Land Application of Treated Wastewater within the Black Belt of Alabama

By: Carey Clark

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfilment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 5th, 2023

Pending Approval by:
Mark O. Barnett, Professor of Environmental Engineering (Advisor)
Joel Hayworth, Elton Z. and Lois G. Huff Associate Professor
Shiqiang Zou, Assistant Professor of Environmental Engineering

Abstract

The Black Belt of Alabama is a region of the United States that has seen its population decrease and poverty rise over the last century. The Black Belt was a thriving part of Alabama due to the rich, fertile soil. The dark soil's color was the cause of the area being called the "Black Belt". The dark soil known as the Blackland Prairie soil is a shrink-swell clay in the vertisol family. The Blackland Prairie soil has a low percolation and conductivity rate. The soil has made it difficult for land application sites in the Black Belt to be effective in draining discharged treated wastewater.

The Black Belt currently has six land application sites, or commonly referred to as "spray fields", located throughout the region. Two of the six spray fields had ten or more NPDES violations, between 2018 and 2020. Two of the remaining four have had a history of NPDES violations, at least three violations between the years 2018 and 2020, and the final two spray fields have had no NPDES violations. Currently there are eighteen spray fields throughout the entire state.

One of the spray fields within the Black Belt is in Uniontown, AL. The spray field in Uniontown has had compliance issues with the Alabama Department of Environmental Management (ADEM) dating back to 2006. The spray field is currently severely flooded due to the spray field being undersized relative to the permitted discharge. The spray field currently has a discharge permit of 1,893 m3 d-1 (500,000 gallons d-1). The spray field regularly exceeds the permitted discharge. The recorded monthly average discharge has been reported as high as 6,284 m3 d-1 (1,660,000 gallons d-1). Groundwater modeling by MODFlow Flex found the spray field site would only be able to work properly if discharged wastewater effluent traveled via the subsurface to Freetown Creek located 330 meters to the west of the discharge sprinklers. The spray field site was found to be able to work properly if the permitted discharge was reduced by 55% to 852 m3 d-1 (225,000 gallons d-1) as opposed to 1,893 m3 d-1 (500,000 gallons d-1), the current permitted discharge. The 1,893 m3 d-1 discharge permit would only be viable for the existing spray field if the hydraulic conductivity of the upper soil layer was almost two orders of magnitude higher. The existing spray field area was found to be undersized based on the loading rates relative to the spray field's capacity.

Acknowledgments

The author would like to express tremendous gratitude for receiving superb encouragement, instruction, and guidance from his advisor Dr. Mark Barnett. Without his guidance, the author would not have been able to draft the research paper that follows or have the opportunity afforded to him at Auburn University. Additional thanks is expressed to the author's committee members, Dr. Joel Hayworth and Dr. Shiqiang Zou, as well as the rest of the environmental faculty in the Civil Engineering Department for the first rate instruction and intentional support over the author's two year term at Auburn University. Finally, the author would like to thank his wife, family, and friends who have supported him without fail throughout his studies here at Auburn University. This research was financially supported by the United States Department of Agriculture (USDA).

Table of Contents

Chapter One.

Introduction

1.1 Problem Statement

About 80% of wastewater from human activities is discharged without sufficient treatment worldwide (Y. S. Huang et al., 2021). The result is deteriorated sanitation and public health for the local communities. Water-borne diseases caused by pathogenic bacteria, viruses, and parasites are the most common and harmful products of not having access to safe sanitation (WHO/UNICEF, 2021). In 2010, the United Nations declared sanitation a human right for all people (United-Nations, 2015). Insufficient sanitation conditions are prominently within impoverished, developing countries but are also found in underserved communities within the United States (Wedgworth, 2013). Insufficient wastewater treatment is one of the many causes of insufficient sanitation.

The Clean Water Act (CWA) was established in 1972 to establish national guidelines for discharging of pollutants into the “waters of the United States” (WOTUS) and regulate standards for surface waters. The WOTUS are navigable waters that fall under the jurisdiction of the United States (EPA, 2015b). These waters predominantly supply drinking water to communities or are streams that feed into surface waters that provide drinking water. The CWA made discharge of pollutants from a point source into WOTUS illegal unless a permit was obtained that certified satisfactory treatment (EPA, 2022b). A point source discharge is a conveyance that utilizes pipes or man-made ditches. The Environmental Protection Agency (EPA) controls pollutant discharge permits through the National Pollutant Discharge Elimination System

(NPDES). Violation of NPDES or discharging without permit results in fines and potentially even criminal prosecution from the EPA.

The WOTUS has been a widely debated term throughout the CWA implementation. Legal challenges have at times forced implementation of different definitions of WOTUS to be applied (EPA, 2020). In 2015, the EPA released a literature review to better outline what constituted a WOTUS and what did not (EPA, 2015a). The literature review based what constituted a WOTUS on five factors: streams, riparian/floodplain wetlands, non-floodplain wetlands, degrees and determinants of connectivity, and cumulative effects (EPA, 2015a).

The Supreme Court in “County of Maui vs. Hawaii Wildlife Fund” ruled that a NPDES is required if an indirect discharge is the “functional equivalent” of a direct discharge ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020). The factors to prove or determine functional equivalent are: transit time, distance traveled, nature of the material a pollutant travels through, extent to which a pollutant is diluted or chemically changed, amount of pollutant entering water relative to the source, and the mechanism, such as advection through soil or surface runoff, a pollutant enters WOTUS. The Supreme Court ruling goes on to say that “time and distance will be the most important factors in most cases” ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020).

Throughout the United States, many municipalities are determining if the updated functional equivalent standard applies to previously certified discharges (Lee, 2020). The parameters for assessing functional equivalence are defined, but weight of evidence must be shown to not be classified as a direct discharge. One form of wastewater treatment and discharge is land application via irrigation, also known as “spray fields”. Engineered spray fields operate as indirect source based on design, operation, and maintenance. Inadequate design and selection of land application areas could result in direct discharge under the new ruling ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020). Therefore, the study of groundwater routing and functional spray fields is important to the discussion of future legislation pertaining to discharges of WOTUS.

The focus area of this thesis is the Black Belt of Alabama. An assessment of spray fields within the Black Belt will be conducted to determine the status and how to improve failing spray fields within the region. All spray fields within the Black Belt are located within 2.5 miles of a WOTUS and 43% being located within a mile. Properly engineered and operated irrigation spray fields have no effluent reaching nearby creeks and streams. Effluent is absorbed by vegetation and the soil (Gohil, 2000). Successful land application sites can have a positive impact on water reuse, aquifer recharge, and vegetation production (EPA, 2022a).

The Black Belt is an area comprised of counties spanning from Sumter County to Russell County that share similar economic and soil characteristics. **Figure 1-1** highlights the counties within the Black Belt by the black border around the designated counties (Prior and Wong, 2022). The Black Belt has a 34.9% poverty rate, almost double the state of Alabama’s average of 18.8% (Diop and Fraser, 2009). For comparison, the United States has a poverty rate of 11.6% (Bureau, 2021).

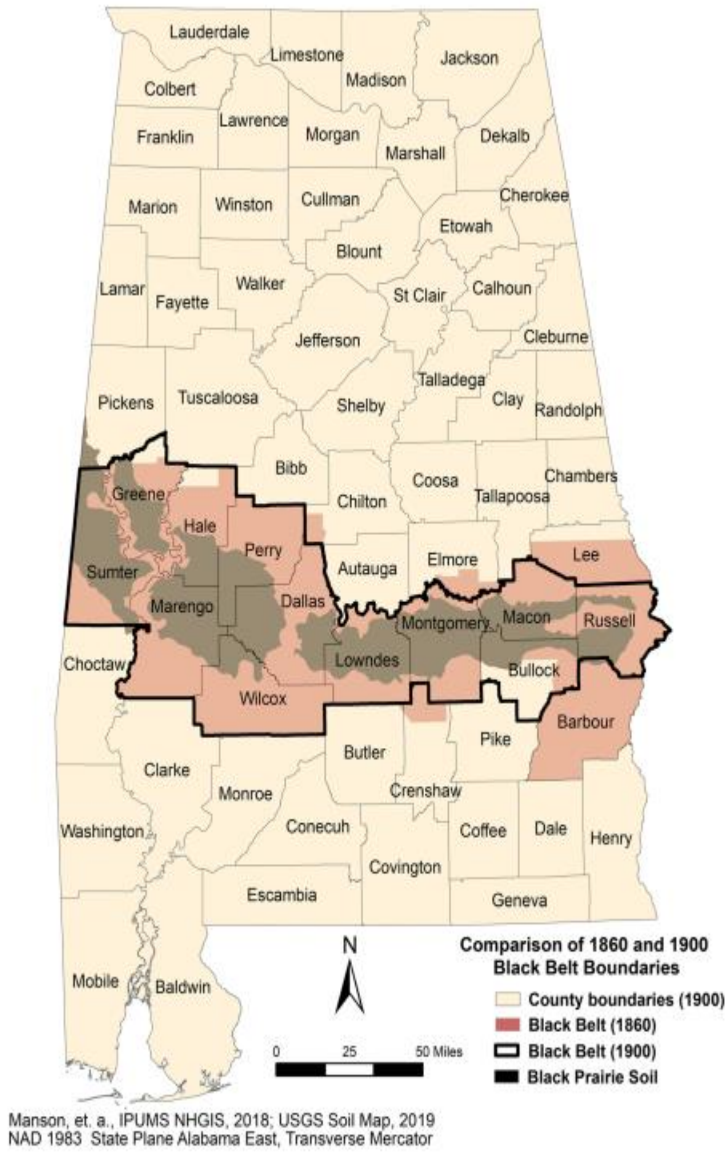


Figure 1-1: Map of the Black Belt of Alabama (Prior and Wong, 2022)

The predominant soil within the Black Belt is called Blackland Prairie soil. The Blackland Prairie soil has a darker color and is very dense shrink-swell clay soil. The soil is what originally led to the naming of the region, "The Black Belt" (Prior and Wong, 2022). Originally, the Black Belt's soil was high in organic matter which led to high crop production. In the 19th century, cotton was the major cash crop for the region (Wedgeworth and Brown, 2013). The current state of the Black Belt's Blackland Prairie soil is classified as a vertisol. Vertisols are a soil type that is composed of mostly clay and little organic matter (Ahmad, 1983). The vertisol clay soil expands drastically when saturated to lower water infiltration and percolation rates (Bandyopadhyay et al., 2003). The vertisol soil has presented challenges for centralized wastewater treatment with a spray field discharge (Gharaibeh et al., 2007). The expansion of the clay soil results in slower infiltration into the soil requiring less treated wastewater to be irrigated onto the discharge location. The depopulation of the Black Belt over the last 50 years has led to stifling economic growth in the region (Mann and Rogers, 2021). The environmental and economic challenges have led for wastewater treatment to be difficult.

Land application discharge requires a large site for the treated effluent, particularly in areas with poorly drained soils (Galegar et al., 1980). The objective of spray fields is to allow the nutrient-rich water, in particular nitrogen and phosphorous, to be utilized by vegetation to treat contaminant levels to sufficient levels. Sufficient land must be available for land application to perform optimally. Humid climate conditions and soil composition within the Black Belt requires greater land size to perform properly. Vertisols present the challenge of ponding on spray fields due to the low infiltration rate and saturation of soils (Ahmad, 1983). If not properly designed, overland water routing then takes place resulting in an unpermitted discharge to nearby water bodies.

Land application areas are mostly used within rural communities due to lower effluent discharge regulations compared to surface discharge and cheaper maintenance within the system (EPA, 2006). Rural communities have higher land-to-population ratio allowing for lower cost of land for municipalities to buy. Approximately 10% of systems discharge through land application throughout the state of Alabama, and 20% of all land application sites in the state are found within the Black Belt (ADEM, 2022b). Seventy percent of the land application sites within the Black Belt have been cited with multiple NPDES violations (ADEM, 2022a). The NPDES program requires permittees, or municipal wastewater dischargers, to report quarterly on water quality and volumetric flow rate.

An example of a failing land application site within the Black Belt is Uniontown, Alabama, a city in the Black Belt, located in Perry County with a population of approximately 2,107 people shown in **Figure 1-2**. Uniontown's wastewater system is an aerated lagoon with a spray field for discharge. Uniontown's municipal wastewater system consistently violates NPDES permits dating back the last decade (ADEM, 2022a). The lagoon overflows and discharges into Cottonwood Creek and the spray field's ponding results in overland effluent runoff into Freetown Creek. Both creeks eventually feed into the Alabama River, the longest river in Alabama. In 2015, the Alabama Department of Environmental Management deemed necessary improvement to be made to Uniontown's wastewater treatment facility due to consistent violations. Necessary actions included: fines to the city, injunctions by courts to force local officials to begin planning improvements, and permit requirements (ADEM, 2021).

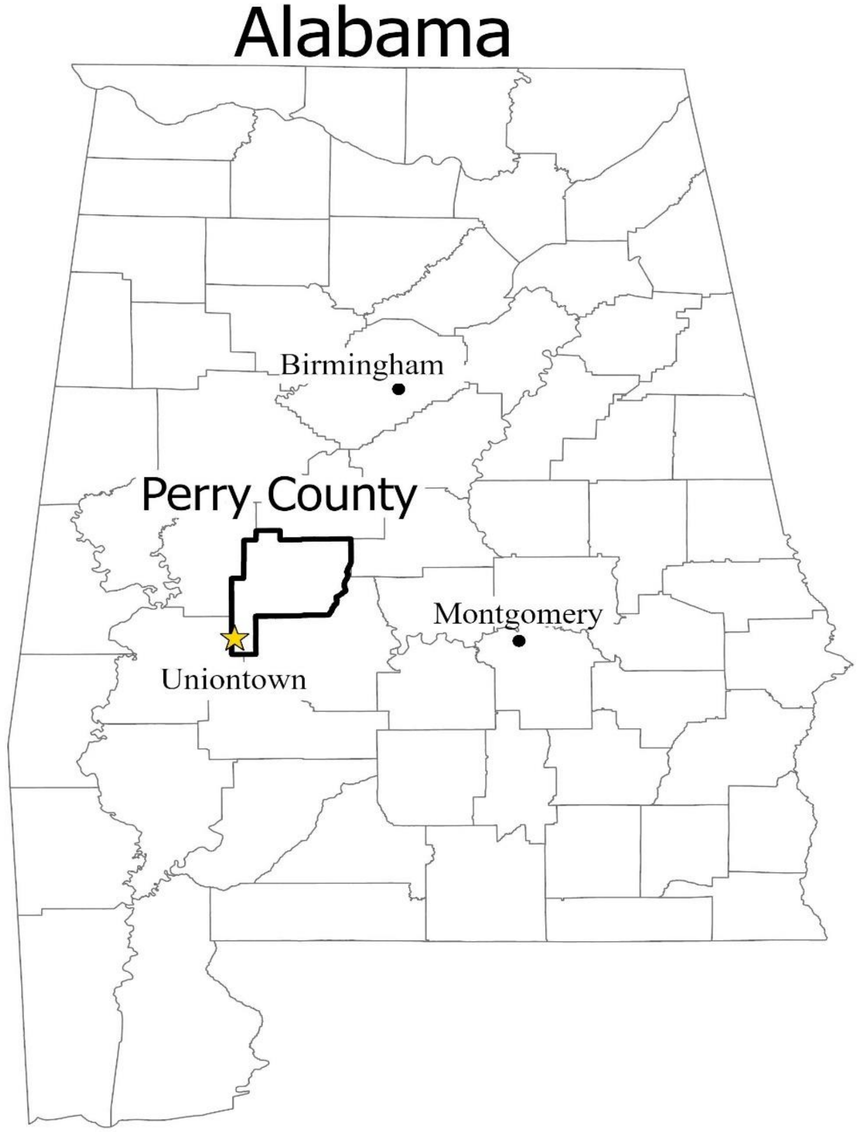


Figure 1-2: State of Alabama and Uniontown, AL

This thesis will seek to determine how the spray field located within Uniontown has failed and what necessary components are needed for a successful spray field. This thesis will also seek to determine how new functional equivalent standards could affect Black Belt land application sites. If new standards do apply functional equivalent discharges to Black Belt land application sites, determining if the site can be improved through engineering strategies will be assessed. The Uniontown, AL land application site will be used as a case example of land application sites throughout the Black Belt to determine if sufficient improvements can be made.

