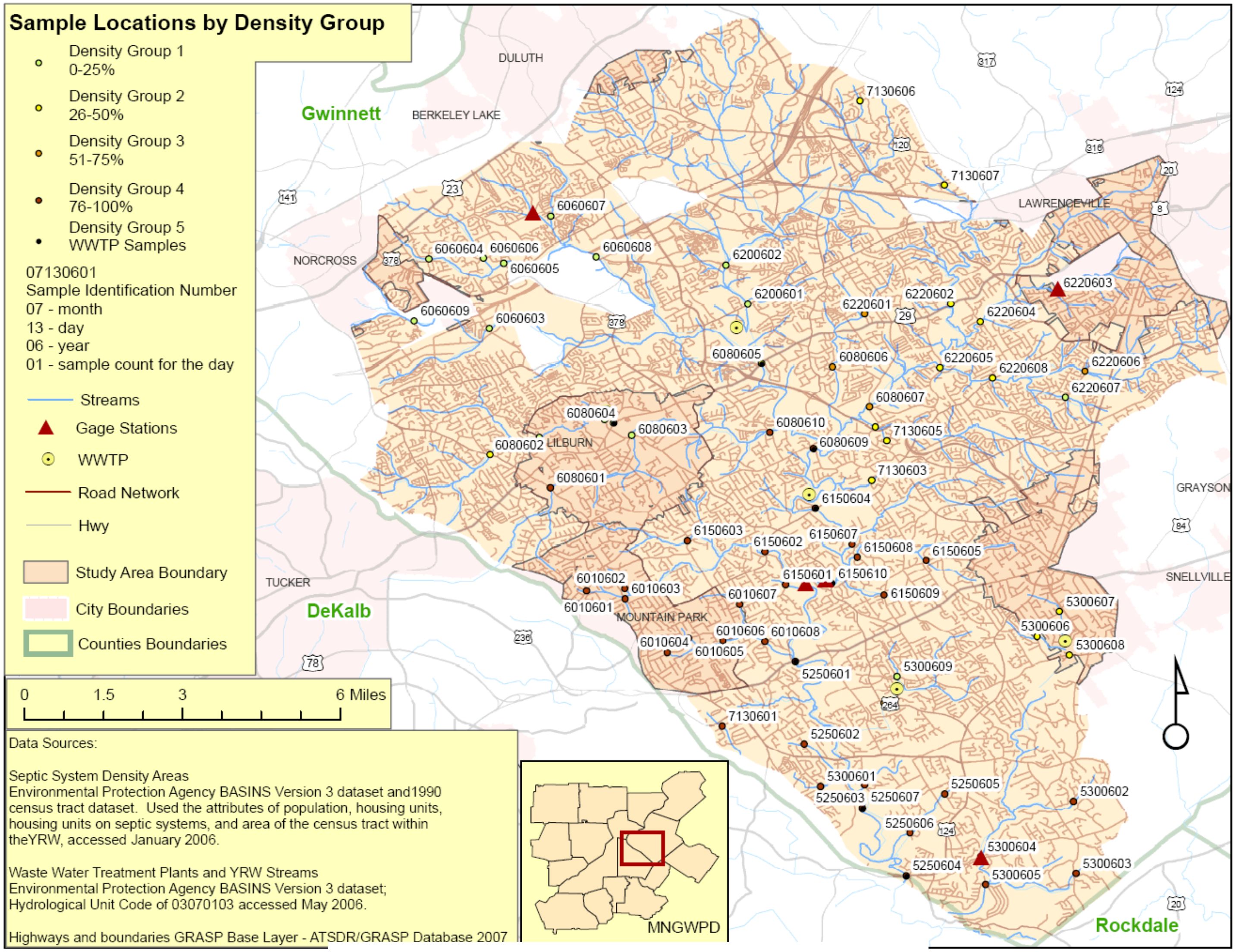


Figure 12 – Sample Location by Density Group

To determine baseflow conditions, United States Geological Survey USGS gage station number USGS02207185 No Business Creek at Lee Road was used. This gage station is located at the outflow point of the watershed and determined as representative of the watershed's baseflow conditions. Baseflow conditions were defined when the discharge which occurs between storm events has a minimal slope on the hydrograph (Rose, 1993). Figure 13 represents the hydrograph used to determine baseflow conditions during the sample period. The points located on the gage line represent the days that water samples were collected. In addition, online weather radar was used to show any precipitation falling in the study area that might influence baseflow conditions.

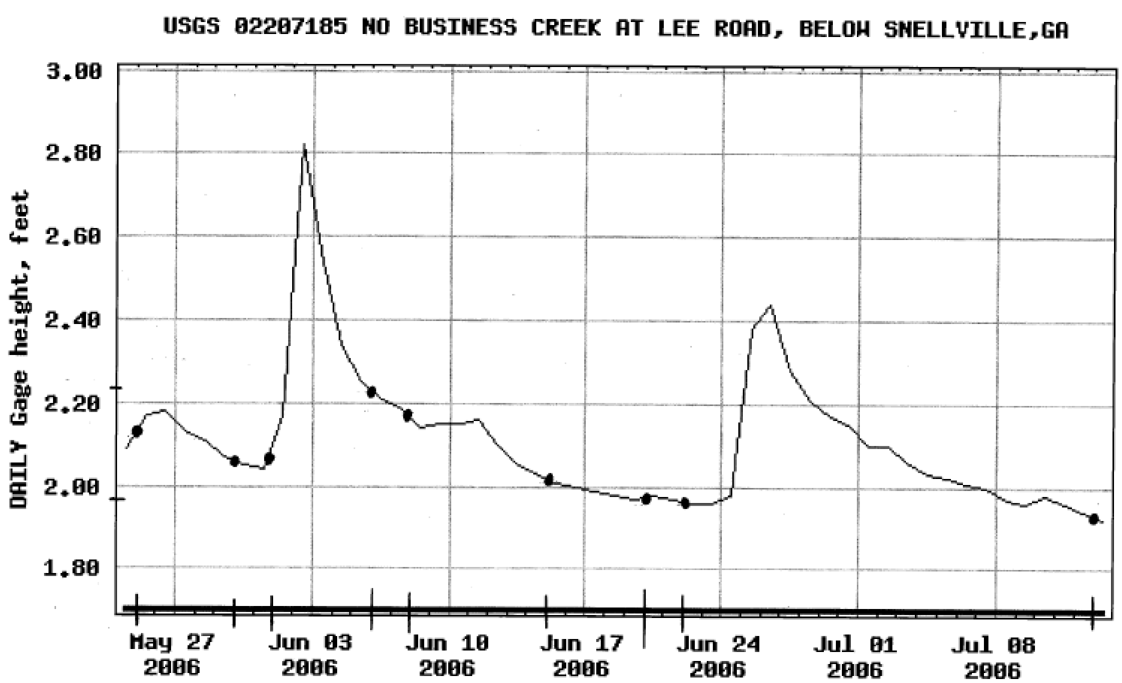


Figure 13 – Hydrograph used to determine baseflow conditions, (after NWIS, 2007).

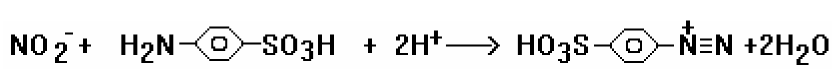
Rainfall amounts totaled 5.5 inches as measured during the sample collection phase (May 2006 to July 2006) in Lawrenceville, Georgia (a city located on the eastern edge of the YRW)

Sample Analysis

The analysis of nitrates and specific conductance were accomplished within 15 minutes of collection at the sample location. Specific conductance and temperature were measured using the YSI model #85/10 FT Oxygen Conductivity Salinity Temperature test probe. Nitrate concentrations were determined with the Hach method Nitrate – Nitrite test kit Model NI-12 Hach catalog number 14081-00. The nitrate tests used cadmium metal to reduce the nitrates (NO_3^-) to nitrites (NO_2^-) by this reaction.

$$NO_3^- + Cd + 2H^+ \dashrightarrow NO_2^- + Cd^{+2} + H_2O \qquad \text{[Equation 12]}$$

The cadmium is contained in the provided powder pillows and was added to the stream water sample following the provided procedure. Nitrite ions then react with sulfanilic acid to form an intermediate diazonium salt contained in the powder pillows by this reaction.



[Equation 13]

sulfanilic acid diazonium salt

This results in the formation of an amber colored solution. The color intensity is directly proportional to the nitrate concentration of the water sample. The color is then matched

to a provided color wheel and the nitrate concentration is read from the color wheel (Juniata College, 2007).

Chloride and sulfate analysis were accomplished at Georgia State University, Geosciences Department Hydrogeology Laboratory from July 27, 2006 to September 12, 2006. Chloride concentrations were determined by titration using the Mohr's method. This method determines the chloride ion concentration of a solution by titration with silver nitrate. As the silver nitrate solution is slowly added, a precipitate of silver chloride forms.

$$Ag^{+}_{(aq)} + Cl^{-}_{(aq)} \text{-->} AgCl_{(s)} \qquad \text{[Equation 14]}$$

The indicator used is dilute potassium chromate solution. When all the chloride ions have reacted, any excess silver nitrate added will react with chromate ions to form a red-brown precipitate of silver chromate indicating the end point.

$$2Ag^{+}_{(aq)} + CrO_4^{2-}{}_{(aq)} \text{-->} Ag_2CrO_{4(s} \qquad \text{[Equation 15]}$$

From the end point value the chloride concentrations were calculated by multiplying the volume of titrant used by the normality and dividing by the sample volume. Multiplying the resulting meq/L of the sample by the atomic weight of chlorine (35.453 grams/mol) yields the concentration of chloride in the sample (Canterbury, 2006).

The sulfate concentrations were determined by using the Hach Test Kit Sulfate Pocket Colorimeter II Analysis System Model number 58700-29. The sulfate concentration used the barium sulfate turbidimetric method. Barium ions contained in

the provided powder pillows react with the sulfate ions to produce insoluble barium sulfate by this reaction.

$$Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4 \qquad \text{[Equation 16]}$$

Since the barium sulfate is insoluble it forms as a milky cloudy precipitate. The amount of this turbidity is proportional to the amount of sulfate present in the sample. A blank sample has light passed through to record the natural turbidity present in the sample, then the sample with the $BaSO_4$ is measured and compared to the blank, the difference is the amount of sulfate in the water sample. The turbidity is measured spectrophotometrically because the cloudiness reduces the amount of light that passes through the sample yielding the sulfate concentration of the sample (Juniata, 2007). A summary of the analytical laboratory and field test results may be found in the Appendix.

The Method Detection Limits (99% confidence level; Table -1) for nitrates, chlorides, and sulfates were determined from an analysis of spiked de-ionized water that was tested using the same methods and procedures as the samples. A total of 15 spikes were analyzed for each anion, the results noted, the mean and standard deviations calculated and then the MDL for each anion calculated by multiplying the standard deviation by the 99% value of the students t-test chart = n-1 (Analytical, 1996).

Precision values were determined from the 15 spikes of each anion mentioned above. The standard deviation was divided by the mean and multiplied by 100 to give the percent of error in precision (Analytical, 1996).

Table 1 - MDL and Precision Values with Calculations.

	[Spike] mg/L	Mean Value	Standard Deviation	Students T-Test Value	Precision percent	MDL mg/L
Nitrates	20	20.1	1.60	2.624	8.0	4.2
Chlorides	10	13.2	0.76	2.624	5.8	2.0
Sulfates	3	2.8	0.56	2.624	20.0	1.5

Statistical Methods

SPSS (Statistical Package for the Social Sciences) is a computer based program that is used for all of the statistical analysis performed in this thesis. SPSS launched its first version in 1968, and is among the most widely used programs for statistical analysis in science. It has many applications including market, education and health research. SPSS datasets have a 2-dimensional table structure where the rows typically represent cases or in this thesis the sample identifier and the columns represent measurements as in this thesis, the concentrations of nitrate, chlorides, sulfates, and specific conductance measurements. All data processing occurs sequentially case-by-case through the file (SPSS, 2007). The sample analysis datasets used in this thesis were created by the author in ArcGIS and converted to Excel spreadsheets, then imported into SPSS for analysis.

The nitrates, chlorides, sulfates, and specific conductance measurements in each density area were statistically compared to the other constituents in another septic system density area. This is a several step process and requires a complete examination of the data for normality and variance.

Kolmogorov – Smirnov Test

The Kolmogorov – Smirnov test was used to test for normality of the concentration data for each of the chemical parameters. The premise behind the Kolmogorov – Smirnov test is that normally distributed data is plotted on a cumulative fraction plot as a control. The individual constituent concentration values are then assigned a Kolmogorov – Smirnov plot value from *Equation 17 – K/S Plot Value Calculation*:

Kolmogorov – Smirnov plot value = (N – ni) / N [Equation 17]

where *ni* is the individual concentration values ranked from highest to lowest and *N* is the number of values. The Kolmogorov – Smirnov plot values are then added to the cumulative fraction plot that already contains the control plot representing normal distribution. The maximum distance is calculated between the two plots resulting in a significance value. A low significance value (generally less than 0.05) indicates that the distribution of the data differs significantly from a normal distribution (NIST, 2007).

Mann – Whitney U Test

The Mann – Whitney U-Test is a non-parametric alternative method to the Student's T-Test. The method requires that the two samples are independent, and the observations are ordinal or continuous measurements. Since the method is non-parametric, an assumption of normal distribution and equal variance is not required. The

null hypothesis for this test is that the two samples are drawn from a single population, and therefore their means are not statically different (Freund, 1992).

The Mann – Whitney U-Test relates to this thesis proposal as follows. All the samples are taken from the same watershed; however, the samples are drawn from different and independent septic system density groups. Using the U-Test, the sample concentrations (NO_3^-, Cl^-, SO_4^{2-} and Specific Conductance) are the variable and the septic density area groups are the grouping number. The sample concentrations are ranked from lowest to highest and their rank number, (not their values are summed). The rationale is if the samples were drawn from the same population (i.e. density groups) then the ranks will be spread evenly. However, if the samples were drawn from different populations, then one group will have a higher ranking than the other (Freund, 1992).

The U statistic is calculated using the SPSS computer statistical program using *Equation 18 – Mann – Whitney U Calculation*:

$$U = (n_1 * n_2) + \{n1(n1+1)/2\} - R_1 \qquad \text{[Equation 18]}$$

Where n_1 and n_2 are the number of samples in each density area and R_1 is the sum of the ranks of the constituent in the designated group. The U-Statistic is compared to a critical value found in a table of Critical Values of the Mann – Whitney U test. For this thesis $U_1 < U_{2\text{ level of significance}}$ one tail test is used to reject the null hypothesis (Freund, 1992) meaning there is a statistical difference of the baseflow water chemistry between the groups that are compared.

Z Scores

Another way to assist in the determination of a rejection, a Z score is also calculated using the SPSS computer program using *Equation 19 – Z Statistic Calculation*:

$Z = (U - m_U) / \sigma_U$ [Equation 19]

Where $m_U = (n_1 * n_2)/2$ and σ_U = *the square root of* $((n_1 * n_2)*(n_1 + n_2+1))/12$ and U is calculated with equation 1. The null hypothesis is the same for the Z score as it is for the U statistic. The Z score at the 95% confidence level is 1.645. A Z score greater than 1.645 rejects the null hypotheses while a Z score less than 1.645 accepts the null hypothesis. A rejection of the null hypothesis means there is a statistical difference in baseflow water chemistry between the density groups.