1.2 Objectives

The purpose of this study is to 1) perform groundwater modeling of the Uniontown spray field to determine reasons for the system's failure; 2) determine to what extent the Uniontown spray field is a functional discharge to Freetown Creek; and 3) determine whether engineering modifications (e.g., increasing sprinkler application area, installation of sand trenches, etc.) would allow the system to operate successfully. The results of this investigation are directly applicable to the Uniontown spray field and generally applicable to spray fields (or other subsurface wastewater discharges) situated in poorly drained soils near surface water bodies.

1.3 Organization

The thesis is composed of four different chapters. Chapter one provides basic background information, an introduction to the problem, and the objectives. Chapter two is an in-depth literature review of wastewater treatment discharge, WOTUS, land application throughout the state of Alabama, and other background material relevant to the research. Chapter three presents the materials, methods, results, discussion, and findings from the research. Chapter 3 is formatted as a draft manuscript, which will be submitted for publication in a scientific, peer-reviewed journal. Chapter four briefly summarizes conclusions of the study as well as recommendations for potential future research. Additional figures and information can be found in the appendices section of this thesis. The report follows the guidelines for a publication-style thesis as outlined in the *Guide to Preparation and Submission of Theses and Dissertations* by Auburn University Graduate School.

Chapter Two.

Literature Review

The following literature review was conducted to determine how land application of treated wastewater effluent is being utilized. The outline of this literature review is broken down into three sections. The first section explains the history and current characteristics within the Black Belt of Alabama. The second section reviews the history and conventional design and processes of land application sites. The last section highlights the current events and regulations that are occurring now and how it could impact current land application sites.

2.1 Black Belt of Alabama

2.1.a. History and Background of the Black Belt

The Black Belt is an area that ranges throughout the mid southern portion of the state of Alabama. The Black Belt is comprised of counties spanning from Sumter County to Russell County (refer to **Figure 2-1**). The Black-Belt region lies within the south coastal plain of the Gulf of Mexico, which is 65-78 kilometers wide and stretches 777 kilometers from eastern south-central Alabama into north-western Mississippi.

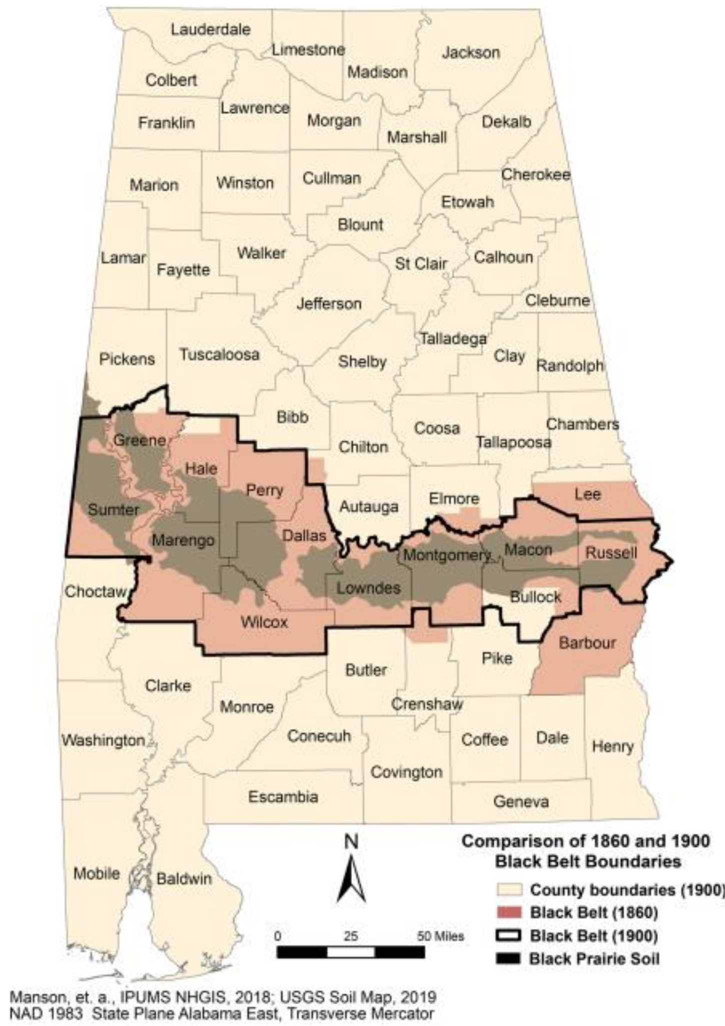


Figure 2-1: The Black Belt of Alabama (Prior and Wong, 2022)

The region is called the Black Belt because of the rich, dark soil in the area and the predominant African-American population (Fraser et al., 2005). The area was a focal point in the mid 1800's to the early 1900's in Alabama for cotton production and the "antebellum-plantation complex" (Webster and Bowman, 2008). In 1916, the boll weevil ravaged cotton crops and led to the failure of the cotton credit system which left the local economy in shambles (Prior and Wong, 2022). Cotton production had decreased by 70% in the between the years of 1915 and 1920 (Prior and Wong, 2022). Residents began migrating out of the area to larger cities due to industrialization and with the hope of coming out of debt due to the cotton economy being decimated (Mann and Rogers, 2021). The population that was left behind is predominantly made up of African Americans that still face adverse economic, education and health situations (Mann and Rogers, 2021).

The Black Belt has a 34.9% poverty rate, almost double the state of Alabama's average of 18.8% (Diop and Fraser, 2008). The median household income averaged over the twelve counties is approximately $34,000 (Census, 2020a). Throughout the region there are strong indicators of poor health. Some indicators include a high infant mortality (ADPH, 2018; Sanspree et al., 2008), prevalence of noncommunicable diseases (Voeks et al., 2008), prevalence of HIV/AIDS (Lichtenstein, 2007), and a shorter life expectancy, which are all highly elevated throughout the region relative to the rest of the United States (Wedgeworth and Brown, 2013). The population has continued to decrease over the past decade. In 2010, the population was approximately 460,000 and the population in 2020 is approximately 440,000 (Census, 2020b). The lack of people moving into the region can be partially attributed to lack of infrastructure needed for the region to be attractive for commerce to be brought in (Mann and Rogers, 2021). The lack of population density, education, and health throughout the region makes government aid difficult to implement (Mann and Rogers, 2021). Without first addressing infrastructure needs within the area, economic resurgence will be difficult.

2.1.b. Soils of the Black Belt

As mentioned, the Black Belt originally derived its name from the rich, dark soil that helped make the area fertile for cotton production. There are seven different major soil areas within Alabama (**Figure 2-2**). The soil that defines the Black Belt of Alabama is known as the Blackland Prairie soil. The Blackland prairie soil family runs 310 miles long and up to 25 miles wide between Alabama and Mississippi (He et al., 2021). The Blackland Prairie soil encompasses a land area of 6,370 square miles. The predominant order of soils that make up the Blackland Prairie soil are vertisols. Vertisols are expansive clay soils that swell during wet seasons and make for low infiltration and conductivity rates (He et al., 2013). During very dry seasons, vertisols form deep cracks that create open pockets for water to infiltrate quickly (He et al., 2021). These shrink-swell characteristics make it difficult for soil-based wastewater treatment systems to be utilized and sustained. The subtropical climate within the Black Belt also risks potential saturated soil overflow during the wet months of the year (Wedgworth & Brown, 2013).

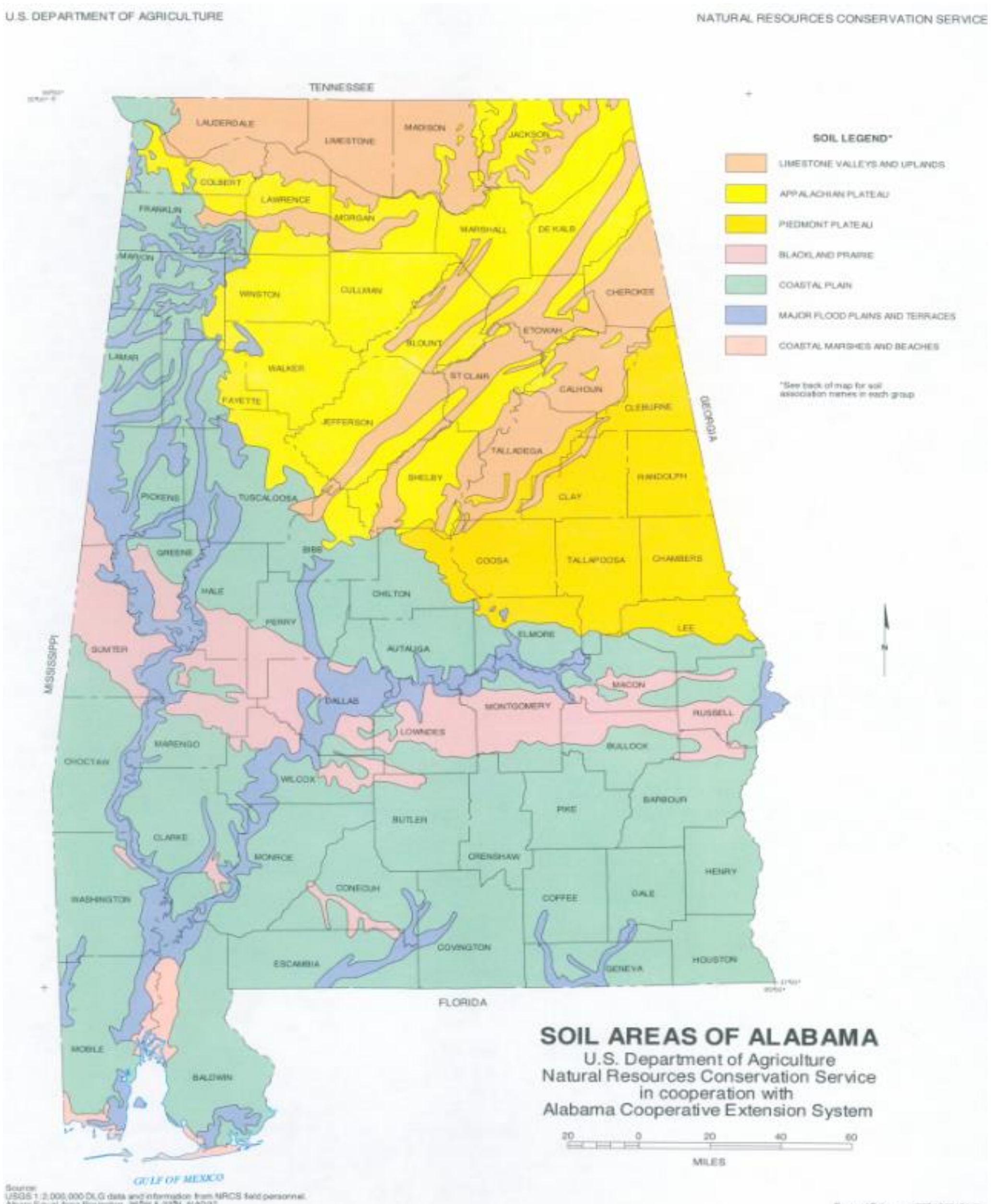


Figure 2-2: Alabama Soil Map (Mitchell, 2008)

The Blackland Prairie soils are derived from alkaline, Selma Chalk or acid marine clays with acid and alkaline soils dispersed throughout the area (Mitchell, 2008). The soil mapping for the Blackland Prairie soil can be found in **Figure 2-3**. The dominant sub order soils are Ochrepts and Udalfs (AGSCS, 1981). Sub-order soils are classified based on geography makeup. Factors include the temperature, moisture, and minerals found based on geography. Typically Ochrepts and Udalfs are in warm temperatures, have high moisture content, and are found over limestone (AGSCS, 1981). The series of soils that make up the Black Belt are the Sumter and Oktibbeha soils predominantly (Mitchell, 2008). The series of soils is based on color. Sumter soils are differentiated from other clayey soils by the darker colored surface layer and the yellow-colored soil underneath the surface overlying chalk. Oktibbeha soils have a red subsoil layer. Last, the group of soils that make up the Sumter and Oktibbeha soils are the Wilcox, Mayhew, and Valden soils (Mitchell, 2008). Each of these groups are defined by the lack of infiltration and characteristically high acidity. The groups also contain a high amount of smectite clays, known for swelling when in contact with water, which give the Blackland Prairie the shrink-swell effect.

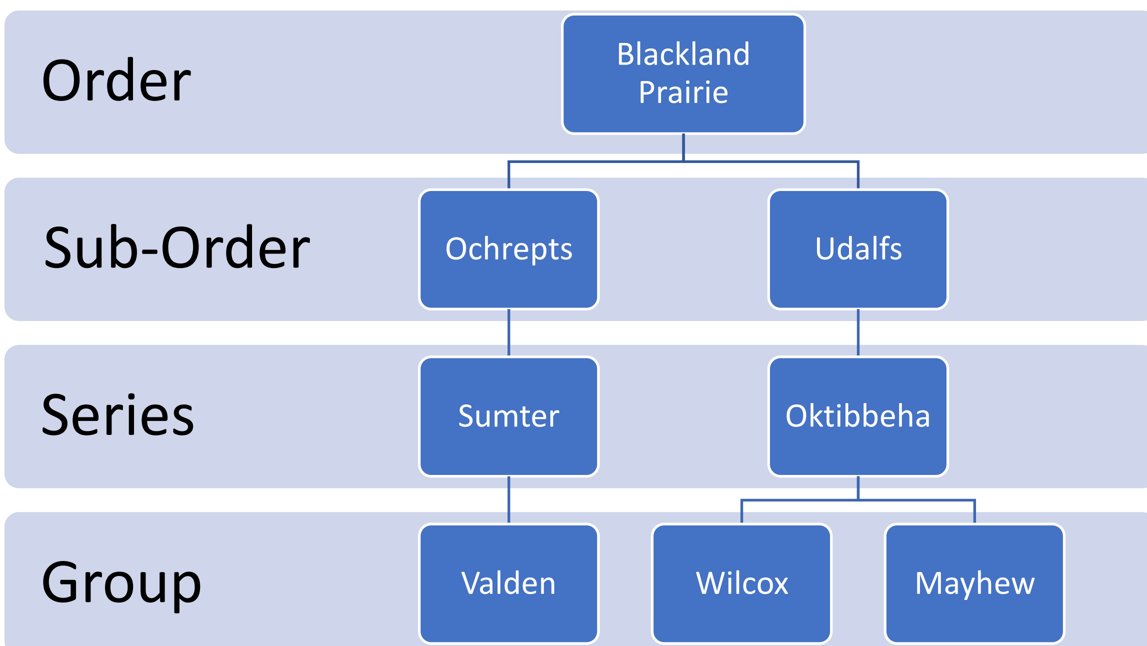


Figure 2-3: Soil Mapping for Blackland Prairie Soils

During the economic boom of the Black Belt, high organic matter was found on the topsoil of the Blackland Prairie soil. Over time, most likely poor farming techniques, the organic matter on the top soil has been reduced drastically (Diop and Fraser, 2009). Currently only about

16% of the land is used for crop production with soybeans and corn being the primary crops (Mitchell and Buehring, 2009). The majority of land use within the Blackland Prairie soil is forests which takes up nearly half, 49%, of the land use (Mitchell and Buehring, 2009). The grassland areas were used mostly by dairy farms but have since been converted to catfish farms and other agricultural companies (Mitchell and Buehring, 2009).

2.2. Land Application

2.2.a. History of Land Application

Wastewater treatment's three basic operations consist of collection, treatment, and disposal. Development of each of the different operations occurred at different stages of time. Collection was first used during ancient Roman times dating back 3000 BC (Gohil, 2000). Treatment and disposal were first used in the United States during the mid-1800's (Gohil, 2000). Wastewater treatment conventionally has two applications of disposal: land and groundwater.

Wastewater discharged into nearby surface waters traditionally needs higher levels of treatment than land application (EPA, 2002). "Land application" refers to the application of treated wastewater to achieve treatment and to meet irrigation the needs of vegetations (Tzanakakis et al., 2006). Land application was traditionally first practiced within the United States around the 1840's (Gohil, 2000). Usage of land application declined due to the emergence of industrialization (Young & Epp, 1980). Industrialization and growing population throughout the United States led to greater volume of effluent that needed to be treated and discharged. The concentration and emergence of new harmful substances also increased (Muga and Mihelcic, 2008). Conventional wastewater treatment plants (WWTP's) began to be constructed to combat the growing demand for collecting and treating wastewater (Bouwer et al., 1978). Conventional wastewater treatment plants soon took the place of land application due to growth and migration towards cities and urban areas (Gohil, 2000).

The growth of the United States coupled with unregulated standards for wastewater discharge led to the establishment of the Clean Water Act (CWA) in 1972. The unregulated wastewater discharging led to an adverse impact on surrounding surface waters and ecosystems. The CWA allowed the United States government to begin enforcing regulations of discharging pollutants into navigable waters (EPA, 2002). The CWA allowed for basic structure for regulating pollutants, implementing pollution control programs, and establishing quality standards for all contaminants in surface waters. The structure for regulation fell under the jurisdiction of the Environmental Protection Agency (EPA). The EPA establishes and implements standards for pollutant concentration necessary for discharge.

After the CWA, a renewed interest of land application grew (Angelakis et al., 2018). Land application was viewed to have many benefits under the new regulations. The primary was the sustainability of further cleaning treated wastewater effluent. Land application discharge traditionally is treated through aerobic or facultative lagoons. Lagoons store water in ponds and are sized directly correlated to the need of sufficient hydraulic and solids retention time (Ewing et al., 2014). Aerobic lagoons have detention times of 3 – 10 days and facultative lagoons are from 5 – 30 days (Muga and Mihelcic, 2008). Typically, facultative lagoons are more efficient at treatment when given the necessary and longer detention time. Lagoons typically have no chemical input but some require mechanical stirring and aeration input. Settling and biological degradation through microorganisms and algae bring pollutant levels within standard parameters to be discharged.

Once the wastewater in the lagoons is treated to sufficient levels, the effluent is discharged onto the land applied area. The entire biosystem of the land applied area acts a “living filter” (Gohil, 2000). The soil, agricultural crops, and/or forests remove nitrates, phosphorous, organics, and other constituents from the effluent (Young & Epp, 1980). Bacteria and other microorganisms also consume the rich effluent and break down the biological elements into nonharmful and nonreactive products. Little improvements are needed to a functioning land application system besides regular maintenance such as tilling the land applied area and dredging the lagoon every five to ten years. Land application can also be used for industrial wastewater as well as municipal. Some wastewater types include landfill leachates, dairy effluents, meat processing wastewater, olive oil mill wastewater, agricultural drainage, and contaminated groundwater (Paranychianakis et al., 2006).

In summary, land application dates to the late 18th century but declined due to industrialization only to see an increase after the establishment of the CWA. Land application has been shown to be a viable alternate treatment of wastewater from conventional wastewater treatment plants for more rural and less densely populated communities.

2.2.b. Land Application Processes

Land application conventionally uses three basic processes to apply the wastewater effluent onto the land applied area. The three processes are: irrigation (slow release), percolation, and overland flow (Gohil, 2000). The type of process used for each system depends on the land applied area’s soil, topography, amount of effluent to be discharged, and geologic formation (Gohil, 2000). Irrigation is used most frequently out of the three processes (Zhang et al., 2019).

Irrigation land application systems apply wastewater onto crops or vegetation through sprinkling or other surface techniques (Gohil, 2000). Wastewater irrigation utilizes biological components to provide nutrients that stimulate vegetative growth. The treatment of the wastewater occurs as the wastewater infiltrates through the soil matrix at the physical, chemical, and biological treatment levels. A study conducted by Zhang et al. (2019), revealed the irrigation rate and field saturated soil hydraulic conductivity (K_{fs}) are the two most important factors to achieve an optimal design and should be considered when designing the system. K_{fs} is the measure by which water can move within the soil at saturation and infiltration rate is the rate at which water moves from surface to subsurface, into the soil. Higher infiltration rates and hydraulic conductivity were found to be desirable when designing the system.

Infiltration rate and soil hydraulic conductivity vary drastically from soil to soil and within space and time of the selected field itself. Several factors can influence infiltration rate. Temperature is a key component due to the impact it can have on viscosity and surface tension (Zhang et al., 2019). Higher temperature causes viscosity and surface tension to decrease resulting in higher infiltration rates. Greater microporosity also increases infiltration rates due to the spacing of the soil particles (Lin et al., 1998). Factors influencing K_{fs} include porosity and pore size distribution. The higher the porosity, the greater capacity for water movement to occur within the soil (Zhang et al., 2019).

The design of irrigation systems falls under two categories: normal and high rate irrigation. Normal rate irrigation ranges anywhere from 1 – 2.5 m/yr (Gohil, 2000). Typical sized sites range from 0.2 – 1.5 square kilometers per 3,785 m^3 d^{-1} (50 – 350 acres per MGD) depending on the irrigation rate. The main objective for normal rate irrigation is to produce vegetation or agricultural products (Paranychianakis et al., 2006). High rate irrigation applies up to 6.5 m/yr (21 ft/yr) (Gohil, 2000). Typical high-rate systems need very permeable soils and require really high infiltration rates. The primary concern for both types of systems is excessive loading rates which could lead to clogging of the soil resulting in ponding (R. B. Duan et al., 2010).

Irrigation systems have three conventional pathways on how wastewater effluent exits a spray field system (EPA, 2006). The first pathway is by application. The vegetation within the spray field uptakes the wastewater effluent and by evapotranspiration, the wastewater effluent exits the system. The second pathway is known as “recovery” pathways. Recovery pathways utilize underdrains or extraction wells in the subsurface to “recover” treated wastewater effluent in the subsurface to be used for irrigation of other vegetation. The last pathway is known as subsurface pathway. Subsurface pathway is where the treated wastewater effluent travels to a nearby surface water body via the subsurface. Typically by the time the treated wastewater effluent reached the waterbody, the wastewater effluent is brought to sufficient levels by the soil acting as a tertiary treatment. **Figure 2-4** depicts each of these pathways.

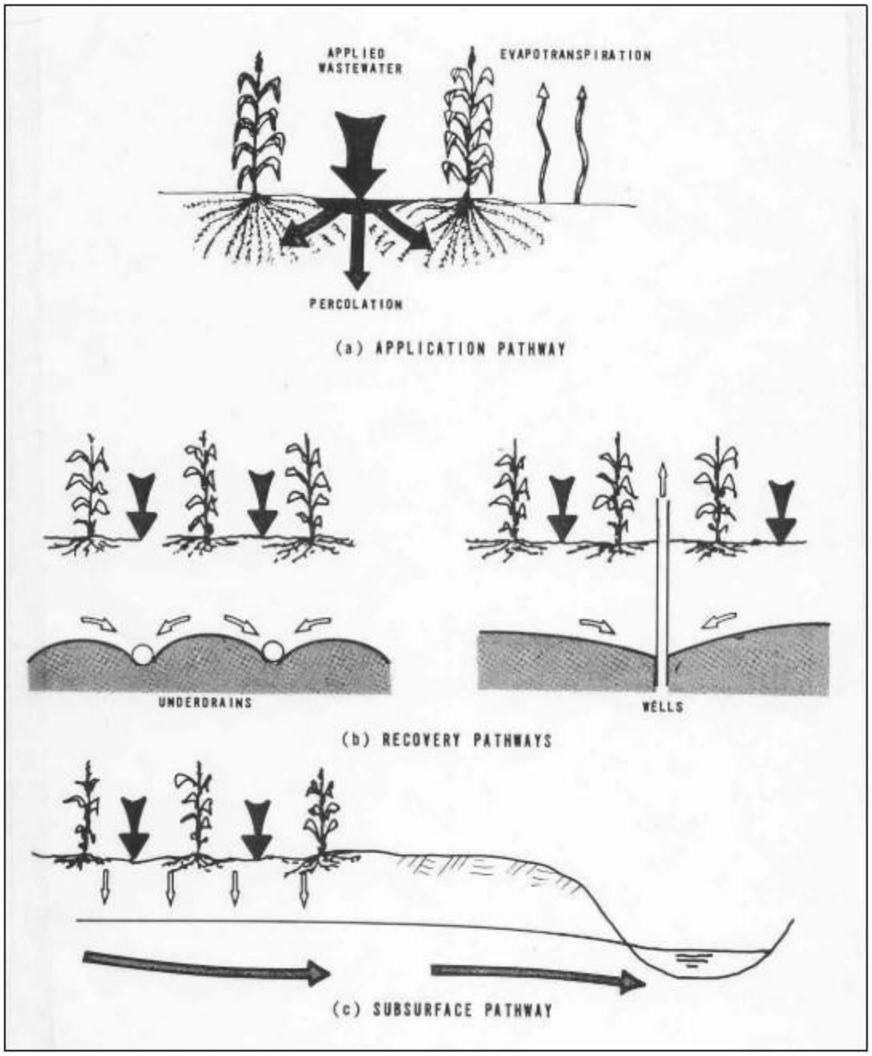


Figure 2-4: Irrigation (Slow Release) Hydraulic Pathways (EPA, 2006)

Percolation land application systems apply wastewater at higher rates by spreading into basins, commonly called recharge basins, and the treatment occurs as it passes through the soil by percolation (Gohil, 2000). Percolation systems are the least common of the three types of land application processes. Vegetation or crop production is not an objective for this process and differentiates it between irrigation systems. Therefore, this system does not require vegetation to operate optimally. Vegetation would be to only support the stabilization of the soil to improve physical conditions of the soil (Galegar et al., 1980). The main objective for percolation is to receive and treat wastewater for groundwater recharge and reuse for irrigation, recreation or industrial-municipal purposes (Bouwer et al., 1978).

Percolation systems are the cheapest of the three to create and maintain (Gohil, 2000). Percolation systems are however the most soil sensitive. Coarse textured soils are preferred due to the high percolation characteristics (Galegar et al., 1980). Loading is generally alternated with drying or resting periods to allow for percolation rates to recover and allow for oxygen to oxygenate the upper part of the soil profile (Bouwer et al., 1978). The annual application rate could reach up to 558 ft./yr. The land required can range between 2 – 55 acres depending on application rate (Galegar et al., 1980). This can also be expressed as 3 – 60 Acre/MGD (Muga & Mihelcic, 2008). Percolation requires less land than irrigation due to application occurring below surface level in basins.

Overland flow systems are a biological treatment process in which wastewater is applied to the upper part of sloped banks (Gohil, 2000). Overland flow is the least developed out of the three land application processes. Overland flow systems are strictly used for industrial wastewater and rarely used for municipal use (Galegar et al., 1980). Vegetative cover such as trees and grass are essential to prevent erosion from occurring and maintain the engineered terrace slopes. Most systems typically return around half of the treated effluent from land application to surface waters. The remaining wastewater is lost primarily to evapotranspiration and percolation into the soil.

The primary two criteria for opting to select overland flow systems are determining if the soil has high impermeability and if the incoming wastewater influent is high in suspended solids (Bouwer et al., 1978). A high-water table is also another factor in utilizing overland flow. These factors are important due to decreasing infiltration rates of the soil. Typically, overland flow systems can have between 2 – 8% slopes which can be engineered or natural (Muga & Mihelcic, 2008). Loading for overland systems can range between 1.5 - 6 m/yr (5 - 20 ft/yr) with 0.5 – 0.2 square kilometers per 3,785 m^3 d^{-1} (10 – 50 acres per MGD) required depending on loading. The level of efficiency increases by intermittent application of wastewater multiple times over a week as opposed to continuous operation. These systems are very effective at removing remaining phosphorous and nitrogen (Payer & Weil, 1987).