Frequency Distribution Diagrams

Frequency Distribution Diagrams were created to visually show the difference in means between the constituent concentration of one density group and another. The histograms were created using unpublished / proprietary graphing spreadsheets developed by Julian C. Gray (1998). The diagrams are used to show the differences in means and standard deviations between the density groups baseflow water chemistry.

Chapter 7 – Results and Discussion

The results of the laboratory and field work were analyzed by using descriptive statistics, tests for normality, non-parametric comparison tests, graphs, charts, and maps. Previous studies indicate that as septic density increases so does the concentrations of nitrates, chlorides, specific conductance, and sulfates (Jordan J. Goulding, 2003; USGS, 2000; Burns et al., 2005).

Statistical Tests and Results

As previously mentioned in the Methods Section, there are two tests that are considered for this thesis; the Kolmogorov – Smirnov Test for distribution and the Mann-Whitney U-Test for comparison between density groups. The Students T-Test was not used because it is parametric and assumes normality and equal variance of the data. The Kolmogorov – Smirnov Test showed not all groups have a normal distribution of their data, so the Mann – Whitney U-Test was used as it is a non-parametric and the Students T-Test assumptions are unnecessary (Freund, 1992).

As a review, the density groups were created using the 1990 US Census tract data. Four groups were created that represent the number of house units on septic per census tract. Group 1 < 25%, Group 2 is 26% - 50%, Group 3 is 51% - 75%, and Group 4 is 76% - 100%. A fifth group was created that represents the samples collected downstream from discharging waste water treatment plants. The fifth group was made to illustrate the

differences between baseflow water quality of streams flowing through areas of septic use and water quality of streams receiving treated sewage.

Table 2 displays the descriptive statistics for each constituent in each group. The means, and the standard deviations are calculated by the descriptive statistic program in Microsoft Office Excel 2003. As shown, the standard deviation between the groups is not equal and this assumption of the Students T-Test is not met.

Kolmogorov – Smirnov Results

Table 3 displays the results the Kolmogorov - Smirnov test. They show that in group 1 the nitrates and sulfates are normally distributed, while the chlorides and specific conductance are not. In group 2 all constituents except the nitrates are normal distributed. In group 3 the specific conductance and the chlorides are normally distributed. In group 4 none of the constituents are normally distributed. Group 5 was not included in this table because it does not represent a density area. The assumption of normal distribution is met in some but not all groups. If the Students T-test is used to compare all constituents in a group with the other groups, then the conclusions derived from the results could be misleading because not all of the parameters for all of the groups were normally distributed therefore, the Mann – Whitney U-Test is used for the statistical analysis.

Table 2 - Descriptive Statistics

Group 1 n=14	NO3 mg/L	SC µS/cm	Cl mg/L	SO4 mg/L
Mean	7.0	93.4	10.5	2.1
SD	3.5	23.6	1.5	1.6
Group 2 n=15				
Mean	9.8	92.2	10.8	2.5
SD	2.4	41.0	2.4	2.0
Group 3 n=6				
Mean	9.7	90.2	10.5	1.1
SD	4.0	14.1	1.7	1.5
Group 4 n=26				
Mean	15.7	86.9	11.4	1.2
SD	6.3	19.8	2.2	1.5
Group 5 n=9				
Mean	40.2	270.6	31.4	35.1
SD	11.1	88.2	17.9	9.7

Group 1 = Septic System Density < 25%
Group 2 = Septic System Density 26% – 50%
Group 3 = Septic System Density 51% - 75%
Group 4 = Septic System Density 76% - 100%
Group 5 = Samples collected downstream from discharging waste water treatment plants

Table 3 - Kolmogorov – Smirnov Test for Normality Results.

Group 1 n = 14	**Significance Value**	SV < = 0.05 means a rejection of the null hypothesis	Distribution	LOW DENSITY GROUPS
NO3	**.139**	***Accept***	***Normal***	
SC	**.050**	Reject		
CL	**.016**	Reject		
SO4	**.200**	***Accept***	***Normal***	
Group 2 n = 15	**Sig.**		Distribution	
NO3	**.010**	Reject		
SC	**.109**	***Accept***	***Normal***	
CL	**.200**	***Accept***	***Normal***	
SO4	**.200**	***Accept***	***Normal***	
Group 3 N = 6	**Sig.**		Distribution	
NO3	**.001**	Reject		
SC	**.200**	***Accept***	***Normal***	
CL	**.200**	***Accept***	***Normal***	
SO4	**.017**	Reject		
Group 4 n = 26	**Sig.**		Distribution	
NO3	**.008**	Reject		
SC	**.000**	Reject		HIGH
CL	**.000**	Reject		DENSITY
SO4	**.000**	Reject		GROUPS

The Kolmogorov-Smirnov statistic tests the hypothesis that the data are normally distributed. A low significance value (generally less than 0.05) indicates that the distribution of the data differs significantly from a normal distribution (SPSS, 2007).

Mann-Whitney U and Z-Test Results

The Mann-Whitney U-Test is a non-parametric alternative to the Students T-Test. The Mann-Whitney is used when the assumptions of equal variance and normal

distribution of the data are not met as in the case of this thesis. The U-Test ranks the results and uses the ranking instead of the analytical results to calculate a U statistic.

Table 4 contains the U and Z statistics associated with the Mann-Whitney U-Test. Using the values found in a table of critical values of the Mann – Whitney U-Test one tail test, if the critical value is less than the U statistic then the null hypothesis is accepted and if the critical value is greater then the U statistic then the null hypothesis is rejected. The critical values are provided in the table for each comparison. At the 95% confidence level the Z score value is 1.645. A Z statistic greater than 1.645 rejects the null hypotheses while a Z statistic less than 1.645 accepts the null hypothesis.

The comparisons are made as follows, group 1 (the lowest septic system density area) is compared with groups 2, 3, and 4 (the highest septic system density area) as well as group 5 (representing samples collected downstream of the wastewater treatment plants). Then group 2 is compared with 3, 4 and 5. Group 3 is compared with 4 and 5. Finally group 4 is compared with group 5. This scheme insures that all groups are compared to each other. The one tail test was run at the 95 % confidence interval with p = 0.05. A rejection means that there is a statistic difference of the constituent between the two groups that are compared. Frequency distribution diagrams (Gray, 1998), figures 14 – 17, are presented to illustrate the difference in means between those groups determined as statistical different and to show the variance of the concentrations in the density groups.

Table 4 - U and Z Statistic Score Result

Group 1 – 2	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 66	59.5	94.0	89.0	93.0
Z Score	2.032	.480	.699	.528
Confidence Level 95%	**Reject**	Accept	Accept	Accept
Group 1 – 3	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 13	30.0	29.0	41.0	25.0
Z Score	1.025	1.072	.083	1.419
Confidence Level 95%	Accept	Accept	Accept	Accept
Group 1 – 4	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV125	34.0	122.0	133.5	115.0
Z Score	4.219	1.701	1.376	1.934
Confidence Level 95%	**Reject**	**Reject**	Accept	**Reject**
Group 2 – 3	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 15	37.5	36.0	43.0	29.0
Z Score	.603	.701	.156	1.258
Confidence Level 95%	Accept	Accept	Accept	Accept
Group 2 – 4	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV126	68.5	146.0	166.0	122.5
Z Score	3.443	1.326	.785	1.999
Confidence Level 95%	**Reject**	Accept	Accept	**Reject**
Group 3 – 4	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV54	29.0	75.0	62.0	76.5
Z Score	2.380	.145	.773	.075
Confidence Level 95%	**Reject**	Accept	Accept	Accept
Group 1 – 5	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 36	.000	.000	.000	.000
Z Score	3.991	3.969	3.973	3.979
Confidence Level 95%	**Reject**	**Reject**	**Reject**	**Reject**
Group 2 – 5	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 39	.000	.000	.000	.000
Z Score	4.049	4.025	4.027	4.035
Confidence Level 95%	**Reject**	**Reject**	**Reject**	**Reject**
Group 3 – 5	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 12	.000	.000	.000	.000
Z Score	3.199	3.182	3.185	3.188
Confidence Level 95%	**Reject**	**Reject**	**Reject**	**Reject**
Group 4 – 5	Nitrate	Specific Conductance	Chloride	Sulfate
U Statistic CV 39	1.50	.000	.000	.000
Z Score	4.368	4.416	4.418	4.473
Confidence Level	**Reject**	**Reject**	**Reject**	**Reject**

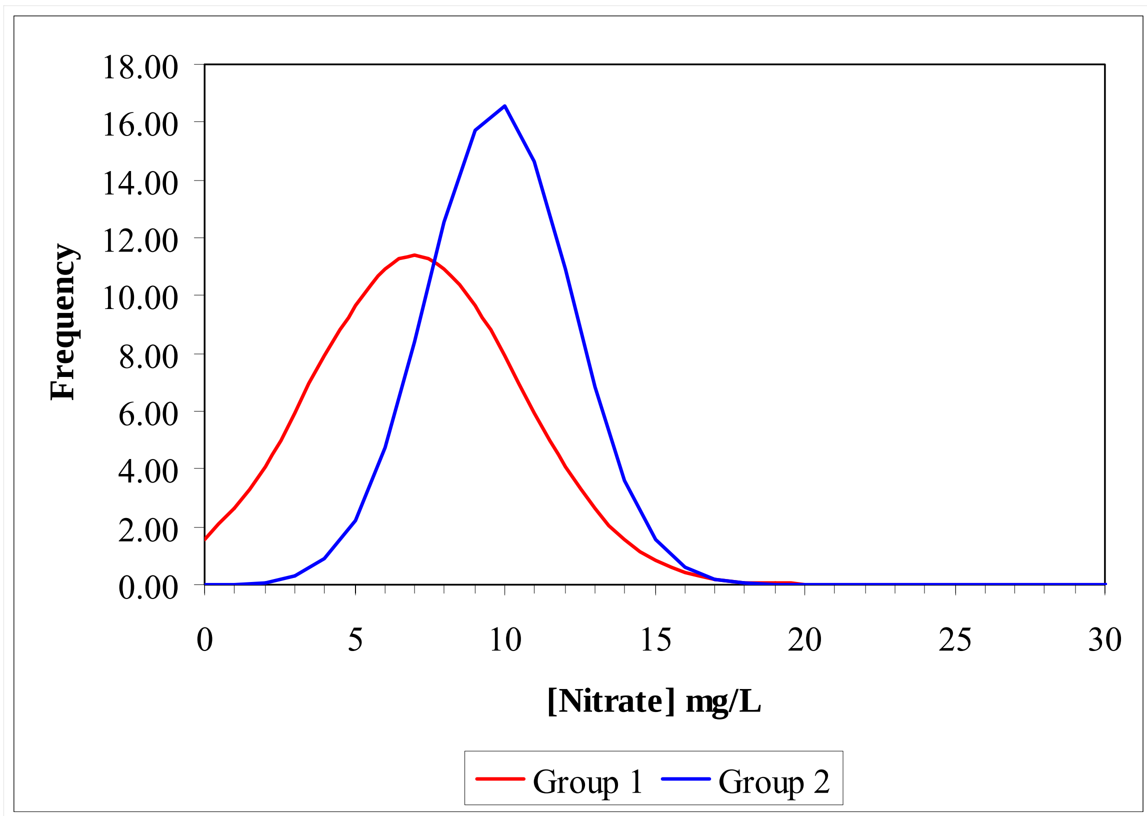


Figure 14a – Nitrate Frequency distribution diagrams Comparing Groups 1 and 2 after Gray 1998

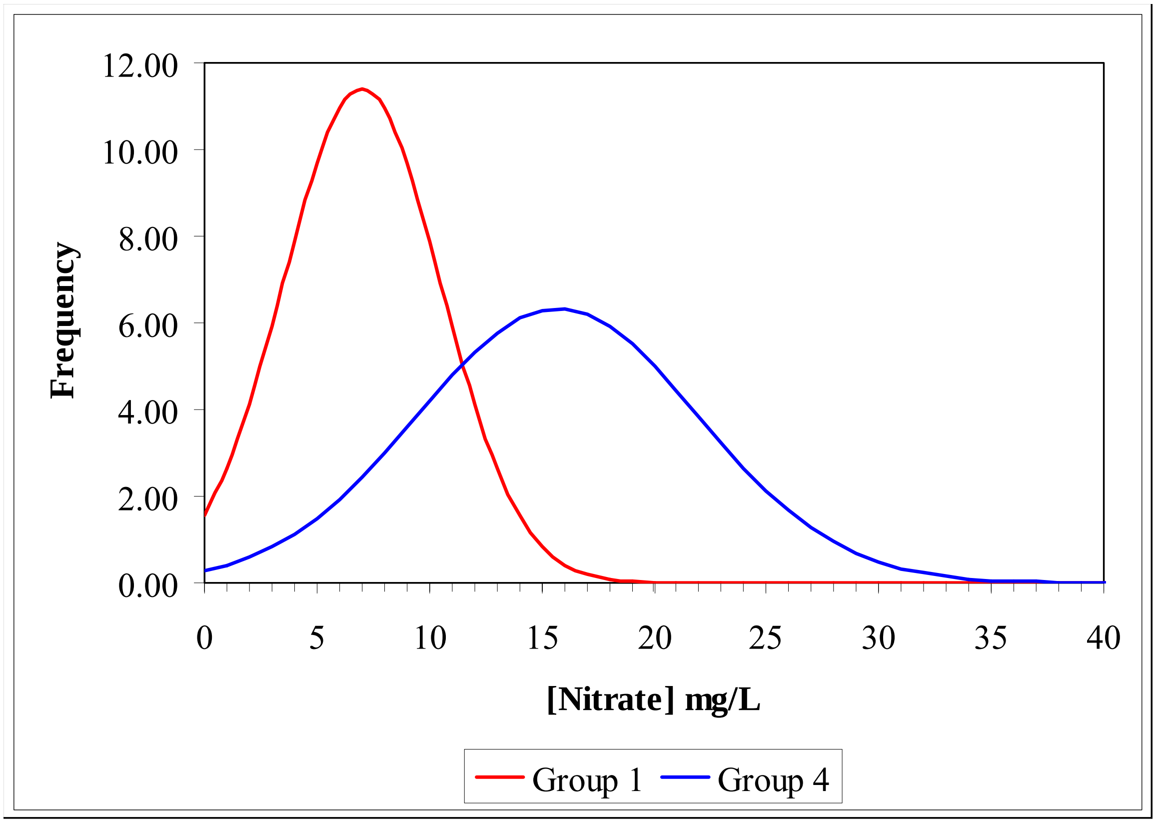


Figure 14b – Nitrate Frequency distribution diagrams
Comparing Groups 1 and 4 after Gray 1998

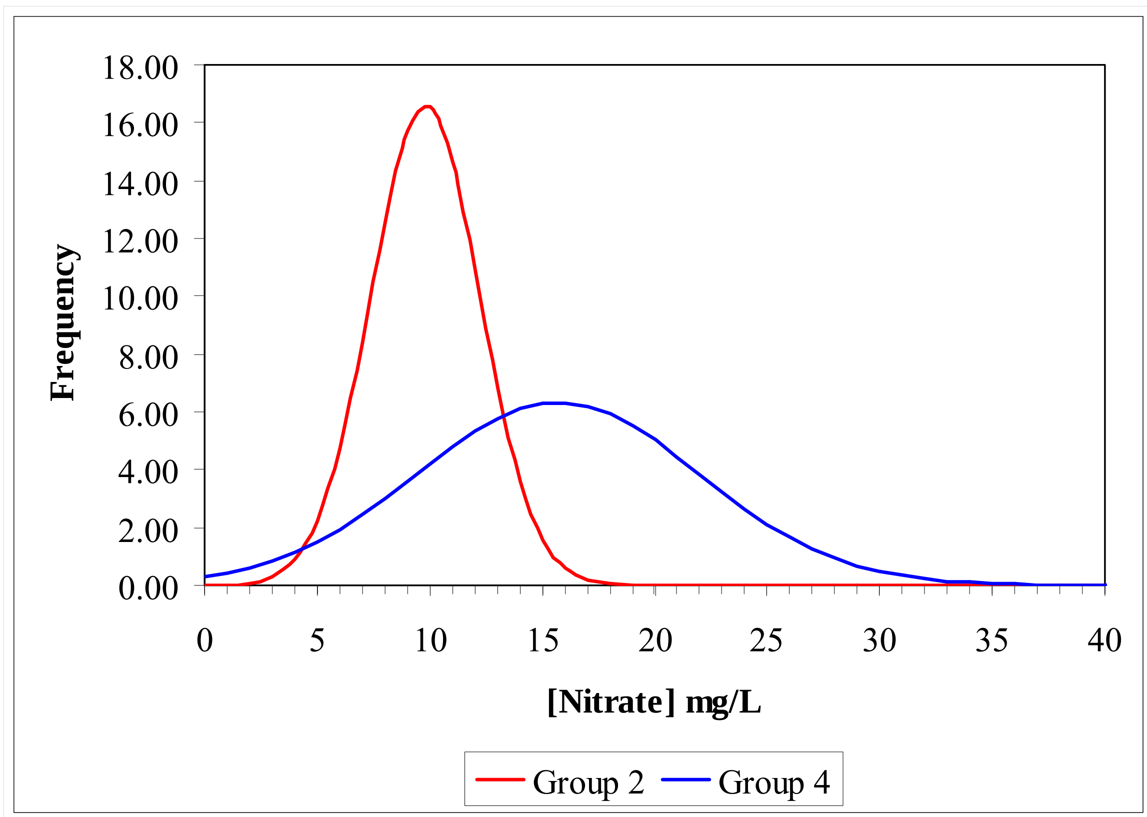


Figure 14c – Nitrate Frequency distribution diagrams Comparing Groups 2 and 4 after Gray 1998

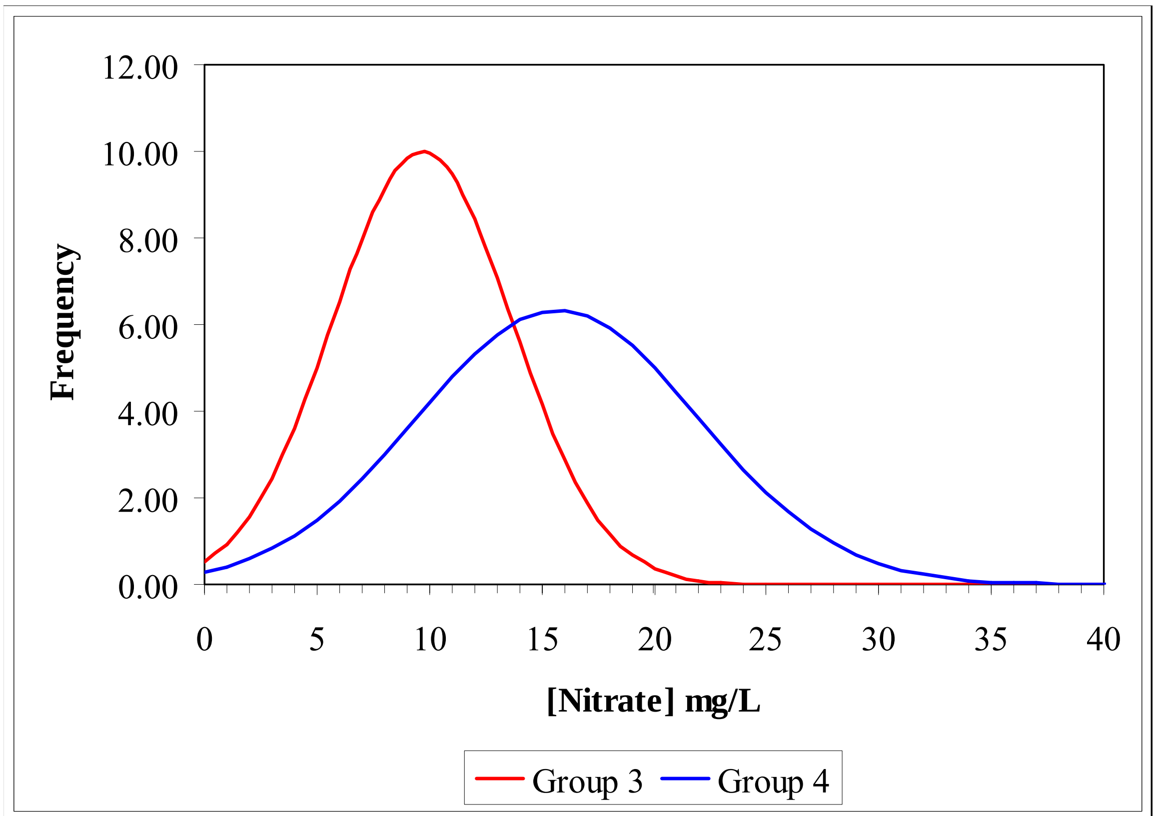


Figure 14d – Nitrate Frequency distribution diagrams Comparing Groups 3 and 4 after Gray 1998

Nitrate is statistically different between groups 1 – 2, 1 – 4, 2 – 4, and 3 – 4 as determined by the U and Z tests. Figure 14a -d shows that group 4 has a higher concentration than group 1, 2, and 3, and group 2 has a higher mean concentration than group 1.

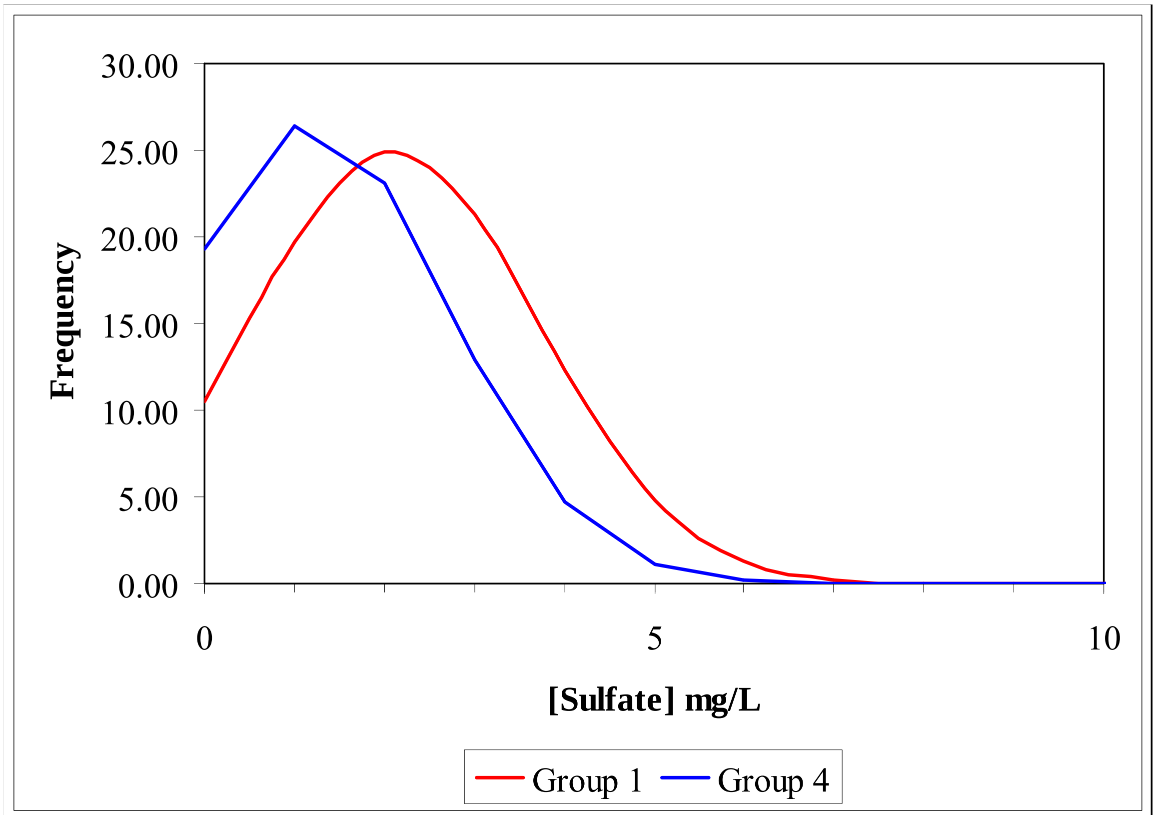


Figure 15a – Sulfate Frequency distribution diagrams Comparing Groups 1 and 4 after Gray 1998

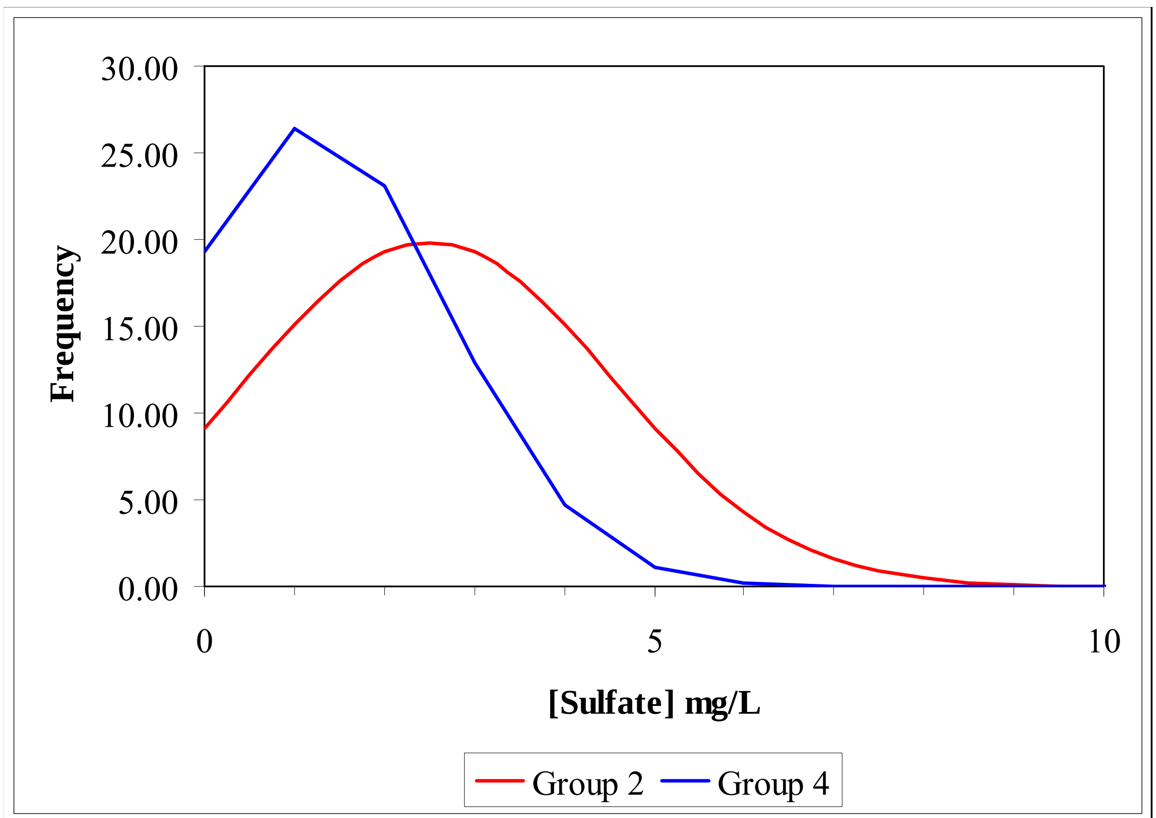


Figure 15b – Sulfate Frequency distribution diagrams Comparing Groups 2 and 4 after Gray 1998

Sulfate is statistically different between groups 1 – 4, and 2 – 4. Figure 15a -b shows that group 1 and group 2 has a higher concentration than group 4.

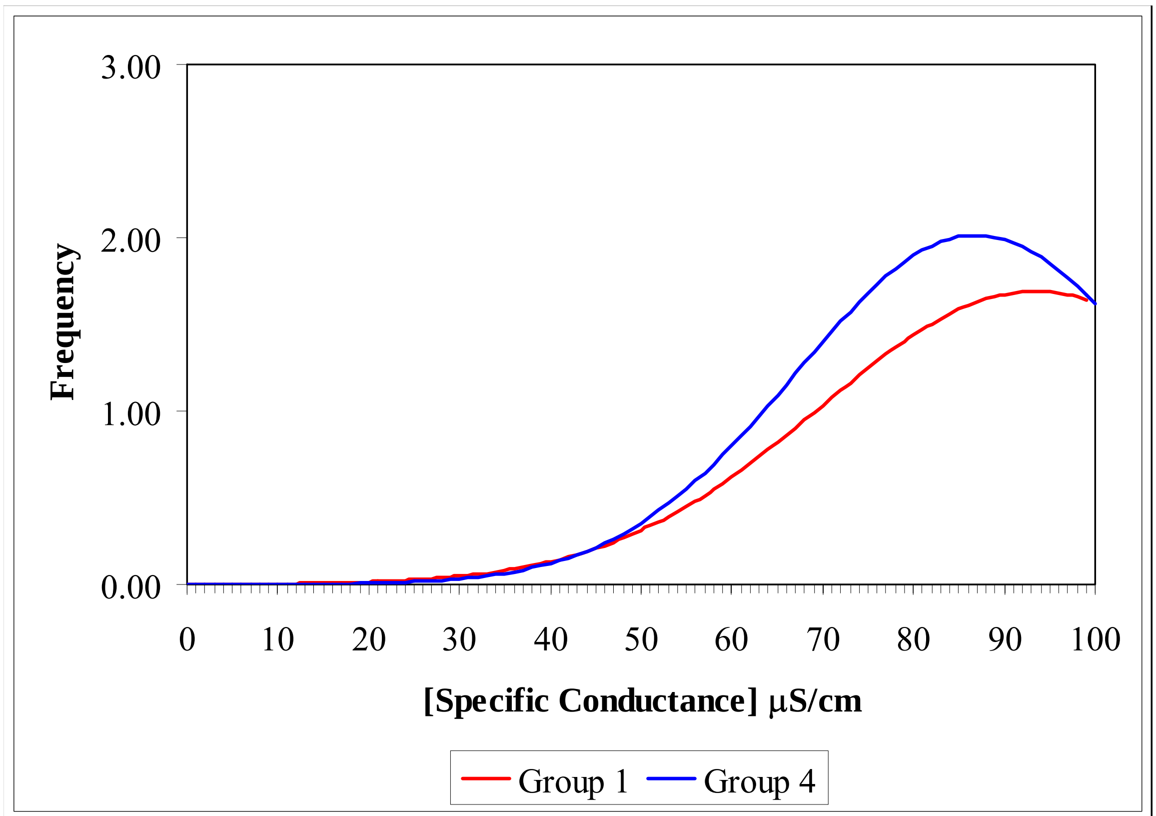


Figure 16 – Specific Conductance Frequency distribution diagrams Comparing Groups 1 and 4 after Gray 1998

Specific conductance is statistically different when group 1 is compared to group 4. Figure 16 shows that group 4 has a higher concentration than group 1.