2.2.c. Factors in Area Selection in Land Application

Several factors are to be considered when determining if land application is applicable to a target area. Each factor stems from possible adverse effects to the surrounding environment depending on the composition of the discharging effluent. Due to wide range of possible types of areas and designs it is not feasible to have well-defined design criteria (Gohil, 2000). For land application sites to be permitted, NPDES requirements for effluent treatment must be cleared to begin operation (EPA, 2006). **Figure 2-5** shows the process for designing and implementation of a land application system. The factors that should receive considerable consideration include characteristics of wastewater, loading rates, topography, climate, soils, geology, surface and groundwater hydrology (EPA, 2006).

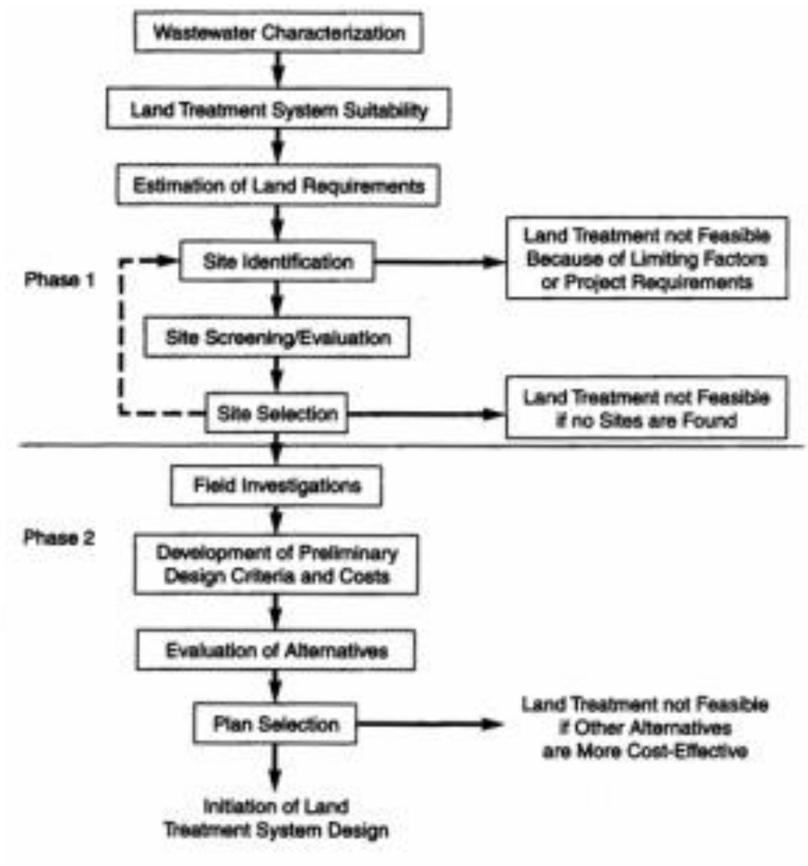


Figure 2-5: Two-Phase Planning Process Diagram (ADEM, 2007)

The type of wastewater and the constituents of the influent will determine the applicability of land application, whereas the amount of wastewater will determine the amount of land needed for land application. Typical municipal wastewater flow range from 65 – 100 gallons per capita per day and industrial wastewater is too variable to generalize (EPA, 2006). BOD_5 and suspended solids rarely limit system capacity but should be monitored for concentrations exceeding 500 mg/L (EPA, 2006). In **Table 2-1** is a table of constituents' average concentrations within domestic wastewater. Nitrogen removal is a primary limiting parameter for the system capability but can be managed with correct crop growth (Duan & Fedler, 2016).

Excessive salts within the wastewater can also be limiting. Sodium and salts cause clay soils to swell and hinder percolation for land applied areas. A study observed a Sodium Absorption Ratio (SAR) can be calculated to determine if salt ratio was found to be detrimental to the system found in **Equation 2.1**. A SAR value of 10 is the beginning value of when sodium could start to hinder the drainage in the soil (Guettaf et al., 2017). **Figure 2-6** shows the different ranges where SAR effects the soil (Guettaf et al., 2017). If taking the high value within the ranges found in **Table 2-1**, the value of the SAR comes out to 24 which would be an excessive value and sodium treatment would need to be incorporated into the system design.

$$SAR = \frac{Na}{\sqrt{\frac{1}{2} * (Ca + Mg)}} \quad \textbf{(2.1)}$$

Where: SAR = Sodium adsorption ration

Na = Sodium concentration (meq/L)

Ca = Calcium concentration (meq/L)

Mg = Magnesium concentration (meq/L)

Table 6 Classification of irrigation water based on SAR

SI No	Types of water and SAR value	Quality	Suitability for irrigation
1	Low sodium water (S1) SAR value: 0–10	Excellent	Suitable for all types of crops and all types of soils, except for those crops, which are sensitive to sodium
2	Medium sodium water (S2) SAR value: 10–18	Good	Suitable for coarse textured or organic soil with good permeability. Relatively unsuitable in fine textured soils
3	High sodium water (S3) SAR value: 18–26	Fair	Harmful for almost all types of soil; requires good drainage, high leaching gypsum addition
4	Very high sodium water (S4) SAR value: above 26	Poor	Unsuitable for irrigation

Figure 2-6: SAR Value Ranges (Guettaf et al., 2017)

Constituent	Concentration, g/m^3 (mg/L)
BOD_5	210
Suspended Solids	210
Nitrogen, total	35
Organic nitrogen	13
Ammonia, total	22
Phosphorous, total	7
Potassium	15
Sodium	50 – 200
Calcium	20 – 120
Magnesium	5 – 15

Table 2-1: Typical Composition of Raw Municipal Wastewater (EPA, 2006)

Topography of the site will determine the type of land application system to be used. (EPA, 2006) The grading of the site should be kept at a minimum to avoid drastic erosion and large amounts of runoff (Gohil, 2000). Crop harvesting is also made difficult due to steep grades. The steep slopes could also lead to unstable soil over time and cause landslides if not designed correctly (EPA, 2006). Irrigation systems of cultivated crops can operate with up to a 5% slope (Gohil, 2000). **Table 2-2** displays which type of land application system is most suitable depending on the site's slope grading factor. The elevation topography of the site can affect the potential of flooding and severity of flooding for sites. Overland flow is the only type of land application that can be utilized within floodplains given that the floodplains are protected from direct flooding events (EPA, 2006). Elevations between different land application sites and pre-treatment sites should be assessed for conveyance of the wastewater. Economically, the difference between a gravity conveyance and pumping conveyance could be significant if carried over several miles.

	Slow Rate Systems			
Grade Factor, %	Agricultural	Forest	Overland Flow	Soil Aquifer Treatment
0 – 12	High	High	High	High
12 – 20	Low	High	Moderate	Low
20+	Very low	Moderate	Eliminate	Eliminate

Table 2-2: Land Application Suitability Depending on Site Sloping Factor (ADEM, 2007)

The local climate primarily poses a limitation on the timing of when land application can be applied (Gohil, 2000). The timing of application can be limited in: the number of days irrigation can take place throughout the year, ensuring the water balance is net even or negative over the calendar year, storage capacity requirements due to precipitation and crop selection (EPA, 2006). The climate also determines the growing season for the cultivated crops. Determining the growing season for the cultivated crops allows operation to discharge at maximum amounts to lower storage volumes within lagoons. During winter and wet seasons, lagoon storages are stressed due to few days of operation (Wax & Pote, 1996). Frozen soil should never receive any effluent irrigation due to very low percolation rates. Arctic climates are the only climate land application is not applicable too (Galegar et al., 1980).

Soil and geology also can have significant impact in determining the ideal site for land application. The soil is a critical way to determine if the expected loading and movement of wastewater effluent is feasible and will meet regulation. Fine textured soils, such as clay, do not drain or retain water sufficiently. Percolation rate is slower which makes for crop management to become difficult to maintain and implement (EPA, 2006). Saturation of clay soils cause the minerals to swell and allow little percolation. Fine textured, clay soils are best utilized for overland flow type systems. Loamy soils and medium coarse soils are optimal for irrigation and percolation systems due to the ability of freely draining the effluent. Crops are easier to grow on this type of soil as well (EPA, 2006).

The common soil names and texture classes are listed in **Table 2-3**. The structure of a soil relates to the degree of aggregation done to the soil particle. A more stable soil refers to a more permeable soil (Sanz et al., 2014). Beneath the soil, the location and nature of the bedrock must be determined. Discontinuities and fractures along the bedrock are the main important factors pertaining to the geology subsurface. These discontinuities and permeable layers of rock can result in perched water tables (EPA, 2006). If the bedrock is not located deeper than 1 meter from the surface, insufficient crop growth and drainage will occur (Gohil, 2000).

General Terms		
Common Name	Texture	Basic Soil Textural Class Names
Sandy soils	Coarse	Sand, loamy sand
	Moderately coarse	Sandy loam, fine sandy loam
Loamy soils	Medium	Very fine sandy loam, loam, silt loam, silt
	Moderately fine	Clay loam, sandy clay loam, silty clay loam
Clayey soils	Fine	Sandy clay, silty clay, clay

Table 2-3: Soil Textural Classes and General Terminology Used in Soil Descriptions (EPA, 2006)

Groundwater depth of about 1.5 meters is sufficient for irrigation and percolation systems (Gohil, 2000). The primary concern for groundwater depth and locating the water table is untreated wastewater mixing with the groundwater and causing contamination. Reducing risk of elevated water tables keep the groundwater out of the root zone where the “living filter” treats the constituents of the effluent (Duan & Fedler, 2016). Stratified levels of groundwater should also be evaluated for vertical leakage due to increased potential of occurrence. Routing of wastewater to nearby surface water is important for two main reasons as well. The first is water rights. Homeowners located along well defined channels or basins or superficial waters not in channels or basins have the right to access and use the water source (Dewsnup et al., 1973). Avoiding violation of waterways and routing to public waterways will reduce potential violation, resulting in fines, and frustration from the surrounding community. The second reason to determine the routing is to minimize erosion from stormwater. Severe storms can cause damage to the physical components of the land application site due to excessive amount of stormwater runoff (EPA, 2006). Designing and implementing terraces and/or ditches helps mitigate adverse scenarios.

2.2.d. Land Application Sizing

The sizing of the required land needed for land application treatment will primarily depend on the amount of wastewater application to be applied. Wastewater applied to the land area for irrigation type of land applications should support vegetation growth throughout the land area. The wastewater effluent discharge, hydraulic loading rate, and time of operation are the preliminary variables to determine an approximate amount of land area to be used. This can be seen in **Equation 2.**2. The hydraulic loading of the land area is shown in **Equation 2.3**. Hydraulic loading rates depend on the precipitation, evapotranspiration, and percolation rates (McCardell et al., 2005). All three of these inputs are variable throughout the year depending on the season, climate, and saturation of the soils. A higher hydraulic loading rate results in less land area needed to sustain adequate drainage at the spray field. Typically the month with the lowest evapotranspiration is used to include a safety factor in the calculation. An example calculation for a proposed spray field site that discharges 378 m^3/d (100,000 gpd) with a hydraulic loading rate of 5 cm/wk at 50 weeks of the year would require an approximate land area of 0.22 square kilometers (54.75 acres).

$$A = \frac{3.65 * Q}{L_w x\ t} \qquad \textbf{(2.2)}$$

Where: A = Field area (acres)

Q = Flow rate (m^3/d)

L_w = Hydraulic loading (cm/wk)

t = Period of application (wk/yr)

$$L_w = ET - P_r + P_w \qquad \textbf{(2.3)}$$

Where: L_w = Hydraulic loading rate (cm/month)

ET = Evapotranspiration (cm/month)

P_r = Precipitation (cm/month)

P_w = Percolation (cm/month)

One factor to keep in scope is the depth to the water table. The water table should not rise above 0.5-meter depth from surface elevation. Crossing this threshold leads to poor agricultural operations and ponding within the site (EPA, 2006). Mounding of groundwater can also occur within the subsurface. Mounding occurs when the effluent encounters the water table or a less permeable layer (EPA, 2006). A groundwater mound can be found in **Figure 2-7**. The heigh of the water mound can increase as more wastewater effluent is discharged onto the soil. Further growth could result in height of the mound reaching the soil surface and causing ponding as well as drastically reducing infiltration rates. Underdrains can be placed within the site to prevent water mounding from occurring (EPA, 2006). Generally, underdrains are spaced every 15 m (50 ft) apart and depths of the drains can reach up to 5m (15 ft). **Equation 2.4**, known as the Hooghoudt method (Luthin, 1971), can be calculated to determine the precise location of the underdrains. **Figure 2-7** shows a schematic of each variable. The assumptions used in this method are:

1. The soil is homogenous with a lateral permeability.
2. The drains are evenly spaced a distance S apart.
3. The hydraulic gradient at any point is equal to the slope of the water table above that point.

4. Darcy's Law is valid.
5. An impermeable layer underlies the drain at a depth d.
6. The rate of application is L_w + P (hydraulic loading and irrigation discharge)

$$S = \left[\frac{4KH}{L_w + P}(2d + H)\right]^{0.5} \quad \textbf{(2.4)}$$

Where: S = drain space (m)

K = Hydraulic conductivity of the soil (m/d)

H = Height of ground water mound above the drains (m)

L_w = Annual wastewater loading rate (m/d)

P = Average annual precipitation rate (m/d)

d = distance from drains to underlying impermeable layer (m)

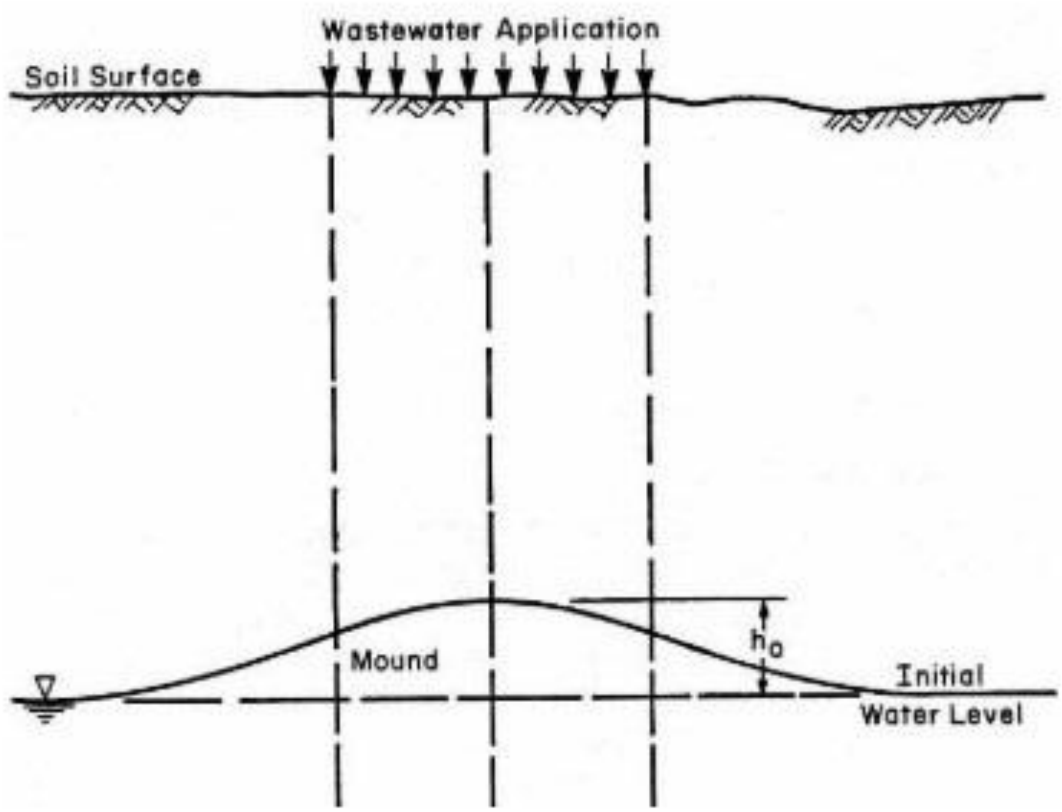


Figure 2-7: Water Mounding (EPA, 2006)

The last consideration when considering land application land requirement is the amount of buffer zone needed around land treatment sites (EPA, 2006). Buffer zones are needed to control public access onto the sites, reduce aerosol contamination through wind, and improve project aesthetics in some cases. There are no set criteria for determining what is a suitable buffer zone for each land application site. Factors to be considered are population density near the site and if the land site is forested or not. Populated areas or sites that have residences close to the site may need a buffer zone of up to 200 feet to prevent access and minimize contamination in the case of storm events or days with heavy winds. Forested areas require less buffer zones compared to vegetation areas due to reduced winds which result in less movement of aerosols. Forested areas also provide as a natural visual barrier to the public resulting in less buffer zone being required.