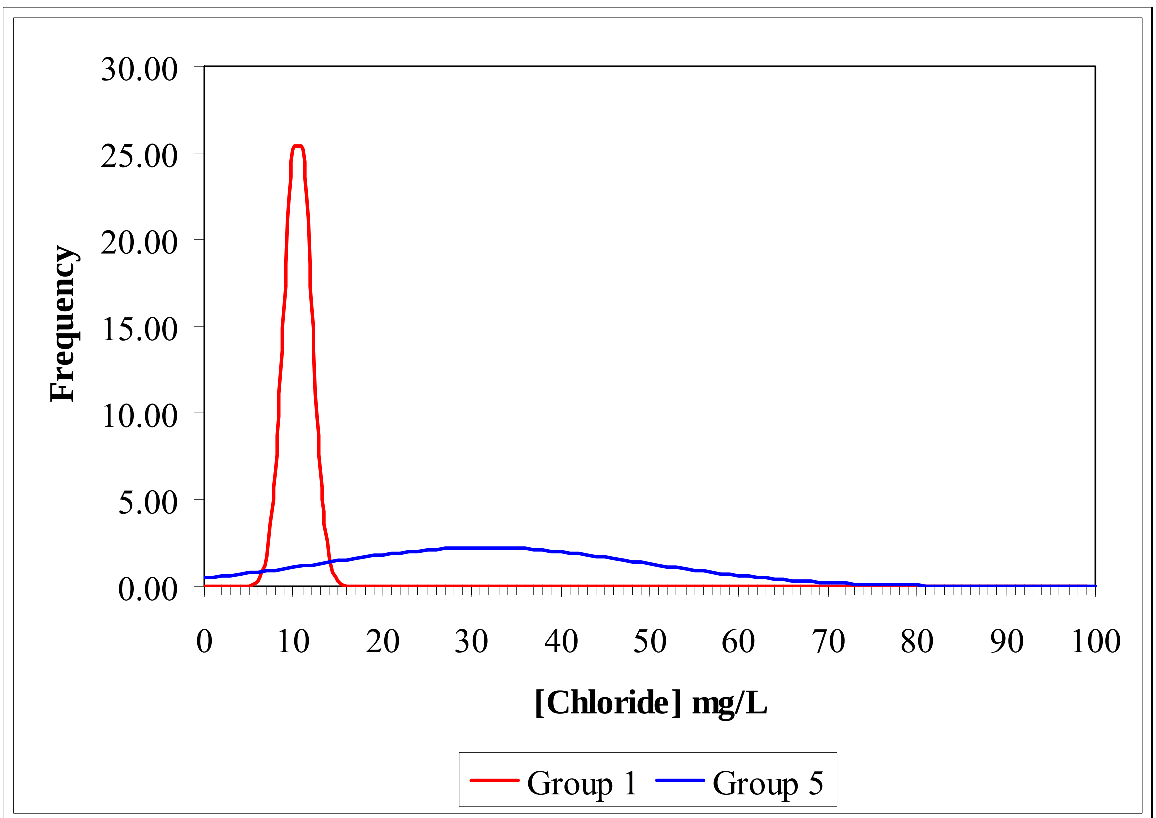


Figure 17a – Chloride Frequency distribution diagrams Comparing Groups 1 and 5 after Gray 1998

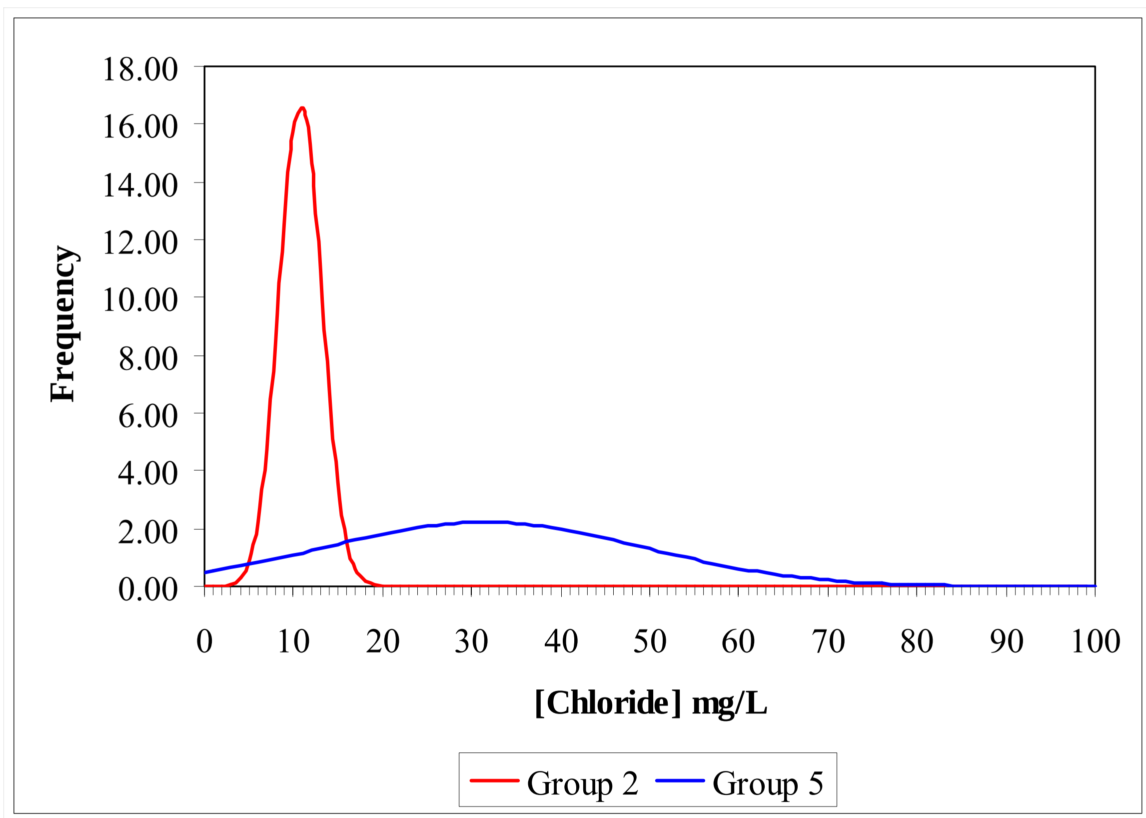


Figure 17b – Chloride Frequency distribution diagrams Comparing Groups 2 and 5 after Gray 1998

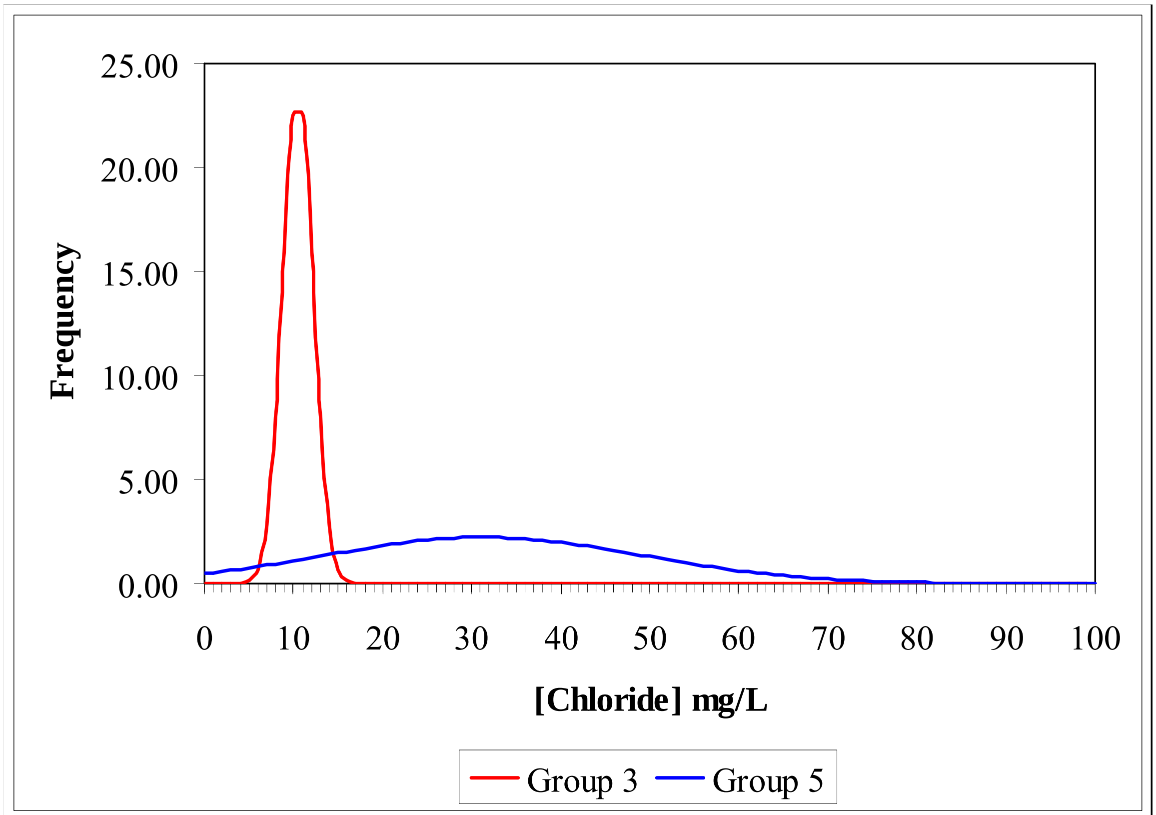


Figure 17c – Chloride Frequency distribution diagrams Comparing Groups 3 and 5 after Gray 1998

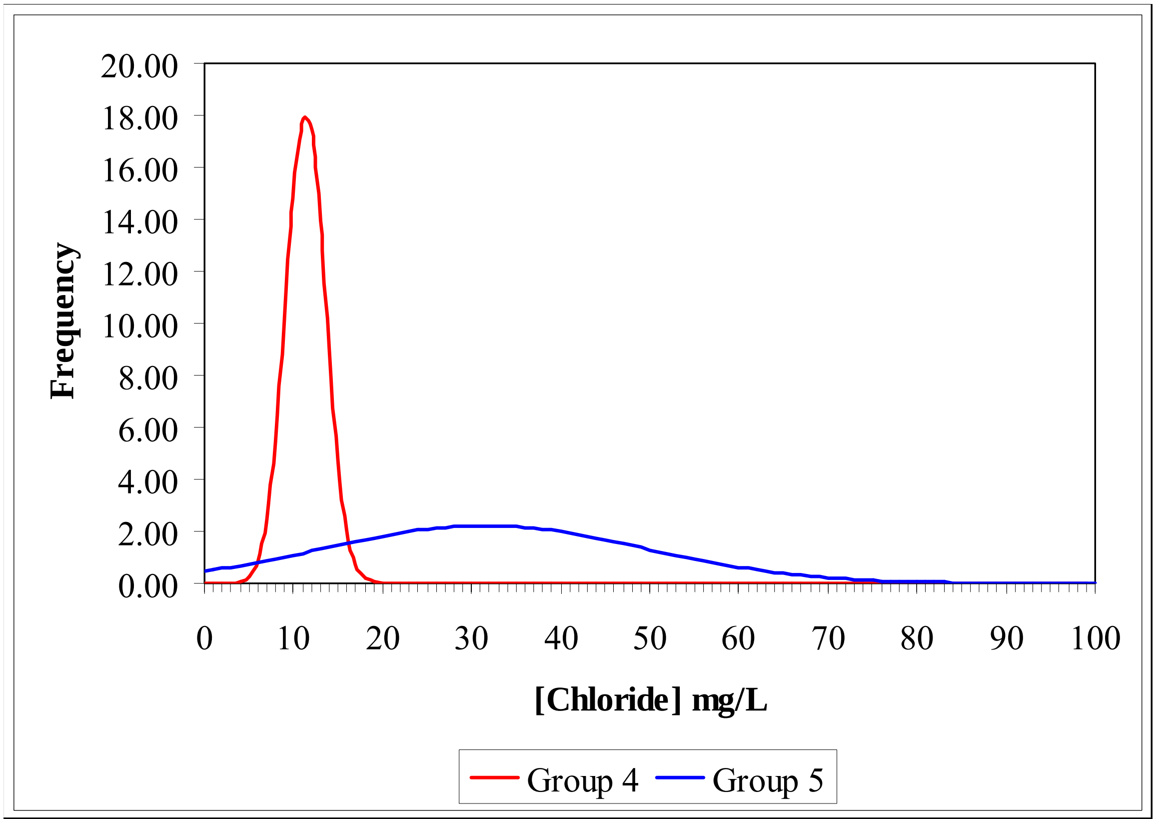


Figure 17d – Chloride Frequency distribution diagrams Comparing Groups 4 and 5 after Gray 1998

Chloride shows no statistical difference when groups 1 thru 4 are compared, but when these groups are compared with group 5 there is a statistical difference. Figure 17a - b shows that group 5 has a higher concentration than groups 1,2,3, and 4.

The nitrates, chlorides, sulfates and specific conductance are statistically lower in concentrations when groups 1, 2, 3, and 4 are compared with group 5.

Mean Value Comparisons

Descriptive statistics presented in Table 4 shows that the nitrate and chloride mean concentrations tend to increase with increasing septic system density. This trend has been found in previous studies (Burns et al., 2005; Nizeyimana, 1996; Sinton, 1982; USGS 2000). Group 5, the Yellow River Group, has the highest mean concentrations of nitrates at 40.2 mg/L and chlorides 31.4 mg/L. The next highest mean concentrations are found in group 4 with the nitrates at 15.7 mg/L and chlorides at 11.4 mg/L. The lowest mean concentrations occur in group 1 with 7.0 mg/L and 10.5 mg/L nitrate and chloride respectively.

Sulfate concentrations follow a negative trend where the highest density groups, represented by groups 3 and 4, yield the lowest mean concentrations at 1.1 mg/L and 1.2 mg/L respectively. Groups 1 and 2 have the highest concentrations of 2.1 and 2.5 mg/L respectively. Group 5, the Yellow River Group has the highest mean concentrations of 35.1 mg/L.

The specific conductance measurements follow a negative trend. The high density groups, groups 3 and 4, yield the lowest mean measurements at 90.2 uS/cm and 86.9 uS/cm, while the low density groups, groups 1 and 2, yield the highest mean

measurements at 93.4 uS/cm and 92.2 uS/cm. Mean specific conductance concentrations are the highest in group 5 at 270.6 uS/cm.

Comparison Graphs

Figures 18 – 20 on the following pages illustrate the correlation between nitrate, chloride, and sulfates in each group and specific conductance. The X axis represents the independent variable (specific conductance measurements in uS/cm) while the Y axis represents the dependent variable (anion concentrations in mg/L). Each density group is represented by a unique symbol. Regression coefficient (r^2) values are provided for each constituent for each group.

As the r^2 value approaches 1 then this can be interpreted that all of the variability in the dependent variable can be explained in the independent variable. A zero value can be interpreted to mean that there is no linear relationship between the dependent and independent variables. The r^2 value does not describe how much change in the dependent variable is caused by the independent variable nor does it imply causation. It only seeks to describe how well the change of dependent variable is contingent on the change of the independent variable. There are two graphs for each anion concentration. The first graph represents density groups 1 through 4 and the second graph represents all groups 1 through 5.