2.2.e. Design for Irrigation Land Application

Designing irrigation land application fields can be best broken down into two sections: delivery of the wastewater effluent and the type of vegetation desired and necessary to achieve satisfactory drainage. Determining how wastewater effluent is to be distributed via sprinklers or another means is important in designing how the land application field is constructed and operated. For all sprinkler irrigation systems, the control parameter has to be the application rate (cm/hr) must be less than the infiltration rate of the top soil to avoid surface runoff or ponding (EPA, 2006). The application rate will vary depending on the soil and which cover vegetation will be present.

There are three main types of sprinkler irrigation that can be used on land application: continuous move systems, move-stop sprinkler systems and solid set systems (Bond, 1998).

Continuous move systems and move-stop sprinkler systems are not as common due to the ability to automate sprinkler systems and the ability to have sprinkler systems throughout the land application site (Zhang et al., 2019). Continuous move systems essentially do not stop moving while being self-propelled. The benefit of a continuous move sprinkler system is the ability to irrigate the land area and have very little chance for ponding. These systems cannot be used in high sloping or forested areas due to the nature of the irrigation. The three different types of continuous move systems are traveling gun systems, central pivot systems, and linear move systems. The difference between these systems is the direction in which the machines operate, whether linearly or radially. The different types of move-stop systems are portable hand move systems, end tow systems, wheel line, and stationary gun systems. The main drawback and cause for the decline is each of these types of systems require operation and more maintenance (Muga & Mihelcic, 2008).

Solid set systems are typically used and are the prevalent type throughout the Black Belt (ADEM, 2022a). Solid set systems remain in one position during the application period and the systems consists of a grid of main pipes coming from the lagoon and lateral pipes extending off. The height of the sprinkler heads is determined by crop heights and desired spray angles (EPA, 2006). The application rate for the solid set systems is expressed in **Equation 2.5**.

$$R = \frac{q_S C}{S_S * S_L} \quad \textbf{(2.5)}$$

Where: R = application rate (in./hr.)

q_s = sprinkler discharge rate (gpm)

C = constant = 96.3

S_s = sprinkler spacing along lateral (ft.)

S_L = lateral spacing along main (ft.)

Sprinkler selection and spacing involves an iterative process (EPA, 2006). First, determining an approximate lateral spacing and then determining the sprinkler discharge capacity. Once determining each of these initial inputs, **Equation 2.4.** is calculated to determine the application rate. The application rate is checked with manufacturer's sprinkler performance data to determine the wetted diameter based on the initial discharge rate. **Table 2-4** shows the recommended spacing criteria based on the wind conditions and the percentage of wetted perimeter and spacing. The other factor when implanting solid set systems is the bigger the irrigation network, the greater the pipe friction loss will be (Gohil, 2000). The simplified approach is to multiply the entire lateral flow of an irrigation grid by the friction loss based on the number of outlets. The number of outlets on a lateral head correlates with the pipe friction loss in **Table 2-5**.

Wind Speed		
Km/h	(mi/h)	Spacing, % of wetted diameter
0-11	(0-7)	40 (between sprinklers)
		65 (between laterals)
11-16	(7-10)	40 (between sprinklers)
		60 (between laterals)
>16	(>10)	30 (between sprinklers)
		50 (between laterals)

Table 2-4: Recommended Spacing of Sprinklers (EPA, 2006)

Numbers of outlets	Value of F
1	1.000
2	0.634
3	0.528
4	0.480
5	0.451
6	0.433
7	0.419
8	0.410
9	0.402
10	0.369
15	0.379
20	0.370
25	0.365
30	0.362
40	0.357
50	0.355
100	0.350

Table 2-5: Pipe Friction Loss Values (EPA, 2006)

A study was conducted within the Black Belt to study the feasibility of a soil-moisture controlled subsurface drip irrigation (SDI) due to the low infiltration rates of Black Belt soil (He et al., 2013). Many such systems are in operation today used throughout the United States (Resources, 2007). The idea of this type of application is to control the moisture within the soil and apply the effluent via subsurface irrigations to avoid the soil from swelling once saturated. This type of application also can avoid the Underground Injection Control (UIC) permit if the discharge is below 50,000 gpd. The study was conducted on wastewater coming from a single-family home of three people. The study was found to have successfully disposed of wastewater disposal by only applying wastewater during the "operational" time frame. The "operational" time frame is when the soil moisture dropped below 0.45 m^3 m^{-3}. Insufficient data was collected to draw a conclusion if this would be sustainable for large scale due to long periods of no application of effluent.

Determining which types of vegetation is desired for the land application site is the other main criteria when designing a site (EPA, 2006). Vegetation provides stability to the soil and provides additional evapotranspiration to facilitate drainage. An additional benefit is further removal of nitrogen and phosphorous of the treated wastewater effluent. The controlling inputs for which vegetation is to be produced are climate and operation schedule. Climates with a harsh winter and summer could require different vegetation seasonally. Some municipalities have a winter vegetation and also a summer vegetation to have operation happening for as long as possible (McCardell et al., 2005). Based on the inputs of **Equation 2.4**, the remaining nitrogen leaving the detention basin will be nitrogen loading needed for treatment on the site. **Tables 2-6** and **2-7** provide a list of the different values for Nitrogen uptake permitted by the state of Alabama.

Vegetative Cover (yield goals)	Nitrogen Up-take (kg/ha/yr)
Forage and Field Crops	
Coastal Bermudagrass with rye overseed	570 + 205 = 775
Coastal Bermudagrass	480 – 600
Reed canary grass	226 – 359
Ryegrass	235
Fescue	275

Table 2-6: Vegetation Cover – Grass (ADEM, 2007)

Vegetative Cover (yield goals)	Nitrogen Up-take (kg/ha/yr)
Alfalfa	155 – 220
Sweet clover	158
Red clover	77 – 126
Lespedeza hay	130
Johnson Grass, 27 metric ton/ha	890
Peanuts, 7.5 metric ton/ha	140
Corn, 7.6 – 12.9 m^3/ha	155
Soybeans, 5.2 m^3/ha	94 – 113
Irish potatoes	108
Cotton	66 – 100
Milo maize	81
Wheat	50 – 76
Sweet potatoes	75
Sugar beets	73
Barley	63
Oats	53
Tobacco, flue cured, 3,300 kg/ha	85
Forest Trees	
Mixed Coniferous & Deciduous	40 – 80
Pines	30 – 70
Deciduous	50 – 100

Table 2-7: Vegetation Cover – Forage (ADEM, 2007)

The harvesting of the crops also typically needs a drying phase before harvest can be conducted. Wastewater effluent dispersion should be ceased a week leading up to harvest so the vegetation can mature and have moisture content that is compatible with harvest machinery (EPA, 2006). The harvest and drying phase also allow for the soil not to be overloaded and have chemical properties change over the course of years. Typically, a dredging of the land site is conducted to bring up fresh subsoil to then become topsoil. Grazing of livestock can also be used for harvesting or keeping vegetation growth under control (Mazeikiene, 2019). Livestock are not to be grazing when the soil is still wet due to compaction of soil and decreasing infiltration rates. The use of grazing could also turn into a financial gain for the municipality.

2.2.f. Benefits of Irrigation Land Application

Slow-release systems, besides treated wastewater effluent, provide benefits for municipality owners. The first benefit is the vegetation produced. Depending on the quality of wastewater effluent, vegetation can be sold to consumers for an economic profit (Thoma et al., 1993). Such vegetation that can be sold include forage vegetation, and trees that are regularly harvested (Paranychianakis et al., 2006). Forage vegetation can be sold to farmers to be used for their livestock while regularly harvested trees can be sold to timber companies for wood. Forage vegetation crops include soybeans, maize, and eucalyptus (Paranychianakis et al., 2006). The profit from selling vegetation needed to be harvested has been reported to be as high as $1,000,000 in Michigan (EPA, 2006). However, initial investment from the municipality is necessary for the correct equipment to harvest and storage. Residual vegetation also makes for fertilizer in agricultural industries. The absorption of the nutrient rich wastewater effluent allows for the harvested vegetation to be applied as a rich source for phosphorous or nitrogen concentrated fertilizer depending on the type of receiving wastewater (Rhoades et al., 2003).

An additional benefit is the product of water reuse. Installation of wells or other methods of capturing the discharged effluent must be installed. The captured treated effluent can again be sold to farmers and agricultural industries to be used to irrigate croplands (Fedler, 2021). There are two advantages for a municipality to use water reuse from land application. The first is to further protect surface water sources from potential pollutant contamination. This is done by decreasing the volume of effluent discharged into surface water bodies (Fedler, 2021). The second benefit is having an increase in freshwater conservation. The water reuse allows for agriculture irrigation to be done by the treated potable water (Fedler, 2021). The primary concern for using water reuse on land application systems is groundwater contamination which is often caused by nitrate due to excessive leaching (R. Duan et al., 2010). The salt accumulation is also of concern due to the accumulation potentially altering the chemical properties of the soil and not being able to have sustainable vegetation growth or treatment of the effluent.

2.3 Functional Equivalent of Direct Discharge

2.3.a. History of Clean Water Act

Powers (2023) outlines the history of how treatment of wastewater progressed throughout the United States. The first major U.S. law to address water pollution was the Federal Water Pollution Act of 1948. After World War II, there was an increase of public awareness and concern for limiting pollutants entering water bodies around the United States. The goal of the Federal Water Pollution Act was to protect streams, rivers, lakes, and bays throughout the United States. It allowed for the Environmental Protection Agency (EPA) to make standards for industries on wastewater effluent discharge. The initial Federal Water Pollution Act only gave authority to the U.S. government over interstate waterways.

In 1972, sweeping amendments were made to the Federal Water Pollution Act and the law then became commonly known as the Clean Water Act (CWA). The amendments produced descriptive definitions on what is prohibited for pollutant discharges throughout the United

States. The CWA forbids “any addition of any pollutant from any point source to navigable waters without an appropriate permit from the Environmental Protection Agency” (EPA, 2022b). The CWA also defined a pollutant “point source” among the amendments as “any discernible, confined and discrete conveyance… from which pollutants are or may be discharged,” including any “container… pipe, ditch, channel, tunnel, conduit… or well.” Pollutant discharge is also defined as, “any addition of any pollutant to navigable waters (including streams, rivers, the ocean, or coastal waters) from any point source,” (EPA, 2022b). The amendments that produced these definitions allowed for establishment of basic structure for regulating all pollutant discharges, not just interstate water bodies, into navigable waters. Part of the basic structure for establishing regulations allowed for the EPA to implement wastewater standards for industries. The CWA also provided flexibility for the need of planning to address potential problems that could arise from nonpoint source pollution in the future.

2.3.b. County of Mauii vs. Hawaii Wildlife Fund 2020 and Sackett vs. EPA 2023

A court case between the County of Maui, Hawaii (appealer) v. Hawaii Wildlife Fund (respondent) in 2020 challenged the clarity of definitions found in the Clean Water Act ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020). The County of Maui operates a wastewater reclamation facility that collects sewage from the surrounding area and community. The facility partially treats the sewage and discharges the effluent through four wells located hundreds of feet below the surface. An estimate of 4 million gallons of partially treated wastewater is discharged through the wells per day. The effluent then travels a half mile through groundwater into the Pacific Ocean. A collection of environmental wildlife groups brought a citizens’ Clean Water lawsuit against the County of Maui alleging that the facility was “discharge[ing]” a “pollutant” to “navigable waters” without the NPDES required permit to do so. The District Court in Hawaii found the discharge was “functionally one into navigable water,” ("Hawaii Wildlife Fund V. County of Mauii," 2014). The appeal went to the Ninth Circuit court and the court also affirmed the previous ruling, stating that a permit is required “when pollutants are fairly traceable from the point source to a navigable water,” ("Hawaii Wildlife Fund v. County of Maui," 2018). The court ruled that a permit is required when there is a direct discharge from a point source into navigable waters or when there is a *functional equivalent of a direct* discharge.

The County of Maui appealed the ruling to the Supreme Court based on two criteria. The first was the interpretation of the word “from” in the phrase “*from any point source*” coupled with how “conveyance” is used in the definition of point source found in the Clean Water Act. Maui argues the meaning of “from any point source” is about *how* pollutants travel to navigable waters not about *where* the pollutants originated. This leads to the conclusion that if point source locations are not ultimately delivering the pollutant to navigable waters, it cannot be classified as a “direct discharge” requiring stricter discharge permits. In comparison, if a pollutant travels through groundwater, then the point source is not the last conveyance to the navigable waters, thus no permit is required for a direct discharge. The County of Maui appealed to the Supreme Court for clarity of the definition found in the Clean Water Act.

The second point that the County of Maui was appealing was based on the criteria of the existing permit. The County of Maui argued that the proposed permitting requirement does not apply if the pollutant travels through groundwater. The Ninth Circuit ruled that there were “fairly traceable” pollutants within navigable waters that justified labeling Maui’s facility as a “functional discharge”. The “fairly traceable” limitation could allow the EPA to have the permitting authority over the release of pollutants years after their initial release of pollutants into the environment which overreaches the scope of the intended power of the EPA. The County of Maui argued classifying Maui’s reclamation facility as direct discharge would endanger existing permits throughout the United States that utilize ground water in a similar method which would cause serious interference with the EPA’s ability to regulate point source discharges by determining which land application sites are “functional discharge” and which ones are not.