Nitrate v. Specific Conductance

Figures 18 and 18a shows the linear regressions of baseflow nitrate concentrations as a function of specific conductance for each density group. Group 1 has a positive r^2 value of 0.77 and group 4 has a positive r^2 value of 0.88 which is the strongest correlation of nitrates and specific conductance. This means that 77% of the nitrate increase can be explained by the increase in specific conductance in group 1, and 88% of the nitrate increase can be explained by the increase in specific conductance in group 4. Groups 2 and 3 have r^2 values of 0.71 and 0.70 respectively. Overall the nitrates are well correlated as a function of specific conductance.

Figure 18a shows that the highest baseflow nitrate concentrations and specific conductance measurements are found in group 5 representing the samples collected downstream of the waste water treatment plants discharge points. It should be noted that these measurements are from treated sewage discharged from upstream into the Yellow River.

Chloride v. Specific Conductance

Figure 19 shows the correlation between chlorides and specific conductance. Group 1 is poorly correlated with an r^2 value of 0.43. Group 2 is well correlated with an r^2 value of 0.80. Groups 3 and 4 are strongly correlated with r^2 values of 0.90. Figure 19a compares all the groups with group 5, which has the greatest chloride and specific conductance concentrations.

Sulfate v. Specific Conductance

Figure 20 shows the correlation between sulfate and specific conductance. Overall the sulfate concentrations are the lowest of the measured constituents. Group 1, 3, and 4 are well correlated with an r^2 value of 0.60, 0.81, and 0.80 respectively. Group 2 shows a strong correlation with an r^2 value of 0.90. Figure 20a compares all the groups with group 5, which has the greatest chloride and specific conductance concentrations.

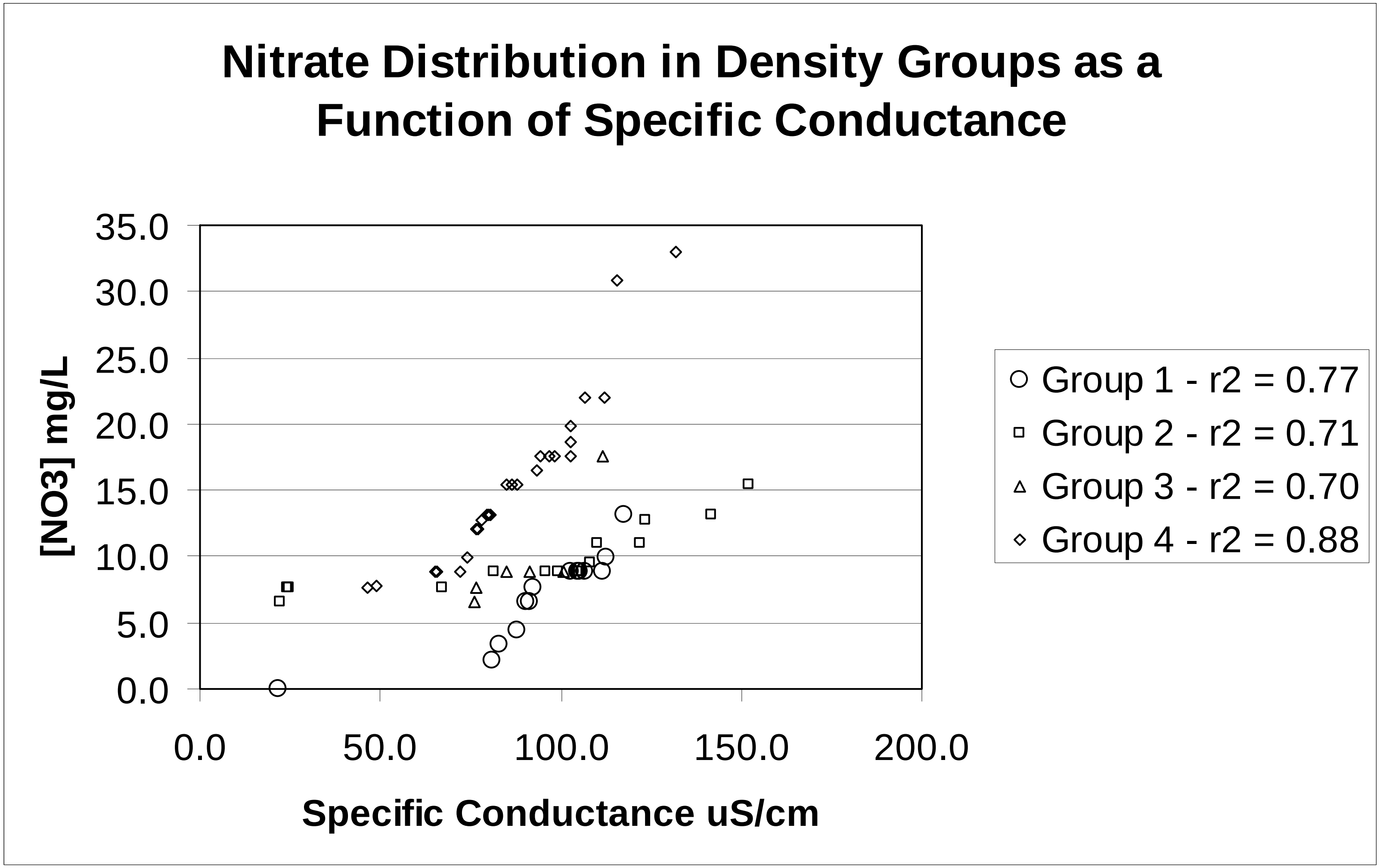


Figure 18 - Nitrate as a function of specific conductance Groups 1-4

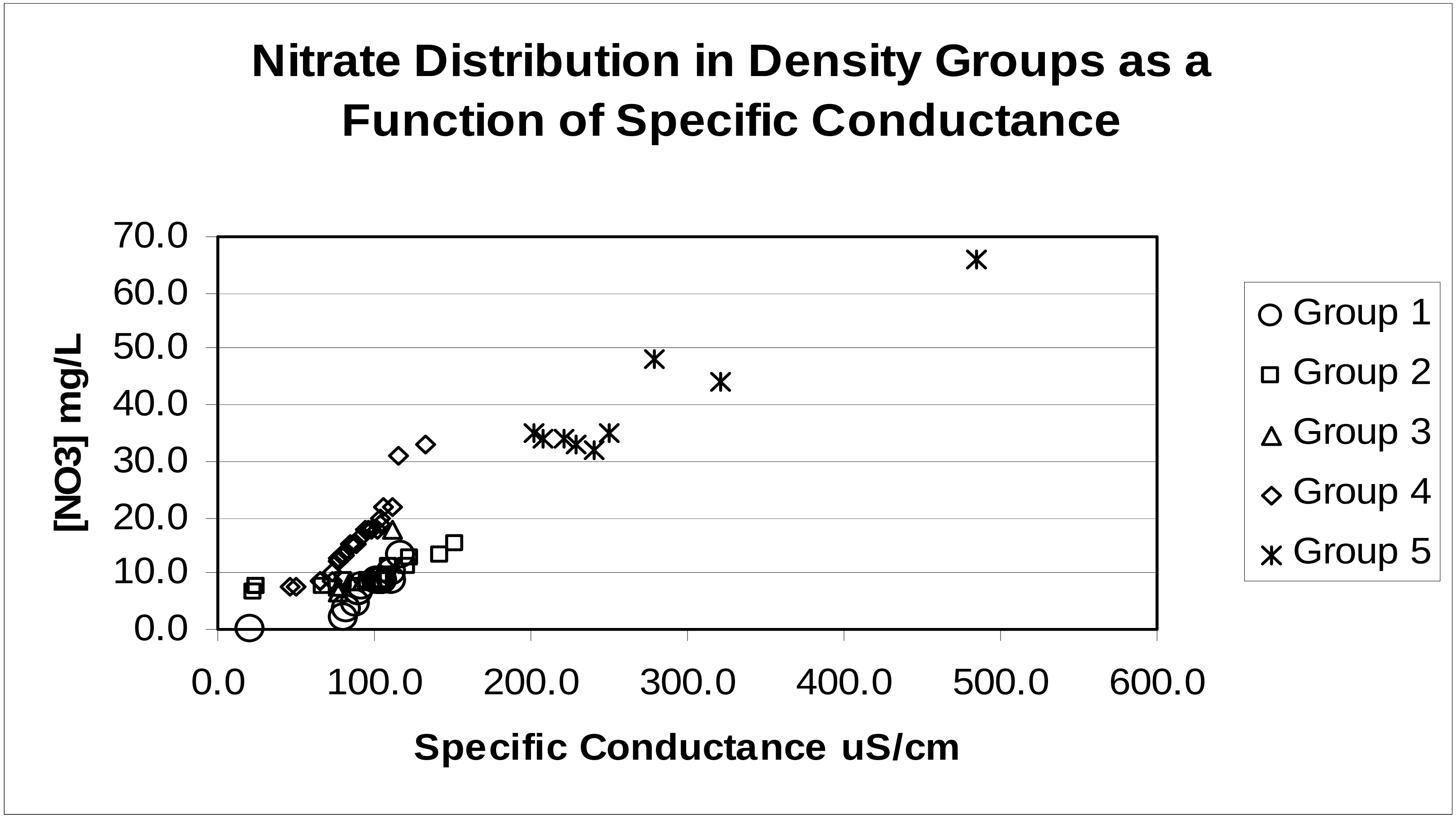


Figure 18a - Nitrate as a function of specific conductance Groups 1-5

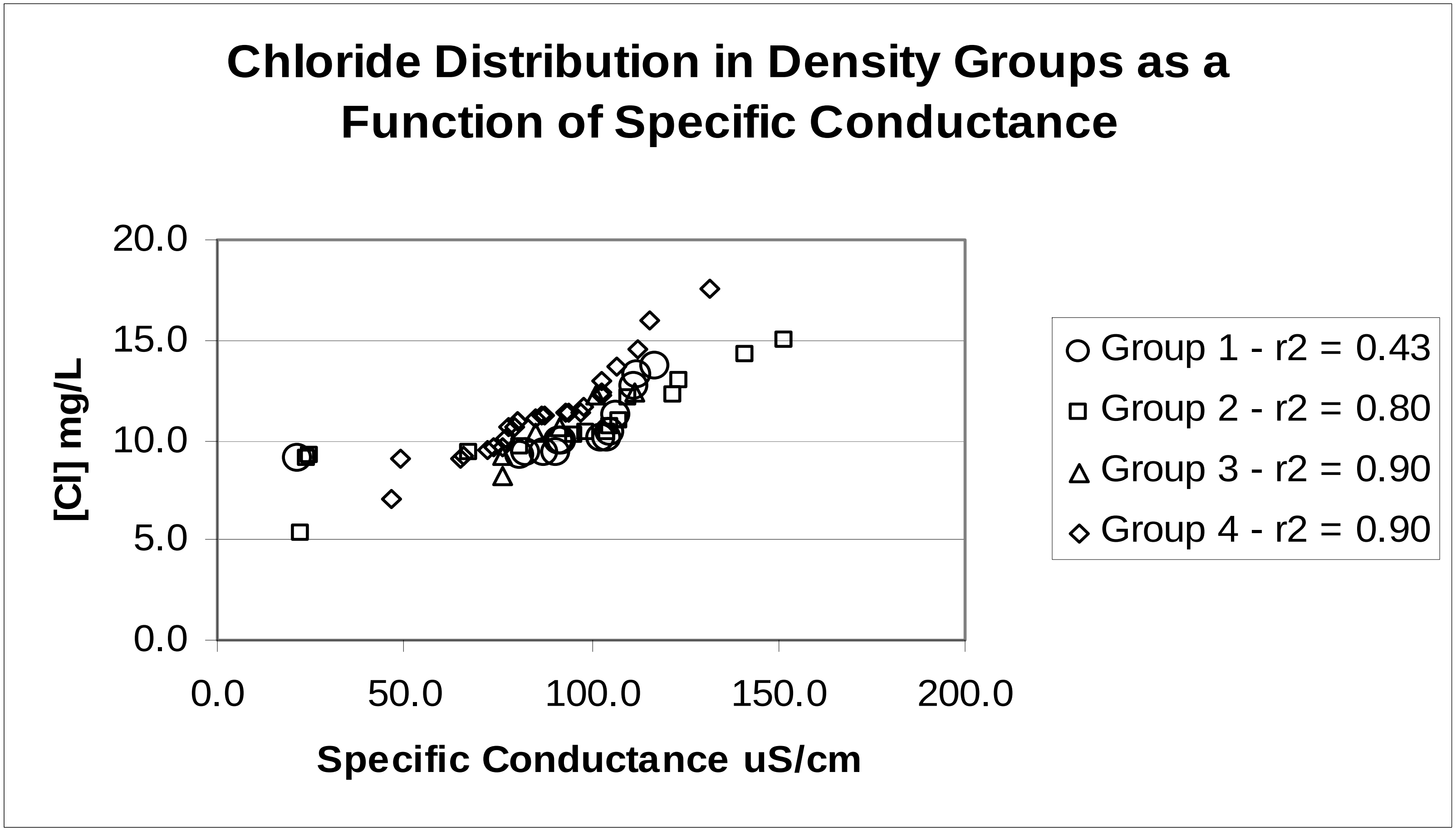


Figure 19 - Chloride as a function of specific conductance Groups 1-4

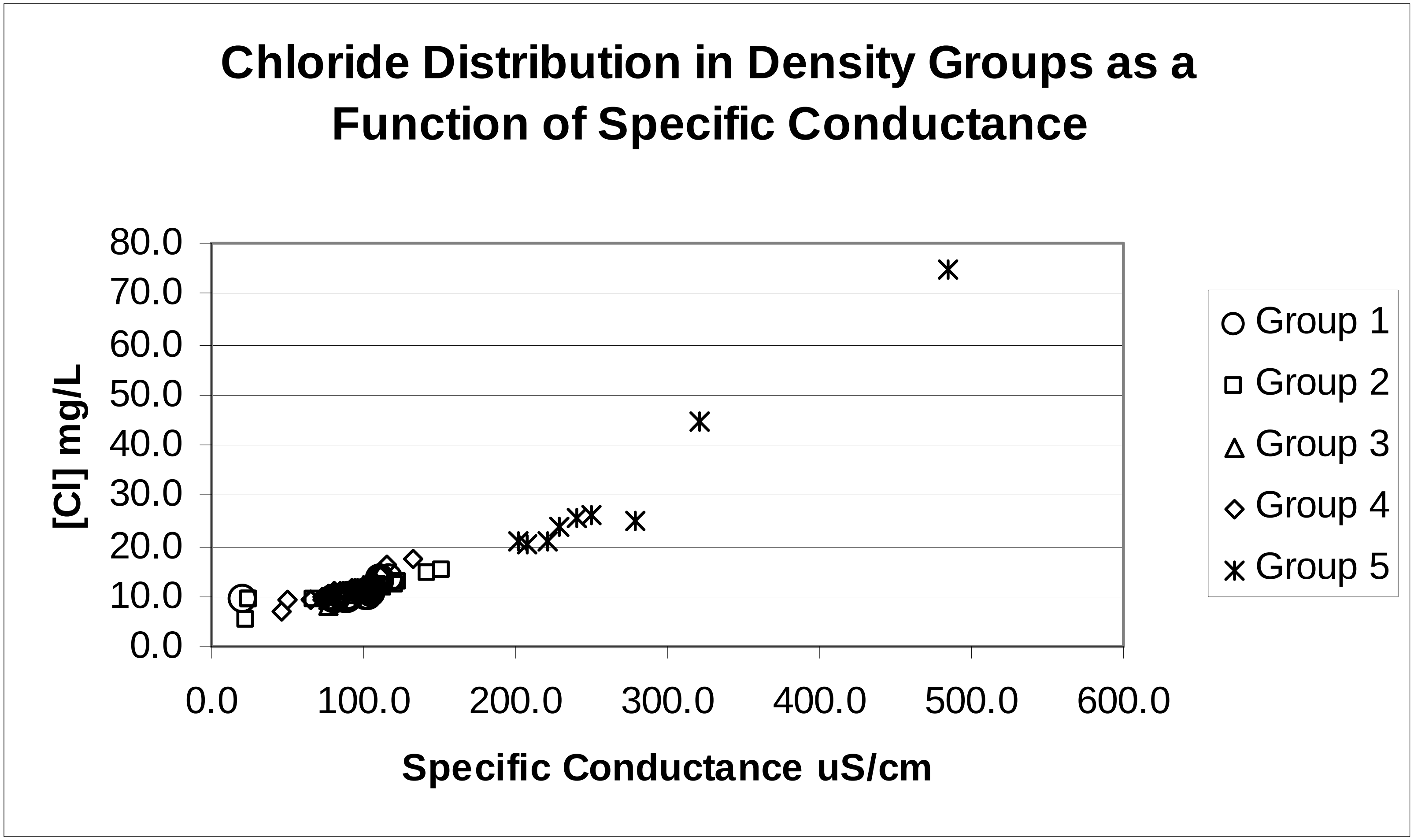


Figure 19a - Chloride as a function of specific conductance Groups 1-5

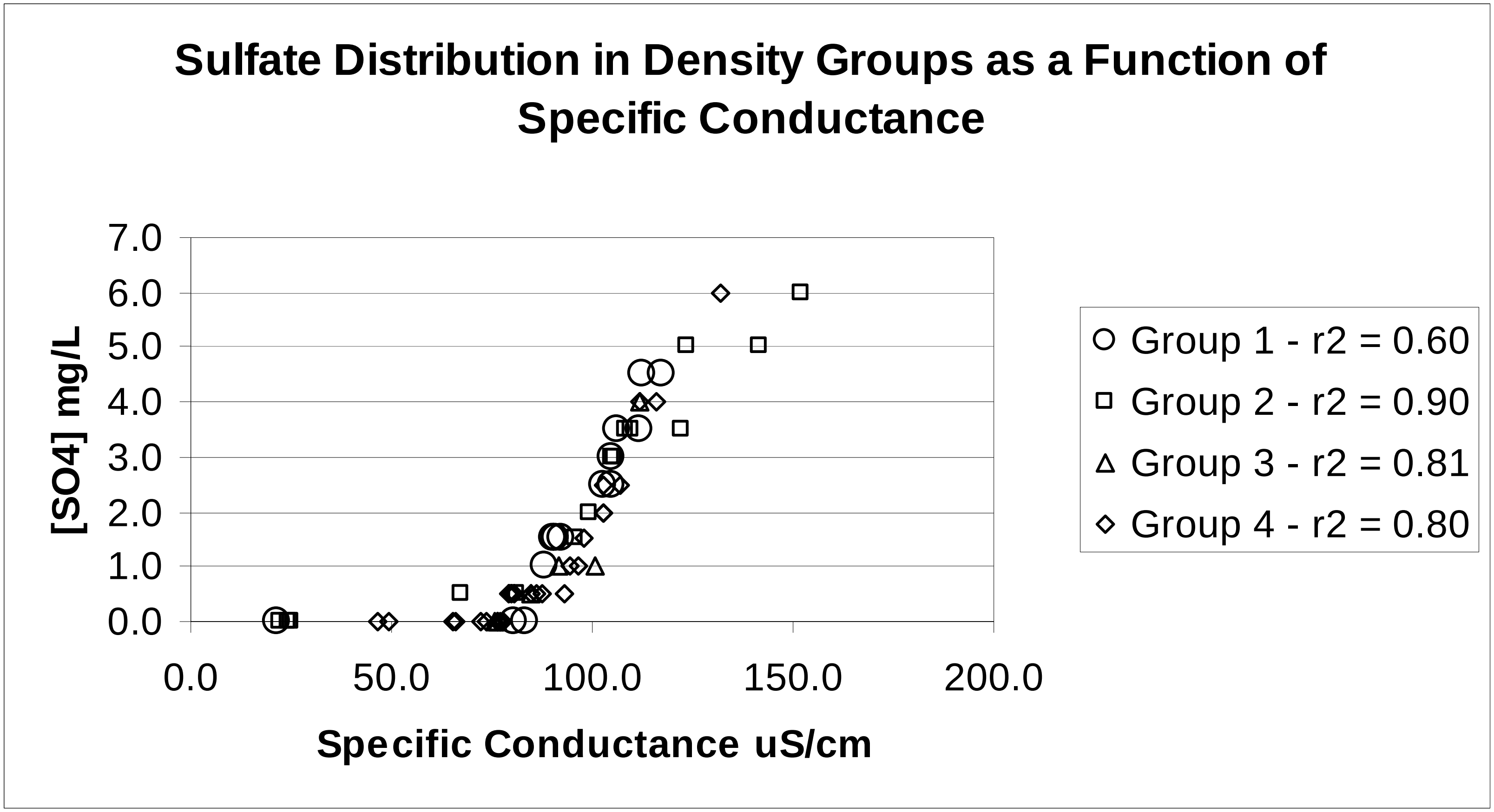


Figure 20 - Sulfate as a function of specific conductance Groups 1-4

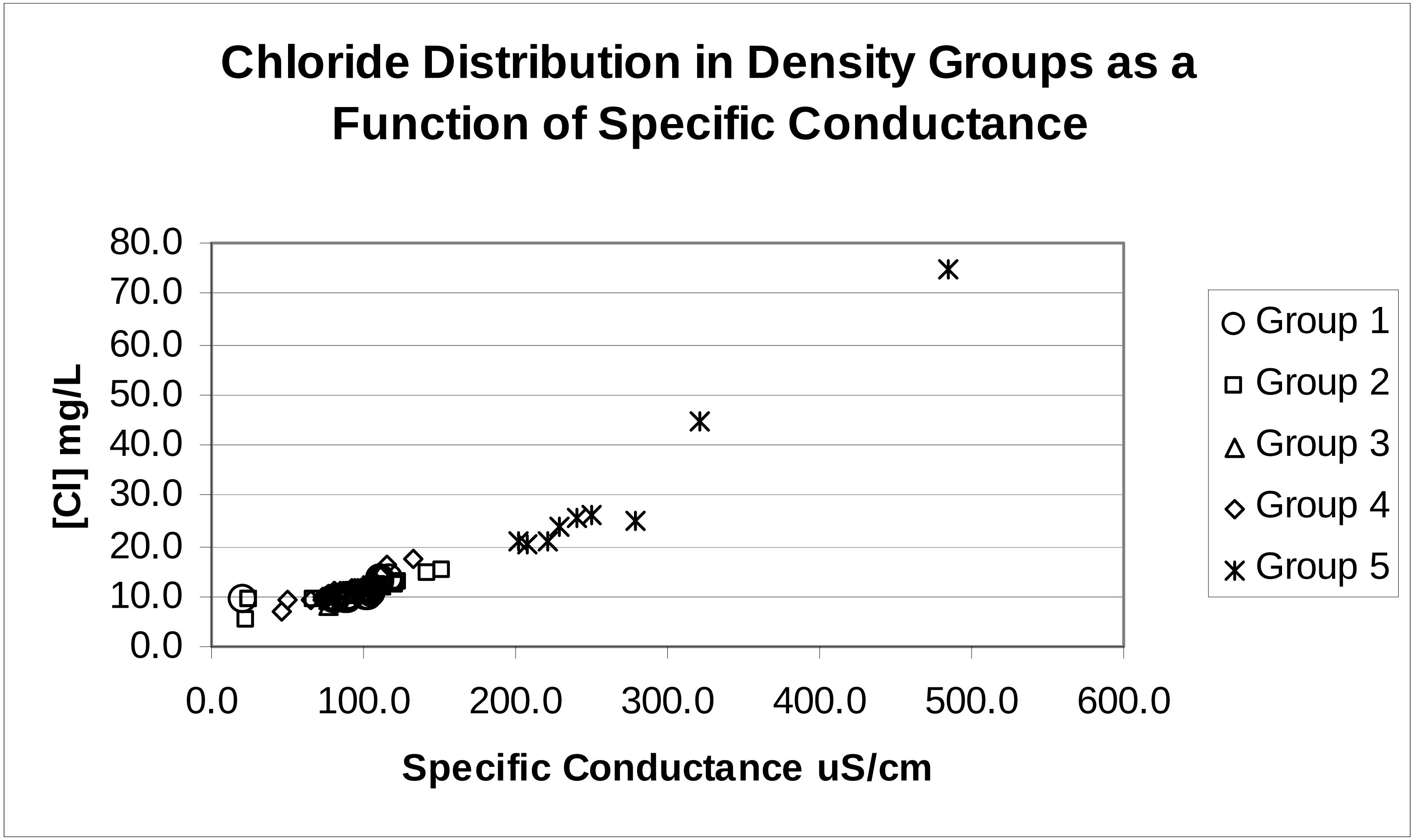


Figure 20a - Sulfate as a function of specific conductance Groups 1-5

Spatial Distribution of Nitrate, Chloride, Sulfate, and Specific Conductance

Figures 21 - 24 represent the spatial distribution of the concentration measurements of nitrate, chloride, and sulfate and the specific conductance measurements within each septic system density group. Each point represents a sample location and the color represents a range of concentrations in mg/L or uS/cm as in the case of specific conductance. The polygons represent the septic system density groups where the lightest color represents group 1 the lowest density and the darker color group 4 the highest density. Table five gives an indication of how short water and pollution pathways are from the septic systems to the streams located in the YRW. The distances were calculated in ArcGIS.

Table 5 - Distances from hilltop to streams, approximate distances in miles.

Average Distance	0.47 Miles
Minimum Value	0.25 Miles
Maximum Value	0.8 Miles
Standard Deviation	0.19 Miles

Figure 21 represents the spatial distribution of the nitrate concentrations within the YRW. Spatially the higher concentrations represented by the colors red and orange tend to appear in the higher density groups, and along the length of the Yellow River however several elevated levels are found in the lower density groups. The lower concentrations represented by the yellow and greens tend to appear in the lower density groups, however they do visually appear sporadically in the higher density groups.

Figure 22 represents the spatial distribution of the chloride concentrations within the YRW. Spatially, the higher concentrations tend to appear in the higher density groups, and along the length of the Yellow River. However in the western center section of the watershed in group 1, the lowest density area, a sample appears with a high concentration of chloride. In the extreme southern section of the watershed, in group 4 the high density area, several samples have low chloride concentrations. The majority of the lower concentrations are located within the low density groups.

Figure 23 represents the spatial distribution of the sulfate concentrations within the YRW. Spatially the higher concentrations tend to appear only along the length of the Yellow River or downstream from a wastewater treatment plant discharge point, represented by group 5. The high density groups tend to have lower concentrations when compared with the low density groups in most but not all samples. This trend is opposite from what is observed in the nitrate and chloride samples.

Figure 24 represents the spatial distribution of the specific conductance measurements within the YRW. The highest concentrations appear along the Yellow River and downstream from the waste water treatment plant discharge points. Interestingly, there appears to be a trend of gradation in terms of the specific conductance measurements. Lower measurements are found distal from the Yellow River and the higher concentrations are found proximal to the Yellow River, likely caused by the treated sewage that is discharged into the Yellow River.