The Supreme Court ruled in favor of the District and Ninth Circuit Courts while denying the “fairly traceable” criteria ruled on by the Ninth Circuit Courts. The Supreme Court operated out of the intent and language used of the Clean Water Act to “restore and maintain the… integrity of the Nation’s waters,” to define the scope and context of the word “from” to define direct point source locations. The Supreme Court’s findings were that the Clean Water Act prohibits discharge from point sources “into navigable waters, or when the discharge reaches the same result through roughly similar means” without a permit ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020). The Supreme Court ruled that the application used for “from” by the Ninth Circuit Court was too broad. Virtually all water over time will reach navigable waters at some point. Utilizing the “fairly traceable” criteria ruled upon exceeds the EPA’s jurisdiction. The Supreme Court also ruled it is the State’s responsibility to rule on in the future.

The Supreme Court issued criteria to determine what is a functional equivalence of a direct discharge: (1) transit time, (2) distance traveled, (3) the nature of material through which the pollutant travels, (4) the extent to which the pollutant is chemically changed as it travels, (5) the amount of pollutant entering the navigable waters relative to the amount of pollutant that leaves the point source, (6) the manner by or area in which the pollutant enters the navigable waters, (7) the degree to which the pollution (at that point) has maintained its specific identity ("County of Maui, Hawaii v. Hawaii Wildlife Fund," 2020). The most important factors in determining functional discharge were determined as time and distance. The Supreme court ruled state regulatory agencies will be responsible for ensuring wastewater disposal for existing land application sites are not functional discharges.

A court case decided May 2023, clarified the definition of the "waters of the United States" definition established in the Clean Water Act in 1984. Sackett v. EPA 2023 ruled that the waters of the United States were ruled as having to have "continuous surface connection to bodies that are 'waters of the United States' in their own right, so that they are indistinguishable from those waters" ("Sackett v. Environmental Protection Agency," 2023). This changes a previous held definition of twenty years that waterways are protected if there is a "significant nexus" connecting the waterbodies or wetlands to major waters of the United States ("Rapanos v. United States," 2006). Under the new ruling, the "significant nexus" test no longer is valid but must have a continuous surface connection to be protected under the Clean Water Act.

2.3.c Regulations

The state of Alabama has three different permits for wastewater effluent discharge throughout the state under the Alabama Department of Environmental Management, direct discharge, underground injection, and land application (ADEM, 2018). The purpose for each of these permits is to protect nearby freshwater bodies that either feed into drinking water systems or the groundwater that is used by private well owners for fresh water.

Direct discharge has the highest level of treatment required of the three permits. Direct discharge is when the municipality directly discharges into a surface water body. High level of treatment is needed to ecosystems are not damaged resulting in an impaired river. Due to the stricter permit required for direct discharge, more advanced technology is needed which increases costs on the municipalities. In the Black Belt of Alabama, only 11% of systems that have direct discharge permits do not utilize high cost technology such as mechanical treatment plants and aerated lagoons with ultraviolet (ADEM, 2022a). The higher the amount of wastewater needed to be treated, the more likely a direct discharge permit is necessary due to the amount of land needed for land application.

Underground Injection Control (UIC) permits are the least common of the three mentioned permits. An underground discharge permit is needed anytime wastewater is discharged below the surface. Drip dispersal systems, injection wells, and other various technologies fall under this category. However, the permit for UIC is only needed to be applied if discharge exceeds 50,000 gallons per day (ADEM, 2023). If discharge is below 50,000 gallons per day, the permit goes through the Alabama Department of Public Health. Class I wells are the only types of wells that are prohibited throughout the state, and they are injection wells that inject effluent below underground sources of drinking water (ADEM, 2023). UIC permits typically have small amounts of discharge (<100,000 gallons per day) and are used for small residential communities or other private small wastewater collections.

Land application permits are more likely to occur in rural areas of the state. Low amount of treatment is needed to the wastewater effluent compared to direct discharge (ADEM, 2018). The primary concern is biosolids and suspended solids settling out within the holding basins before being applied to the land application site (EPA, 2006). The two primary concerns for the land application permits are overland routing of wastewater effluent into nearby creeks and insufficient treatment through the soil and vegetation before the effluent reaches the groundwater (ADEM, 2018). The land application permit allows ADEM to monitor effluent quality to ensure sufficient treatment is taking place.

Chapter Three.

A Case Study of Uniontown, Alabama's Spray Field: A Failing Land Application within the Black Belt of Alabama

3.1 Introduction

Uniontown, AL is located within Perry County, one of the seventeen counties located within the Black Belt of Alabama shown in **Figure 3-1**. Uniontown is located 70 miles west of Montgomery, Alabama and 90 miles southwest from Birmingham, AL. Uniontown has a population of 2,107 (Census, 2020b) and the primary source for residents is groundwater via private wells. The city utilizes an aerated lagoon to treat wastewater and discharges treated effluent via sprinkler irrigation onto a spray field located 3.2 miles south of the lagoon site. Uniontown has had consistent permit violations dating back to 2009 which led to renovations of the lagoon and collection system in 2013 (ADEM, 2021).

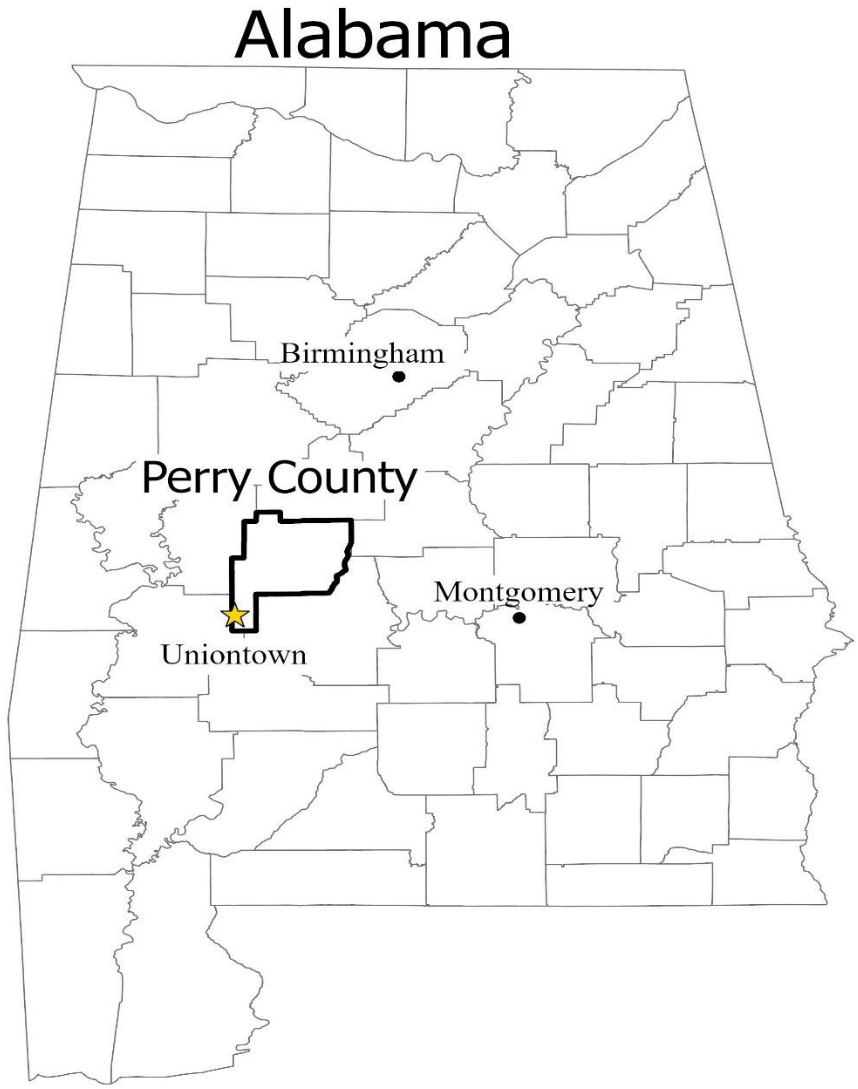


Figure 3-1: State of Alabama and Perry County

Unfortunately, the wastewater treatment and discharge problems were not solved in the 2013 renovations. In 2015, a court order was filed by the Alabama Department of Environmental

Management to further renovate the system to increase treatment and disposal capacity (ADEM, 2022a). The spray field is permitted to receive a discharge of 1,893 m^3 d^{-1} (500,000 gallons d^{-1}), but discharges have consistently exceeded the permit amount over the last ten years with the highest monthly average being 6,284 m^3 d^{-1} (1,660,000 gallons d^{-1}) (ADEM, 2022a). Extensive and extreme ponding has occurred throughout the spray field site (**Figure 3-2**) with substantial amounts of the treated wastewater effluent overflowing into Freetown Creek, located to the west of the sprinklers, via overland flow.

Figure 3-2: Existing Spray Field Conditions

The purpose of this study is to 1) perform groundwater modeling of the Uniontown spray field to determine reasons for the system's failure; 2) determine to what extent the Uniontown spray field is a functional discharge to Freetown Creek; and 3) determine whether engineering modifications (e.g., increasing sprinkler application area, installation of sand trenches, etc.)

would allow the system to operate successfully. The results of this investigation are directly applicable to the Uniontown spray field and generally applicable to spray fields (or other subsurface wastewater discharges) situated in poorly drained soils near surface water bodies.

3.2 Methods

3.2.a Model Structure

The software used for modeling Uniontown's spray field groundwater was Visual MODFlow Flex v8.0. Inputs for MODFlow are categorized into model structure, boundary conditions, and grid structure. Previous engineering drawings of the spray field were utilized in constructing the model.

The original design of the site can be found in **Figure 3-3**. A 110-meter distance is located between the first sprinkler row and Kelly Fields Road. Data was collected from 2018 to 2020 from Uniontown's Discharge Monitoring Reports (DMR's) which report the incoming wastewater flow to the lagoon and discharging wastewater flow to the spray field every month. DMR's were collected from the Alabama Department of Environmental Management E-File (ADEM, 2022a). **Table 3-1** shows the recharge applied on the sprinkler areas. The spray field has a permit discharge of 1,893 m^3 per day (500,000 gpd), which was consistently exceeded.

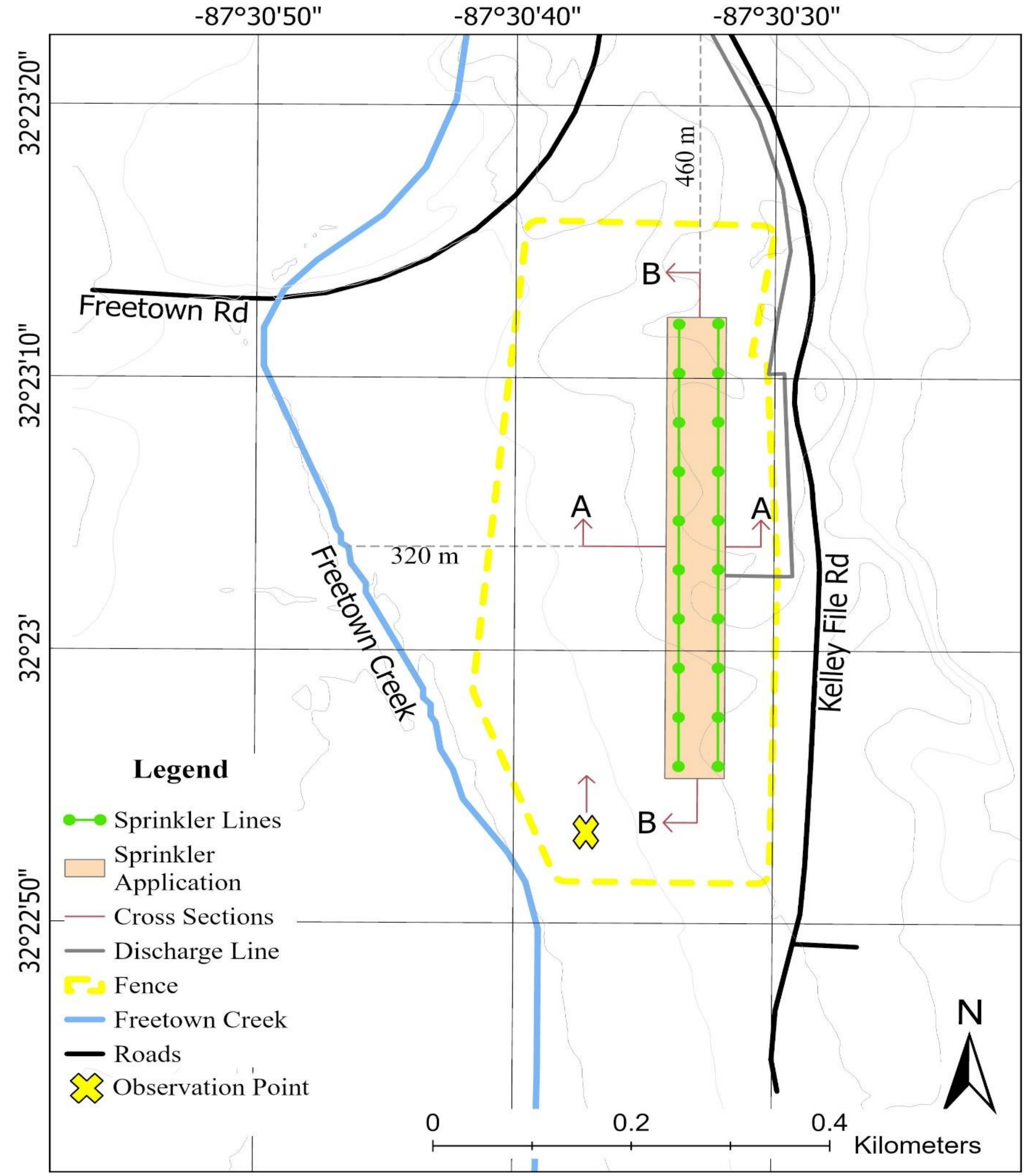


Figure 3-3: Map of Existing Spray Field Conditions with "X" Showing the Location of Figure 3-2

Year	Month	Discharge (m^3 d^{-1})	Discharge (m d^{-1})
2018	January	2377	0.064
	February	1783	0.048
	March	2055	0.055
	April	2127	0.057
	May	2691	0.072
	June	2703	0.073
	July	2097	0.056
	August	2476	0.067
	September	3123	0.084
	October	2018	0.054
	November	2907	0.078
	December	2423	0.065
2019	January	2063	0.055
	February	2006	0.054
	March	1931	0.052
	April	1968	0.053
	May	6284	0.169
	June	2385	0.064
	July	2196	0.059
	August	2461	0.066
	September	2196	0.059
	October	2196	0.059
	November	2953	0.079
	December	2082	0.056
2020	January	2044	0.055
	February	1893	0.051
	March	2347	0.063
	April	2196	0.059
	May	2120	0.057
	June	1779	0.048
	July	2120	0.057
	August	1855	0.050
	September	2006	0.054
	October	1968	0.053
	November	2309	0.062
	December	1666	0.045

Table 3-1: Sprinkler Irrigation Rates

A site visit was conducted to determine the extent of ponding occurring within the site. The spray field had several meters of ponding throughout the entirety of the site shown in **Figure 3-2**. The photo was taken from the observation point found in **Figure 3-3**. Various aquatic vegetation, such as cattails, were found around the spray field. Ponding may be due to improper design of the spray field and sprinkler configuration or exceeding the discharge permit of 1,893 m^3 d^{-1} (500,000 gallons d^{-1}).

Discharge to the spray field consistently exceeded the permitted amount from 2018 to 2020 with some average monthly discharges exceeding the permit by 50%. Thirty-one out of the thirty-six months exceeded the permitted amount with an average exceedance of 28%. The highest monthly average occurred in May of 2019 at 6,284 m^3 d^{-1} (1,660,000 gallons d^{-1}), over three times the permitted value. Sprinklers were in operation on the site visit. A trench was excavated by the city of Uniontown to create a buffer around Freetown Creek as a safety measure but only allowed for five meters of buffer between the ponding of the spray field and Freetown Creek. The area of the spray field is 0.2 km^2 (49 acres) and the area used for modeling the groundwater of sprinkler application was 1.41 km^2 (348 acres). The closest point from the sprinkler recharge area to Freetown Creek is 275 meters (903 feet).

The surface elevation for the spray field was obtained through the National Resources Conservation Service (NRCS, 2023). The highest point on the site is 76 meters above sea level. The spray field has two different subsurface layers (USDA, 2023). The top layer is classified as “soil”. The second layer is classified as “Selma Chalk”. The description of the two soil layers is found in **Table 3-2**. The soil layer was approximated to be at a depth of four meters throughout the spray field. The soil depth was approximated by soil boring logs conducted nearby in Perry County and the USDA soil survey map (USDA, 2023). The hydraulic conductivity of the first soil layer was calculated using a composite weighted average of the different soil types found within the spray field. **Table 3-3** show the different soil units and the respective hydraulic conductivities and percent area surveyed at the site (USDA, 2023). The average hydraulic conductivity was calculated to be 7.07 x 10^{-7} m s^{-1}. The EPA classifies "clay, poor drainage" soils as anything that has hydraulic conductivity below 3.13 x 10^{-7} m s^{-1} (0.06 ft d^{-1}) (EPA, 2006), just below the conductivity of the soil.

Layer	Ksat (m s^{-1})	Depth range (m)
Layer 1	7.07E-07	0 - 4
Layer 2	1.51E-10	4 - 76

Table 3-2: All Layer Hydraulic Conductivities

Map Unit	Name	Ksat (m s^{-1})	%	Weighted
DsD2	Demopolis-Sumter complex, 3-8% slopes, eroded	2.96E-06	0.034	1.01E-07
KpB	Kipling clay loan, 1-5% slopes	7.64E-07	0.439	3.35E-07
SeA	Sucarnoochee silty clay, 0-2% slopes, frequently flooded	2.78E-07	0.409	1.14E-07
SmB	Sumter silty clay loam, 1-3% slopes	8.69E-07	0.019	1.65E-08
SoD2	Sumter-Oktibbeha complex, 3-8% slopes, eroded	3.20E-06	0.039	1.25E-07
VaA	Vaiden clay, 0-1% slopes	2.67E-07	0.06	1.60E-08
Cumulative				7.07E-07

Table 3-3: Top Soil (Layer 1) Hydraulic Conductivity (USDA, 2023)

The Selma Chalk layer begins four meters below the surface and ends at sea level elevation due to the model's restrictions and ground water not moving at that depth due to the low hydraulic conductivity of the Selma Chalk. The intrinsic permeability of the chalk was previously measured to be 1.5 x 10^{-17} m^2 (Sadler, 1996). The intrinsic permeability is related to the hydraulic conductivity through the Kozsny-Carmon equation found in **Equation 3.1**. The hydraulic conductivity for the second layer was calculated to be 1.65x10^{-10} m s^{-1}, over three orders of magnitude less than the overlying soil.

$$K = k(\frac{\rho g}{\mu}) \tag{3.1}$$

Where: K = Hydraulic conductivity (m s^{-1})

k = Intrinsic permeability (1.5 x 10^{-17} m^2)

ρ = Density of water (997 kg m^{-3})

g = Gravity (9.81 m s^{-2})

μ = Dynamic viscosity of water (8.90 x 10^{-4} kg m^{-1} s^{-1} at 25^0C)

Two main boundary conditions and inputs were used for the model. The boundary conditions input into the model were Freetown Creek, the sprinklers, and evapotranspiration. Freetown Creek was assumed to maintain constant depth throughout the model run. The shape and location of Freetown Creek within the model was collected from the NRCS hydrography surveying data for Perry County (NRCS, 2023). The surface elevation of Freetown Creek was set to be 1.5 meters below the ground elevation. The bottom of Freetown Creek was set to 3 meters below ground elevation. The depth of the creek was set to be 1.5 meters. A cross section of the Freetown creek boundary condition can be found in **Figure 3-4**. This was determined by approximating the depth of the river channel by human observation. The width of the creek was set to ten feet which was also approximated by human observation. The creek bed thickness was calculated to be one meter by determining the difference between bottom of Freetown Creek and the beginning of the Selma Chalk soil layer. The riverbed conductivity was thus made to be 7.07 x 10^{-7} m s^{-1} due to Freetown Creek residing within the upper soil layer.

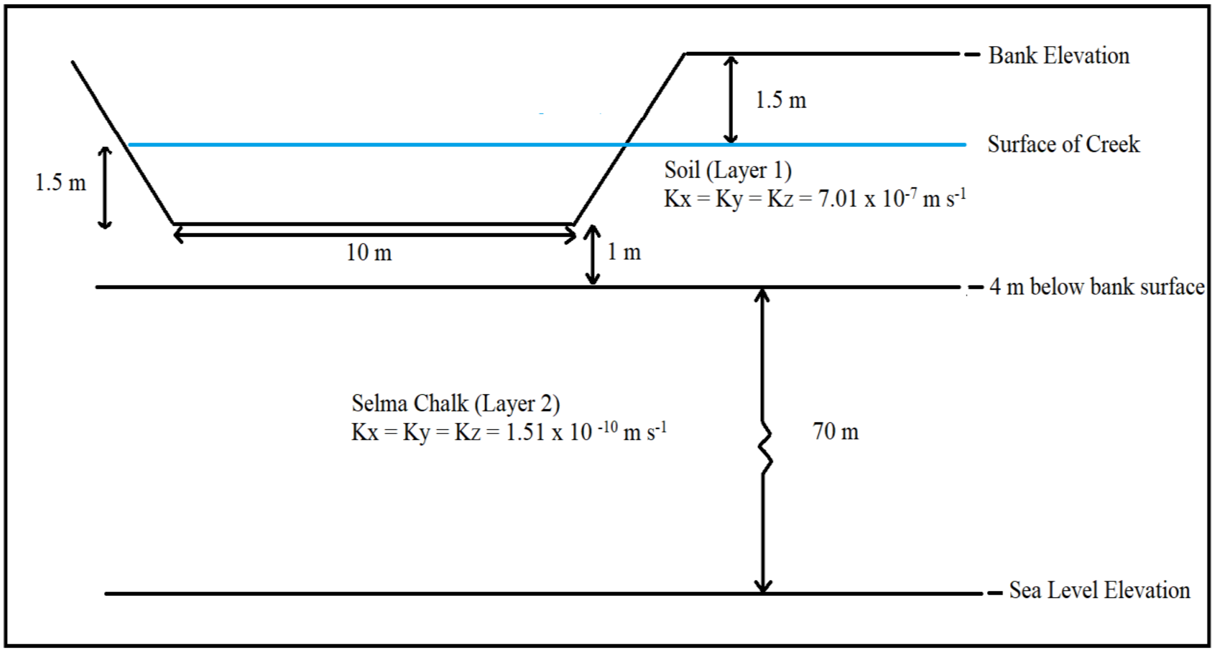


Figure 3-4: Cross Section of Freetown Creek

The second input for boundary conditions was the irrigation sprinklers, or recharge. Visual MODFlow Flex does not have a designated "sprinkler" boundary condition but it does fall under the recharge boundary condition. Two rows of ten sprinklers are aligned vertically along the eastern side of the spray field (**Figure 3-2**). The sprinklers within each row are spaced sixty meters apart and the rows of sprinklers are spaced forty meters apart. Discharge was assumed to be applied evenly throughout between the two sprinkler lines. To account for the sprinkler application that falls outside of the two sprinkler lines, the recharge area was given a 10-meter buffer. The recharge area was calculated to be 37,200 m^2 (9.24 acres) and the recharge area was used to model the effect of the discharge sprinklers.

Precipitation and evapotranspiration were also considered for the model but were not incorporated. The change in storage of the spray field depends on the net difference between precipitation and runoff, evapotranspiration, and infiltration. Precipitation and evaporation data was collected between 2019 – 2021. Precipitation data was taken from Montgomery, AL and evaporation data was taken from Huntsville, AL due to availability of recorded data and proximity to the spray field. Each can be found in **Tables 3-4** and **3-5**. The average precipitation was found to be 1.36 meters per year (53.4 inches) and the average evaporation was found to be 0.676 meters per year (26.6 inches). This would result in 0.681 meters (26.8 inches) of precipitation remaining. The application rate for the year at permitted discharge would be 18.6 meters (61 feet). Due to the application rate being an order of magnitude larger, precipitation and evaporation would not have a significant impact on the how the spray field would operate. If precipitation were included, the spray field would pond faster but only marginally. The difference between precipitation and evaporation found in **Tables 3-4** and **3-5** was applied over the entire model area. Ponding began occurring on the spray field on day 136 as opposed to day 158 without precipitation, a 14% increase. Due to the minimal effect of precipitation, the spray field is assumed to be in equilibrium with Freetown Creek before application begins including the precipitation and evaporation.

Month	Evaporation (m/month)	Daily Average (m/d)
January	0.012	0.0004
February	0.014	0.0005
March	0.042	0.0014
April	0.061	0.0020
May	0.084	0.0027
June	0.102	0.0034
July	0.121	0.0039
August	0.074	0.0024
September	0.059	0.0020
October	0.051	0.0016
November	0.034	0.0011
December	0.018	0.0006

Table 3-4: Average Evaporation Rates from Weather from 2019 - 2021

Month	Precipitation (in.)	Precipitation (m)	Average Precipitation (m/d)
January	2.52	0.064	0.0021
February	2.94	0.075	0.0027
March	6.62	0.168	0.0054
April	5.67	0.144	0.0048
May	2.45	0.062	0.0020
June	7.28	0.185	0.0062
July	3.73	0.095	0.0031
August	5.26	0.134	0.0043
September	4.87	0.124	0.0041
October	6.00	0.152	0.0049
November	1.42	0.036	0.0012
December	4.63	0.118	0.0038

Table 3-5: Average Precipitation Data for 2019-2021 (NOAA, 2023)

A finite difference grid was selected with a cell size of 10 meters by 10 meters. The finite difference grid converts the irregular shapes of the inputs of the conceptual model into a finite shape of cells to model the groundwater flow of the system. A deformed grid was selected so the model layers of the grid would conform to the elevations of the different soil layers. Once the selected grid was chosen, the conceptual model was then converted into a numerical model to begin inputting initial conditions to the system.

The numerical model digitizes the conceptual model into the selected grid. The numerical model allows for changes to be made to initial conditions such as water table, hydraulic conductivity, and porosity. The water table, or hydraulic head, throughout the spray field was assumed to be at equilibrium with Freetown Creek at the beginning of the model simulation. The surface of Freetown Creek sits at 66 meters above sea level elevation. The weighted average of the soil bulk density (ρ_b), found in **Table 3-6** was found to be 1.34 g/cm^3, and the particle density (ρ_p) was estimated to be 2.8 g/cm^3 based on the soil content of silt, clay, and sand. **Equation 3.2** shows the relation between bulk density and particle density to determine porosity. The porosity was calculated to be 0.48 throughout the model area and spray field.

$$\varepsilon = \frac{\rho_b}{\rho_p} \tag{3.2}$$

Where: ε = Porosity

ρ_b = Bulk density (g cm^{-3})

ρ_p = Particle density (g cm^{-3})

Map Unit	Name	Bulk Density (g/cm^3)	% Area	Weighted
DsD2	Semopolis-Sumter complex, 3 to 8 percent slopes, eroded	1.32	0.034	0.0449
KpB	Kipling clay loam, 1 to 5 percent slopes	1.41	0.439	0.62
SeA	Sucarnoochee silty clay loam, 1 to 3 percent slopes	1.36	0.409	0.56
SmB	Sumter silty clay loam, 1 to 3 percent slopes	1.34	0.019	0.025
SoD2	Sumter-Oktibbeha complex, 3 to 8 percent slopes, eroded	1.35	0.039	0.05
VaA	Vaiden clay, 0 to 1 percent slopes	1.18	0.06	0.071
Cumulative				**1.37**

Table 3-6: Cumulative Soil Bulk Density (USDA, 2023)

Two different model outputs were selected to quantify the effect of the sprinkler irrigation. The first output was a zone budget for Freetown Creek to determine how much effluent is entering Freetown Creek via the subsurface. The zone budget determines after each time step the amount of effluent reaching Freetown Creek by measuring the change in storage at the beginning and end of the time step. The second output was tracer particles created through MODPath. The tracer particles show where wastewater effluent is traveling through the subsurface over time. The routing of wastewater effluent through the subsurface will help determine if wastewater flow is naturally traveling to Freetown creek. The MT3DMS transport engine was selected for computing the groundwater flow.

3.3. Results and Discussion

The modeling of the discharge of wastewater effluent onto the spray field was conducted in two phases. The first phase was to determine how the spray field operated in existing conditions without any variables being changed to enhance drainage. The second phase of modeling included testing different engineering designs with the existing sprinkler configuration to see if the spray field could work more effectively for the wastewater effluent.

3.3.a Existing Conditions

Existing conditions were modeled to determine the severity of the ponding and where the discharged wastewater effluent was traveling. Determining what the severity of the ponding and determining what the hydraulic heads of the subsurface look like will determine if any engineered designs can achieve sustainable drainage throughout the spray field.