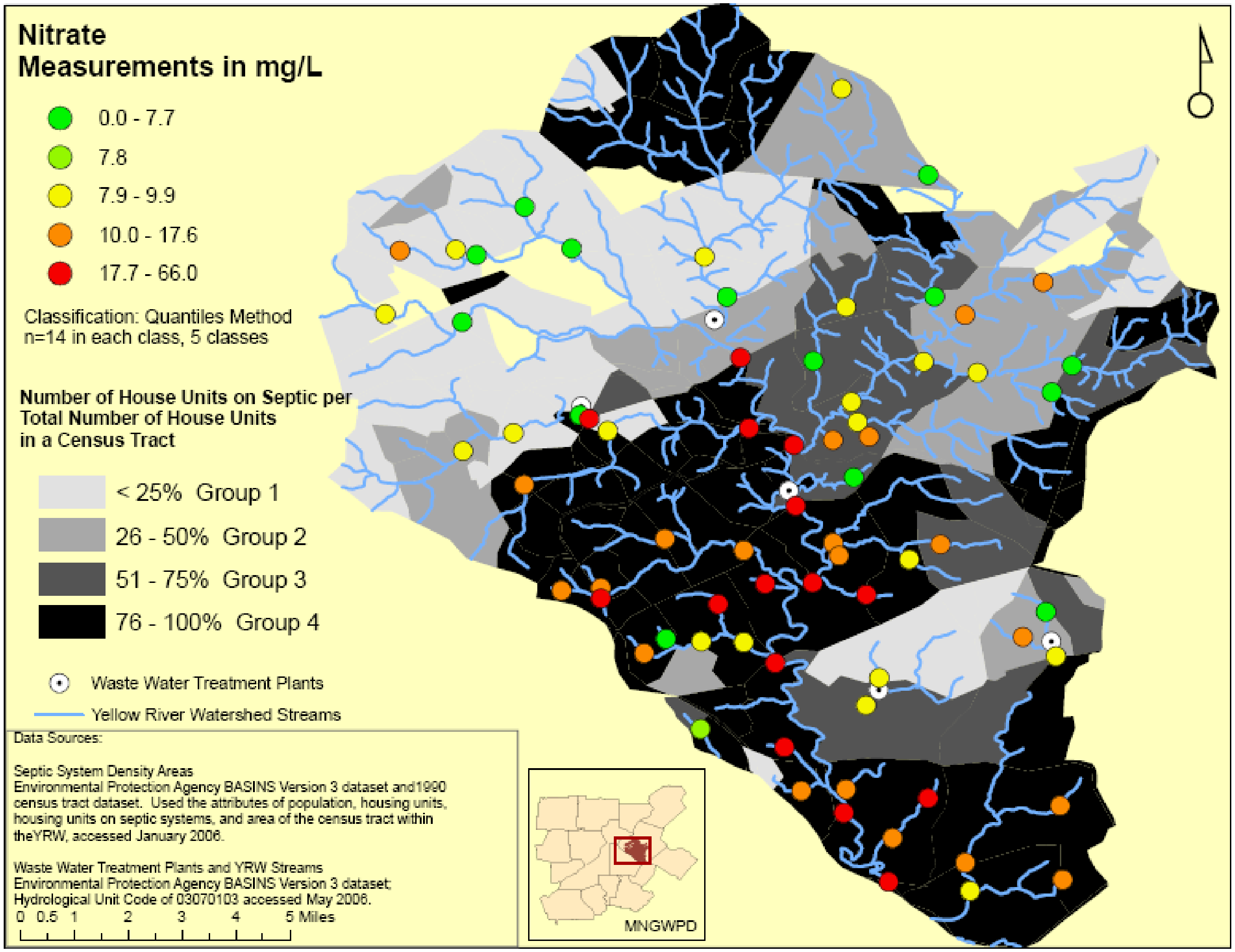


Figure 21 - Nitrate spatial distribution

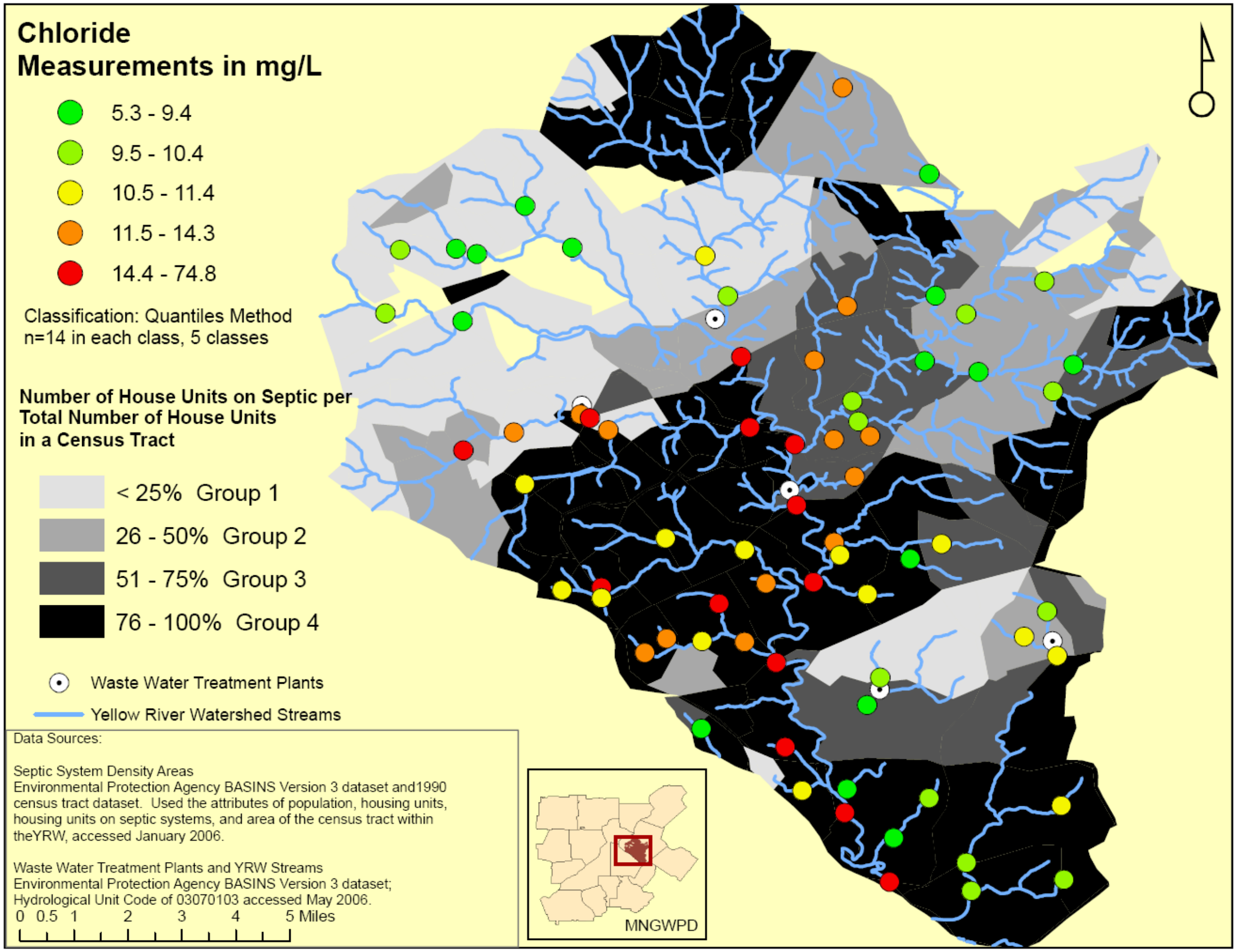


Figure 22 - Chloride spatial distribution

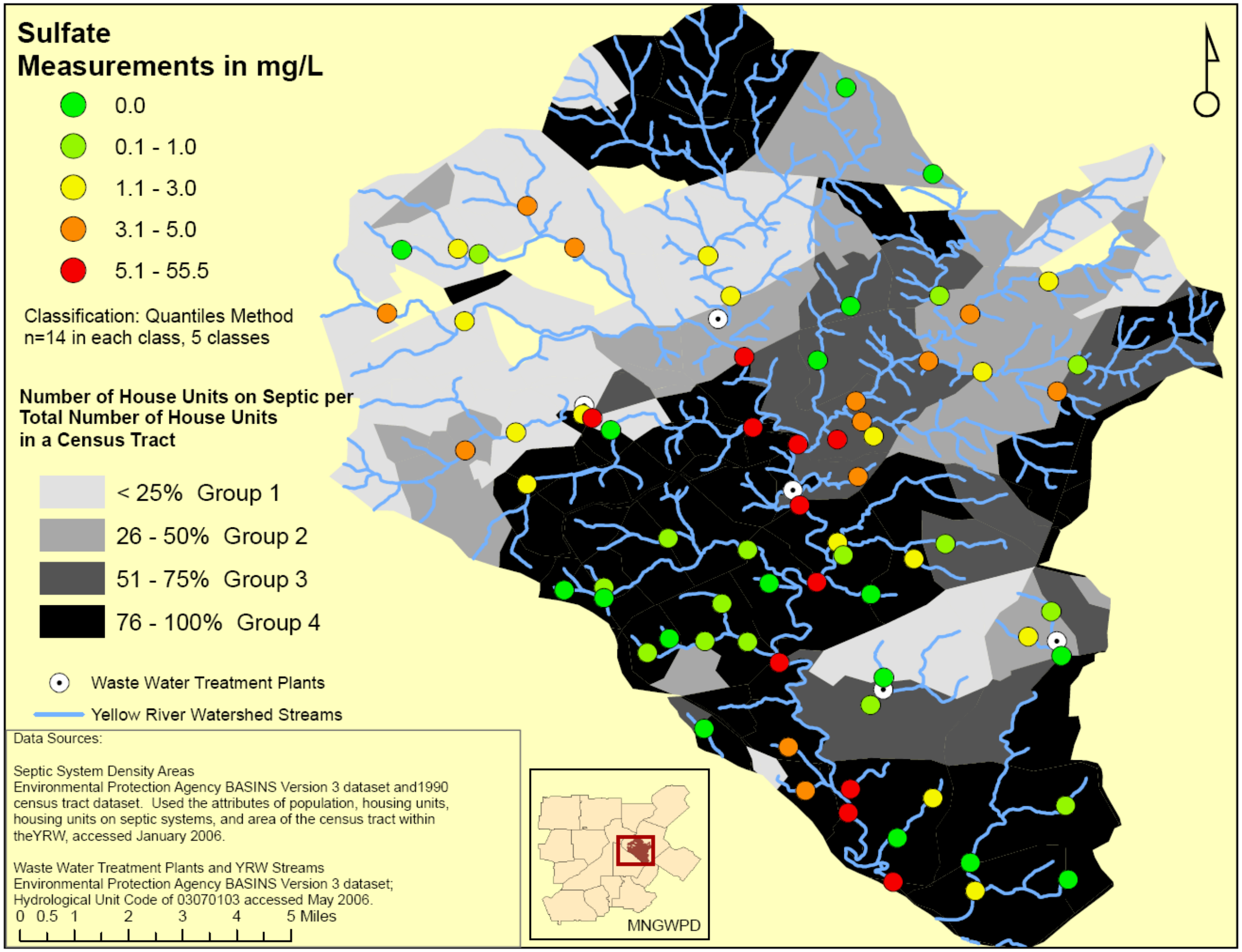


Figure 23 - Sulfate spatial distribution

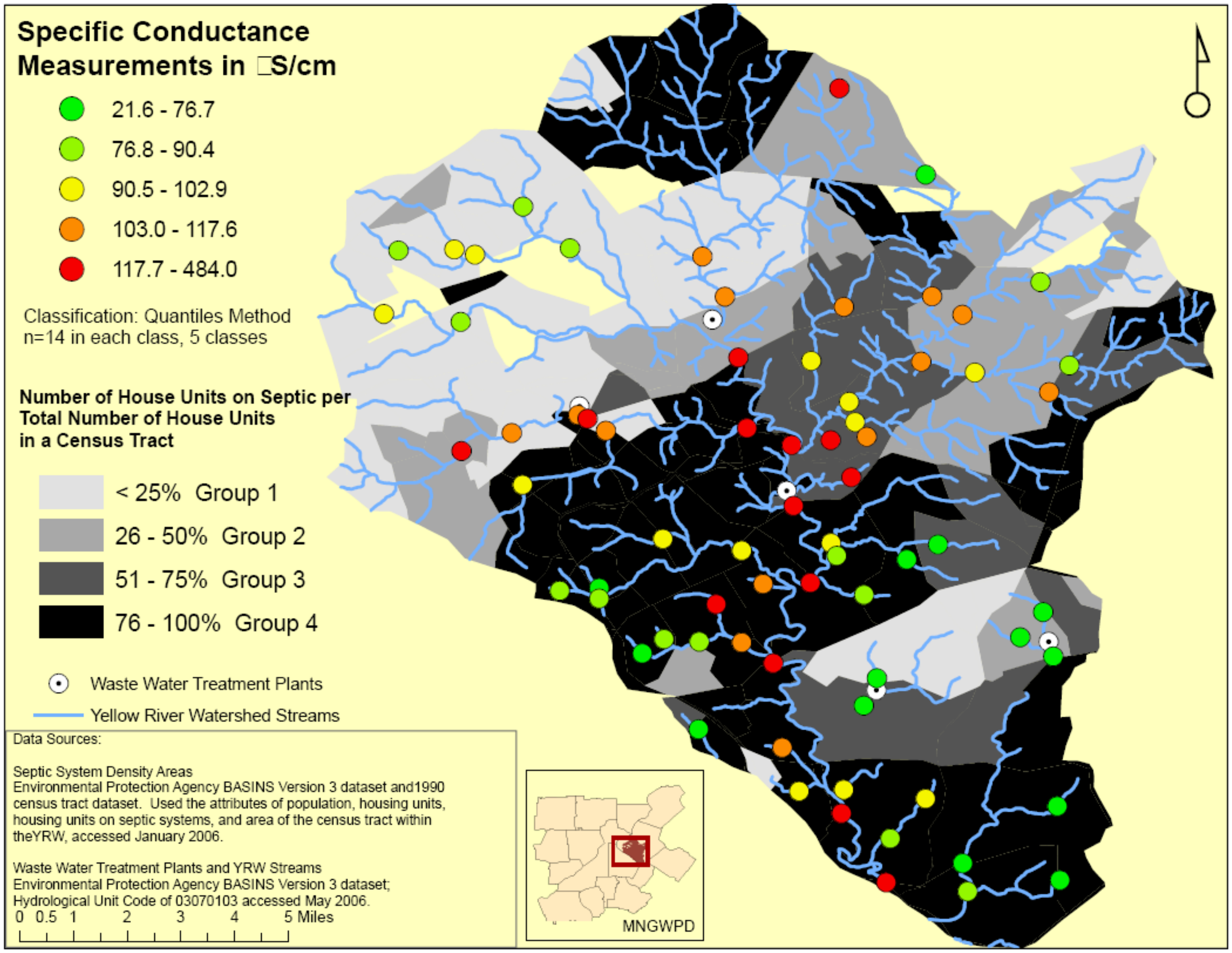


Figure 24 - Specific Conductance spatial distribution

CHAPTER 9 - Summary and Conclusions

The study of septic systems within the Metropolitan North Georgia Water Planning District has been mainly from a management perspective. This thesis is one of the first to specifically study the effects of septic system usage on the water quality of a watershed within the Water District. As mentioned before the Water District recognizes that there are very little data available to determine the exact pollutant contribution to the streams from septic systems (MNGWPD, 2006).

Even though there is very little data available, Water District Health Department Officials have stated that non-point source pollution is a factor responsible for the deteriorating water quality. Septic systems have been specifically identified as one possible source of the contamination (MNGWPD, 2005). This observation has led to a concern over the increasing volume of septic systems in unsuitable soils and locations within the Water District and their effect on the associated streams (MNGWPD, 2005; JJG, 2003).

In order to gain an understanding of the impact of septic system usage within the Water District, this thesis was developed to test the working hypothesis that elevated concentrations of sulfates, chlorides, nitrates, and specific conductance are directly related to septic system density. To test this hypothesis, water samples were collected and analyzed for the abundance and distribution of chlorides, sulfates, nitrates, and specific conductance. Then statistical techniques were applied to determine if there is a significant difference in the baseflow water chemistry between the different septic system

density groups. Finally the results were displayed using geographic information system software for a visual understanding of how septic system usage impacts the water quality of the Yellow River Watershed.

In drawing conclusions it is important to note there are variables that were not controlled in this study. Some of these variables are found in, and are related to, the individual septic system drainfield soil characteristics and the specific location of these systems. The variables are the seasonally fluctuation of the water table, the height below the drainfield of bedrock or other impervious strata, if the drainfield contains any back filled soil, the grading of the drainfield area, the slope of the drainfield, how long the drainfield has been operation, and the drainage patterns of the drainfield. A change in any one or a combination of these variables could have an affect on the residence time of the effluent in contact with the environment and ultimately a change in the baseflow water chemistry. The longer the residence time of the effluent then the longer the favorable biochemical processes have to breakdown the effluent to N_2, H_2O, and CO_2 (USGS, 2000, USEPA, 2002). Future studies could include the residence time of the baseflow and the approximately determined hill top to closest stream average distance of 0.47 miles to give an indication of how short water and pollution pathways are from the septic systems to the streams located in the YRW.

Previous studies (Gill, 2005; Roberson, 1990; Sherlock, 2002) have isolated one or more of these variables for study. These variables could be isolated because the authors have access to the specific septic system locations or have created bench level

septic systems for their study. Unfortunately, individual septic system location data are not available for this thesis. Presently, the Water District is in the process of updating their database to include the specific locations of septic systems. Future studies could be enhanced and should include specific locations of septic systems.

Additional studies could involve isotope work along the lines of Cravotta, 1997 and also Khayat et al., 2006. Cravotta, 1997 used the isotopes of carbon, nitrogen and sulfur to determine the source of nitrogen in the ground water. He concluded that the anaerobic and aerobic conditions present within a septic system produce different isotopic signatures that can be used to identify whether the nitrogen came from a septic system or from natural processes. Khayat et al., 2006 studied only nitrogen isotopes to find nitrogen plumes originating from septic systems and animal farms.

The following conclusions can be made for the Yellow River Watershed:

1. The baseflow concentrations of nitrate, chloride, sulfate, and the specific conductance measurements were lower in all the septic system density groups, groups 1 – 4, than the samples collected in group 5. Groups 1 – 4 represent baseflow containing septic system effluent that is treated by natural biochemical processes at work within the septic system including the tank and drainfield. Group 5 represents the samples collected downstream from the wastewater treatment plants. The water collected in group 5 is mostly treated sewage that is discharged from the wastewater treatment plants into the Yellow River. It appears that baseflow water even in high septic density areas (group 4) contains

lower concentrations of septic indicators than treated wastewater discharged from a wastewater treatment plant. This is a good indication that the drainfield soils are working correctly in attenuating the septic effluent.

2. Nitrate concentrations tend to be lower in the lower density groups and tend to be higher in the high density groups. This conclusion is similar to other studies (Burns, 2005; Nizeyimana, 1996; Sinton, 1982; USGS 2000) where the authors correlated baseflow nitrate concentrations with septic and / or housing density. Nitrate r^2 values show a positive well correlated trend in all density groups with respect to specific conductance.

3. Chloride concentrations shows a r^2 value that is positive and well correlated in group 2, poorly correlated in group 1 and exhibits a positive strong correlation in groups 3 and 4 with respect to specific conductance. Chloride concentrations are more spatially scattered then nitrate. This difference could be attributed to impervious surfaces in the low septic density groups that would increase the runoff component to the recharge areas of the streams adding an increase concentration of chloride then what would naturally be found (USGS, 2000). This increase chloride concentration could come from residual chloride from winter road salting (Burns, 2005).

4. Sulfate concentrations are the lowest of all the constituents analyzed. This observation can be attributed to the sulfate ion's properties of a negative two charge. The negative two charge makes the sulfate ion (SO_4^{2-}) easily sorbed to soil surfaces (Delfosse, 2006). Sulfates r^2 value exhibits a positive well correlated trend in groups 1, 3, and 4 and a positive strong correlation in group 2 with respect to specific conductance.

In conclusion, the working hypothesis of this thesis is that high concentrations of sulfates, chlorides, nitrates, and specific conductance are directly related to septic system density. In summation of the conclusions from testing the hypothesis, only a limited relationship is shown between septic system density and baseflow water quality. However due to the findings of elevated nitrate concentrations in the high density groups, this could suggest that there maybe hydrogeological pathways exist that could provide a conduit for septic system contamination flow to streams. Future studies might discover the portion of contamination in streams that are caused by septic systems. It can not be stressed enough that the member streams of the Yellow River Watershed are not contaminated with septic system effluent meaning that all sample concentrations were within the US Environmental Protection Agencies maximum contaminant levels for each anion and specific conductance.

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APPENDIX

Table A – 1 Analytical Results

Table A1. Field and Laboratory Analytical Results.

Maximum Contaminant Level (MCL) Is the highest level of a contaminant that is allowed in drinking water.
The MCL for nitrate measured as nitrogen is10 mg/L (USEPA, 2006)
The MCL for chloride is 250 mg/L (USEPA, 2006)
The MCL for sulfate is 250 mg/L (USEPA, 2006)
The MCL for Specific Conductance (Total Dissolved Solids) is 500 mg/L (USEPA, 2006)

Sample Locations	Time of Collection	Water Temp Celsius	NO3 mg/L	Specific Conductance uS/cm	Date Filtered 0.45 micron	Cl mg/L	Date Processed	SO4 mg/L	Date Processed
5250601	1010	20.8	**30.8**	**228.6**	72706	**24.0**	72706	**33.5**	82206
5250602	1110	20.9	**30.8**	**112.1**	72706	**14.5**	72706	**4.0**	82206
5250603	1210	23.0	**33.0**	**221.0**	72706	**21.0**	72706	**30.0**	82206
5250604	1315	21.8	**33.0**	**208.2**	72706	**20.3**	72706	**27.0**	82206
5250605	1400	19.9	**22.0**	**93.1**	72706	**10.1**	72706	**2.5**	82206
5250606	1430	20.1	**17.6**	**87.8**	72706	**9.1**	72706	**0.0**	82206
5250607	1510	22.4	**13.2**	**98.1**	72706	**9.2**	72706	**6.0**	82206
5300601	855	19.4	**17.6**	**102.9**	72706	**10.9**	80806	**4.0**	82206
5300602	1003	19.0	**17.6**	**65.8**	72706	**10.7**	80806	**0.5**	82206
5300603	1040	19.3	**13.2**	**46.2**	72706	**9.5**	80806	**0.0**	82206
5300604	1119	21.6	**11.0**	**73.9**	72706	**9.7**	80806	**0.0**	82206
5300605	1157	24.4	**8.8**	**76.9**	72706	**9.6**	80806	**2.5**	82206
5300606	1234	24.4	**8.8**	**24.4**	72706	**10.6**	80806	**3.0**	82206
5300607	1305	24.9	**4.4**	**24.9**	72706	**10.4**	80806	**0.5**	82206
5300608	1334	22.4	**8.8**	**22.4**	72706	**10.9**	80806	**0.0**	82206
5300609	1420	21.6	**8.8**	**21.6**	72706	**9.9**	80806	**0.0**	82206
6010601	935	18.2	**17.6**	**77.8**	80806	**11.2**	80806	**0.0**	82406
6010602	1009	18.5	**13.2**	**76.7**	80806	**17.6**	80806	**0.5**	82406
6010603	1030	19.0	**17.6**	**80.7**	80806	**11.4**	80806	**0.0**	82406
6010604	1116	19.3	**13.2**	**65.1**	80806	**12.3**	80806	**0.5**	82406
6010605	1205	23.4	**8.8**	**79.5**	80806	**11.6**	80806	**0.0**	82406
6010606	1235	24.2	**8.8**	**86.4**	80806	**11.4**	80806	**1.0**	82406
6010607	1305	20.8	**30.8**	**131.9**	80806	**16.0**	80806	**1.0**	82406
6010608	1340	28.2	**8.8**	**106.6**	80806	**13.0**	80806	**0.5**	82406
6060601	932	16.2	**8.8**	**104.8**	80806	**13.6**	81006	**2.5**	82906
6060602	1000	16.6	**6.6**	**105.2**	80806	**13.3**	81006	**1.5**	82906
6060603	1100	19.0	**0.0**	**90.4**	80806	**9.3**	81006	**1.5**	82906
6060604	1130	17.0	**13.2**	**83.1**	80806	**9.9**	81006	**0.0**	82906
6060605	1215	19.1	**2.2**	**92.1**	80806	**9.4**	81006	**1.0**	82906
6060606	1230	18.5	**8.8**	**91.3**	80806	**9.4**	81006	**1.5**	82906
6060607	1305	18.4	**4.4**	**80.9**	80806	**9.0**	81006	**3.5**	82906
6060608	1330	19.6	**4.4**	**87.9**	80806	**9.2**	81006	**4.5**	82906
6060609	1400	18.6	**8.8**	**102.8**	80806	**10.1**	81006	**4.5**	82906

Sample Locations	Time of Collection	Water Temp Celsius	NO3 mg/L	Specific Conductance uS/cm	Date Filtered 0.45 micron	Cl mg/L	Date Processed	SO4 mg/L	Date Processed
6080601	920	17.9	**13.2**	**102.7**	80806	**11.2**	81006	**2.0**	83106
6080602	942	18.0	**8.8**	**123.7**	80806	**15.0**	81006	**3.5**	83106
6080603	1010	19.5	**8.8**	**117.6**	80806	**12.6**	81006	**0.0**	83106
6080604	1030	20.0	**66.0**	**484.0**	80806	**74.8**	81006	**55.5**	83106
6080605	1110	20.2	**48.4**	**278.7**	80806	**24.7**	81006	**46.5**	83106
6080606	1155	19.1	**6.6**	**100.9**	80806	**12.3**	81006	**0.0**	83106
6080607	1215	19.9	**8.8**	**91.6**	80806	**10.4**	81006	**4.0**	83106
6080608	1230	21.3	**8.8**	**95.6**	80806	**10.4**	81006	**5.0**	83106
6080609	1300	22.6	**35.2**	**201.7**	80806	**21.0**	81006	**26.0**	83106
6080610	1320	20.6	**44.0**	**320.7**	80806	**44.8**	81006	**34.5**	83106
6150601	932	18.8	**22.0**	**115.7**	81006	**13.6**	81506	**0.0**	90506
6150602	950	19.6	**13.2**	**96.8**	81006	**11.1**	81506	**0.5**	90506
6150603	1015	20.6	**11.0**	**94.1**	81006	**10.6**	81506	**0.5**	90506
6150604	1045	20.9	**33.0**	**241.2**	81006	**25.7**	81506	**31.0**	90506
6150605	1140	20.2	**8.8**	**72.2**	81006	**9.0**	81506	**1.5**	90506
6150606	1215	21.0	**17.6**	**76.0**	81006	**10.7**	81506	**1.0**	90506
6150607	1240	21.0	**15.4**	**102.9**	81006	**12.4**	81506	**2.0**	90506
6150608	1255	20.5	**15.4**	**80.2**	81006	**10.9**	81506	**0.5**	90506
6150609	1315	22.9	**19.8**	**85.0**	81006	**11.4**	81506	**0.0**	90506
6150610	1335	21.9	**35.2**	**250.9**	81006	**25.9**	81506	**32.0**	90506
6200601	1000	23.1	**4.4**	**106.5**	81206	**10.1**	81506	**3.0**	90706
6200602	1030	23.9	**8.8**	**112.4**	81206	**11.2**	81506	**2.5**	90706
6220601	910	21.6	**8.8**	**111.5**	81206	**12.4**	81706	**0.0**	90706
6220602	935	22.2	**6.6**	**104.6**	81206	**9.4**	81706	**0.5**	90706
6220603	1010	21.3	**12.3**	**81.5**	81206	**10.2**	81706	**1.5**	90706
6220604	1045	22.2	**11.0**	**108.0**	81206	**9.7**	81706	**5.0**	90706
6220605	1130	25.2	**8.8**	**105.4**	81206	**9.0**	81706	**3.5**	90706
6220606	1230	24.6	**6.6**	**84.8**	81206	**9.2**	81706	**0.5**	90706
6220607	1250	25.7	**6.6**	**111.6**	81206	**10.4**	81706	**3.5**	90706
6220608	1515	24.4	**8.8**	**99.1**	81206	**9.2**	81706	**3.0**	90706
7130601	835	20.4	**7.7**	**49.1**	81206	**7.1**	81706	**0.0**	91206
7130602	900	21.7	**8.8**	**76.4**	81206	**8.2**	81706	**1.0**	91207
7130603	930	21.5	**6.6**	**141.7**	81206	**13.0**	81706	**3.5**	91208
7130604	955	20.8	**22.0**	**151.9**	81206	**14.3**	81706	**6.0**	91209
7130605	1020	19.9	**13.2**	**110.0**	81206	**12.3**	81706	**2.0**	91210
7130606	1150	25.5	**8.8**	**122.0**	81206	**12.1**	81706	**0.0**	91211
7130607	1220	23.7	**6.6**	**67.1**	81206	**5.3**	81706	**0.0**	91212

Table A-2 Summary of Map Titles with Layers, Description, and Reference.

Map Title	*Layers Used*	*Description*	*Reference*
Geologic Map of the Yellow River Watershed			
	YRW Boundary	Polygon of the watershed / study area	USGS, 2002
	YRW Streams	hydrologic unit code 03070103	USEPA, 1998
	MNGWPD Geol	Surface geology of the 16 county Atlanta area	GDNR, 1999
Sample Locations			
	Gage Station Locations	Gage Stations locations within study area	USEPA, 1998
	WWTP Locations	WWTP locations within study area	USEPA, 1998
	Sample Locations	70 sample collection sites used in the thesis	Shapefile created by author
	Road Network	Subset of United States road network	Grasp Baselayer, 2007
	YRW Boundary	Polygon of the watershed / study area	USGS, 2002
	YRW Streams	Hydrologic unit code 03070103	USEPA, 1998
	MNGWPD Boundary	16 county Atlanta area; Water Planning District	Shapefile created by author based upon Atlanta Regional Commission Water Planning Districts
Metropolitan North Georgia Water Planning District			
	MNGWPD Boundary	16 county Atlanta area; Water Planning District	Shapefile created by author based upon Atlanta Regional Commission Water Planning Districts
	Major Georgia Highways	Subset of the US Highways	ESRI SDE Layer, 2004
	Georgia Counties	Subset of the U.S. County Boundaries	ESRI SDE Layer, 2004
Location of the Study Area			

	MNGWPD Boundary	16 county Atlanta area; Water Planning District	Shapefile created by author based upon Atlanta Regional Commission Water Planning Districts
	YRW Boundary	Polygon of the watershed / study area	USGS, 2002
	Georgia Major Watersheds	Subset of US major watersheds	USEPA, 1998
Study Area			
	Gage Station Locations	Gage Stations locations within study area	USEPA, 1998
	WWTP Locations	WWTP locations within study area	USEPA, 1998
	Septic System Density Groups	The four density groups based on the 1990 census data	USEPA, 1998
	Road Network	Subset of United States road network	Grasp Baselayer, 2007
	YRW Boundary	Polygon of the watershed / study area	USGS, 2002
	YRW Streams	Hydrologic unit code 03070103	USEPA, 1998
	MNGWPD Boundary	16 county Atlanta area; Water Planning District	Shapefile created by author based upon Atlanta Regional Commission Water Planning Districts
Spatial Distributions of Constituents			
	Sample Results	70 sample results of nitrate, chloride, sulfate, and specific conductance	Shapefile created by author
	YRW Streams	Hydrologic unit code 03070103	USEPA, 1998
	Highway Network	Subset of United States highway network	Grasp Baselayer, 2007

Table A-3 Summary of Collection Sites, Density Groups and Streams

	Sample ID	Stream		Sample ID	Stream
Septic Group 1			Septic Group 2		
	6060609	Beaver Ruin		6080602	Jackson Creek
	6060603	Beaver Ruin		7130606	Lee Daniel Creek
	6060601	Jackson Creek		7130607	Member Stream/Yellow River
	6080603	Camp Creek		6220603	Pew Creek
	6060602	Camp Creek		6220602	Yellow River
	6060604	Bromolow Creek		6220604	Pew Creek
	6060606	Bromolow Creek		6220608	Rocky Branch
	6060605	Bromolow Creek		6220605	Rocky Branch
	6060607	Bromolow Creek		7130603	Member Stream/Yellow River
	6060608	Bromolow Creek		7130604	Member Stream/Yellow River
	6200602	Sweetwater Creek		6080608	1550699
	6200601	Sweetwater Creek		7130605	Member Stream/1550699
	6220607	Rock Branch		5300607	No Business Creek
	5300609	Jacks Creek		5300606	Member Stream/ No Business Creek
				5300608	No Business Creek
Septic Group 3			Septic Group 4		
	6220606	1552077		5250602	Member Stream/Yellow River
	6220601	Member Stream/Yellow River		5250605	Centerville Creek
	6080606	Member Stream/Yellow River		5250606	Centerville Creek
	6080607	Yellow River		5250607	Member Stream/Yellow River
	6150606	Watson Creek		5300601	Member Stream/Yellow River
	7130602	Jacks Creek		5300602	Do Little Creek
				5300603	Doc Moore Branch
Septic Group 5				5300604	No Buisness Creek
	6080604	Camp Creek		5300605	Doc Moore Branch
	6080605	Sweetwater Creek		6010601	Garner Creek
	6080609	Yellow River		6010602	Member Stream/Garner

					Creek
	6150604	Yellow River		6010603	Garner Creek
	6150610	Yellow River		6010604	Pounds Creek
	5250601	Yellow River		6010605	Member Stream/Pounds Creek
	5250603	Yellow River		6010606	Pounds Creek
	5250604	Yellow River		6010607	Member Stream/Pounds Creek
				6010608	Pounds Creek
				6080601	Camp Creek
				6080610	Jackson Creek
				6150601	Member Stream/Yellow River
				6150602	Garner Creek
				6150603	Hale Creek
				6150605	Member Stream/Watson Creek
				6150607	Turkey Creek
				6150608	Watson Creek
				6150609	Weed Branch
				7130601	Member Stream/Yellow River