The spray field was modeled with a continuous discharge at the permitted discharge amount of 1,893 m^3 d^{-1} (500,000 gallons d^{-1}) over the 37,200 m^2 of sprinkler irrigation area. The test was conducted to determine how long the spray field could operate before ponding began on the site. Continuous application was assumed, a conservative measure due to no peak loading throughout the day and application occurring at all hours of the day. Application was also assumed to be continuous due to no record of when application was and was not applied on the site (i.e. time schedule).

The spray field was predicted to have ponding occurring by the 158th day of operation if operated continuously at the permitted discharge. **Figure 3-3** shows the location of the cross sections in the west to east and the north to south directions. The west to east cross section is labeled as cross section “A-A” and the north to south cross section is labeled as cross section “B-B”.

Figure 3-5 shows cross section “A-A” and **Figure 3-6** show cross section “B-B”. **Figure 3-5** and **Figure 3-6** were generated to determine how far in each direction the wastewater effluent was traveling before ponding occurred within the site. The results show that wastewater effluent could not infiltrate through the Selma Chalk, making it an effectively impermeable layer. A perched water table began to form throughout the site due to the Selma Chalk. Water mounding began to accumulate on top of the Selma Chalk as opposed to the initial heads of the site being in equilibrium with Freetown Creek. Wastewater effluent traveled 210 meters west and 120 meters east in cross section “A-A” direction of spray field site before ponding occurred and wastewater effluent traveled 220 meters south and 190 meters north in cross section “B-B” direction.

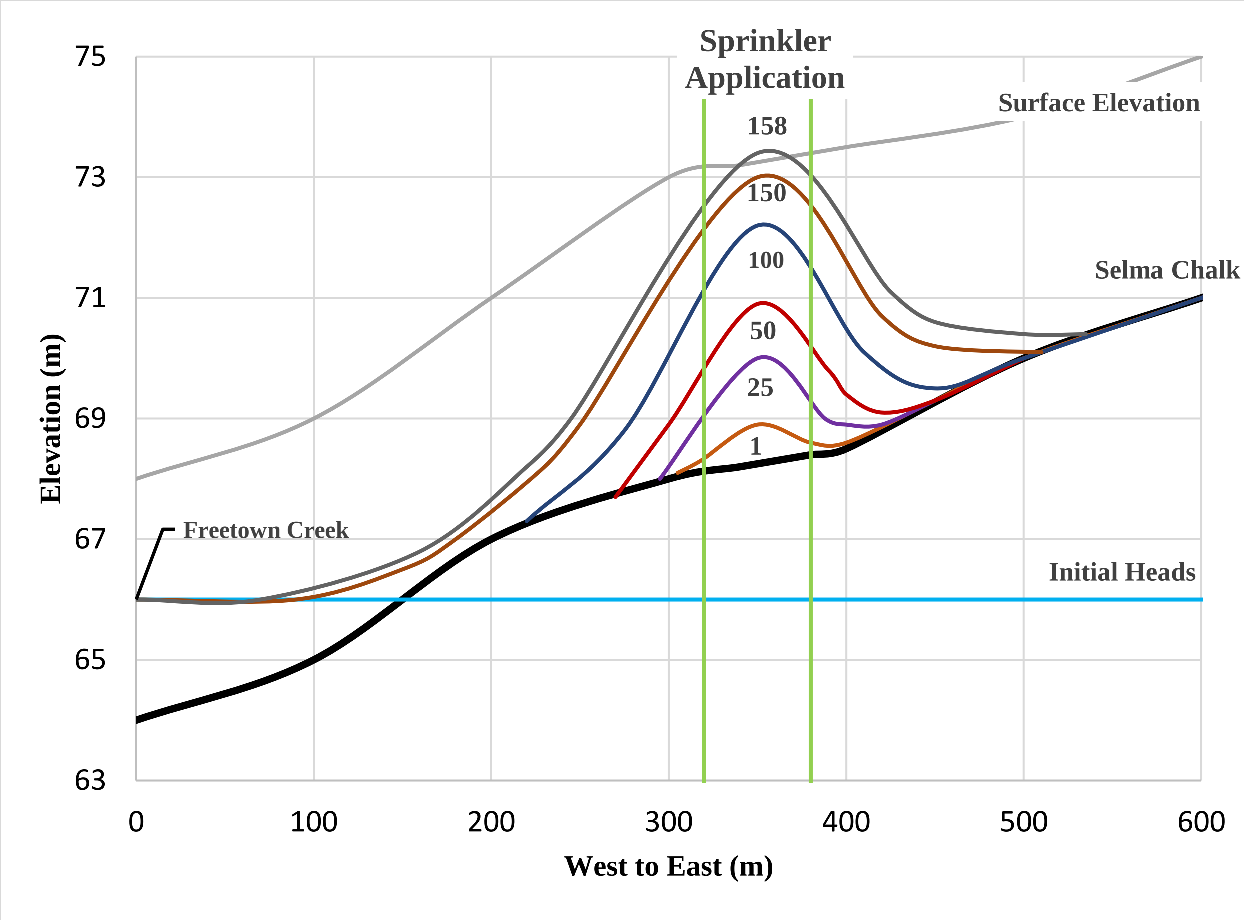


Figure 3-5: Water Table Height at Cross Section "A-A" Over Time Represented in Days at Permitted Discharge Rate

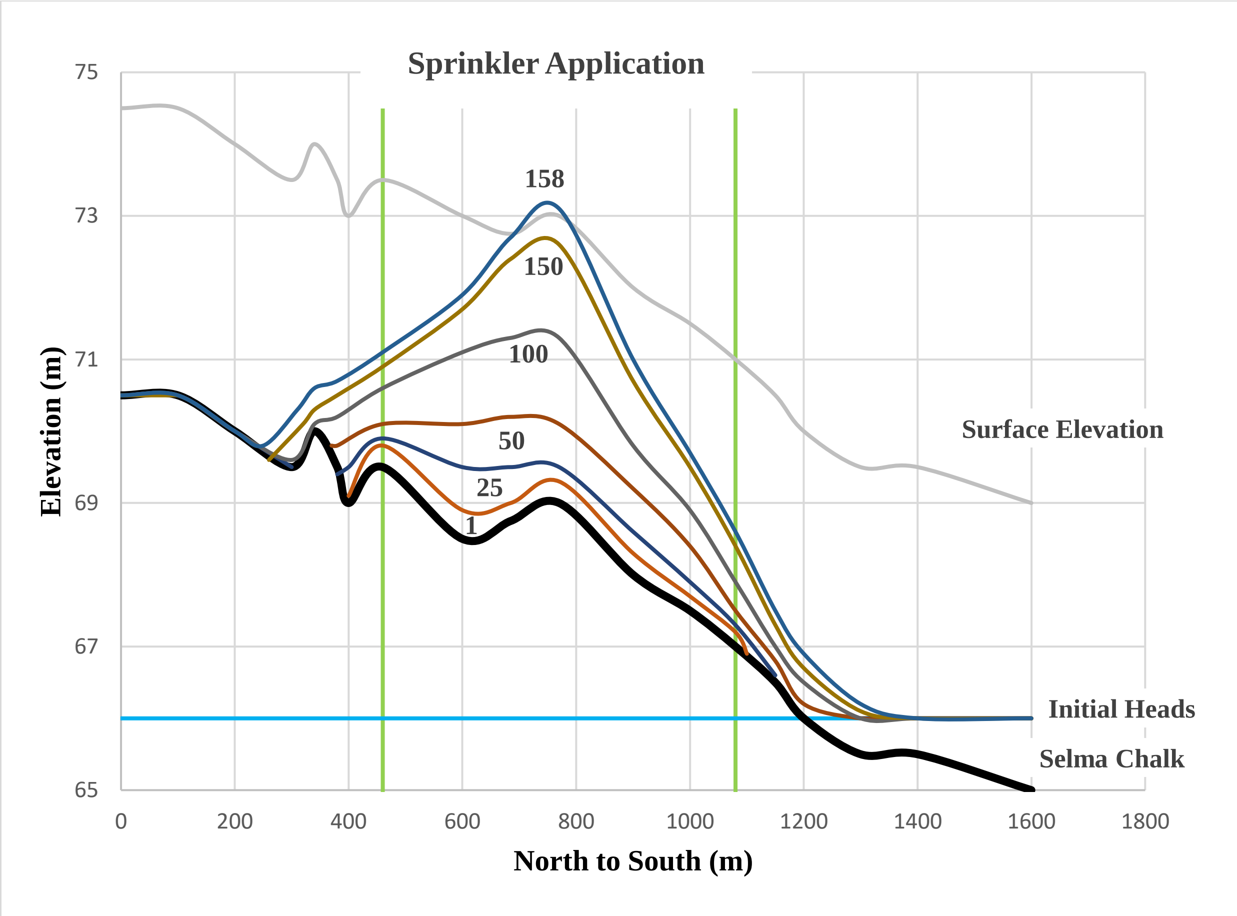


Figure 3-6: Water Table Height at Cross Section "B-B" Over Time Represented in Days at Permitted Discharge Rate

Figure 3-5 and **Figure 3-6** show that sustainable wastewater effluent drainage cannot be achieved with the current permitted discharge. **Table 3-1** show the previously reported discharge amounts occurring on the spray field between 2018 and 2020. Thirty-one out of thirty-six months the discharge permit was exceeded. The spray field has been in operation since 1999. The permitted discharge is much too large, and with actual discharging amounts exceeding the permit amount, extreme flooding will occur on the site, as is currently the case (**Figure 3-2**).

Based on the existing sprinkler configuration and current permitted discharge, the soil conductivity would have to be drastically increased uniformly across the spray field to be able to sustainably drain the discharged wastewater effluent. The soil conductivity was increased incrementally in the model until the spray field was able to achieve a steady state condition without ponding. Steady state occurs when the water table and hydraulic heads of the system do not change with respect to time and loading. In other words, the incoming wastewater effluent matches the outgoing water from the system. Tests of 1.0×10^{-6} m s^{-1}, 5.0×10^{-6} m s^{-1}, and 1.0×10^{-5} m s^{-1} were conducted but ponding occurred before steady state was able to be achieved. A soil conductivity of 5.0×10^{-5} m s^{-1}, almost over 100 times the actual conductivity, was able to reach steady state with the permitted discharge of 1,893 m^3 d^{-1} (500,000 gallons d^{-1}). The soil classification with a conductivity of 5.0×10^{-5} m s^{-1} is fine sand. Results from this model run can be found in **Figures 3-7** and **3-8**.

Figure 3-7 shows the distance the wastewater effluent traveled in the x-y directions relative to time until steady state was able to be achieved. **Figure 3-7** shows all wastewater effluent eventually traveled to Freetown Creek with wastewater effluent beginning to arrive at Freetown Creek by day 113. Wastewater effluent stopped travelling in the north, south, and east directions but did not stop in the west direction (i.e., Freetown Creek). **Figure 3-8** show the spray field at steady state with path lines of inserted tracer particles that were inserted around the boundary of the application area. The tracer particles on the western side of the application area traveled a direct path to Freetown Creek. The tracer particles on the eastern side initially moved eastward but eventually looped westward towards Freetown Creek.

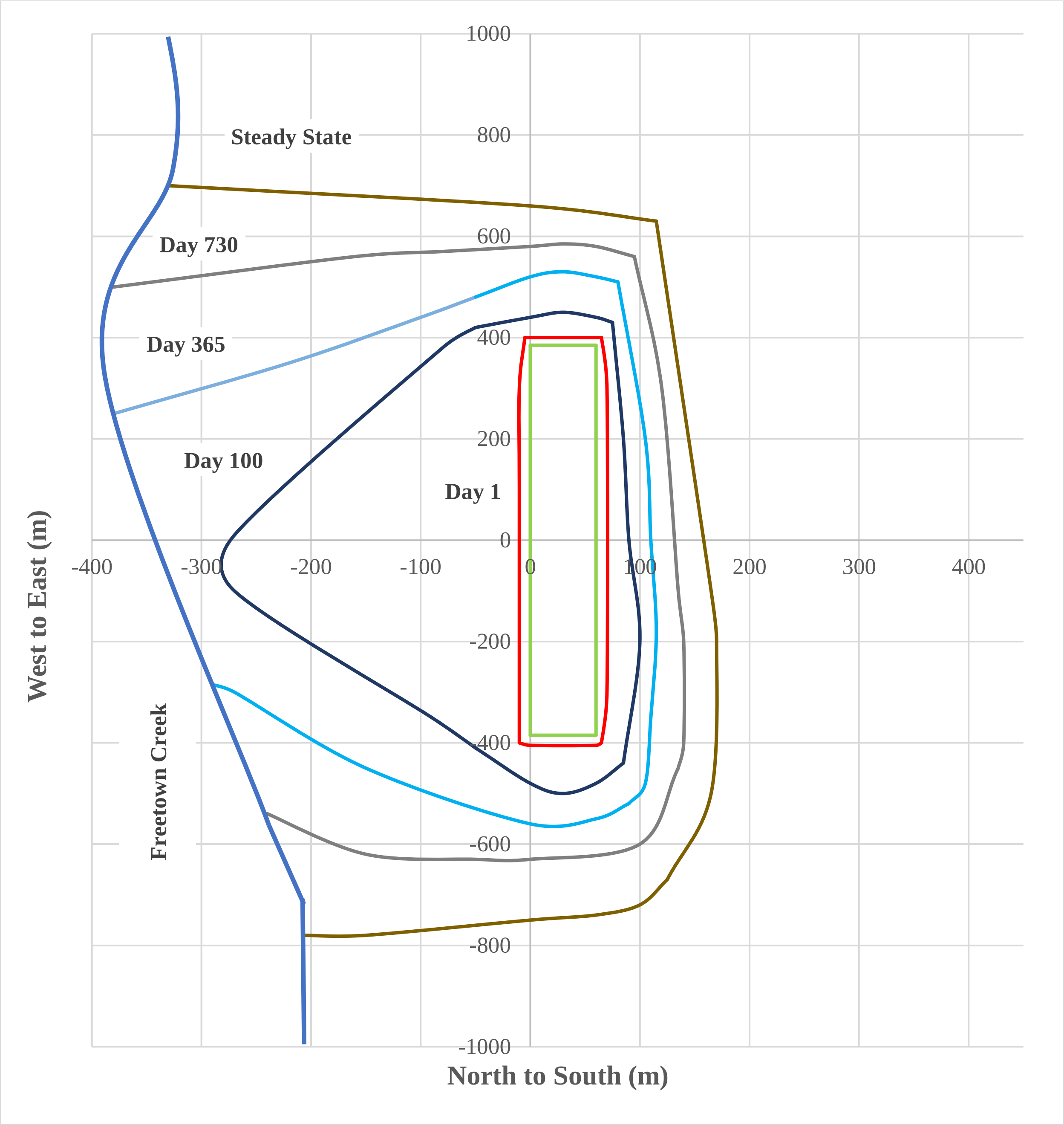


Figure 3-7: Travel of Wastewater Effluent Over Time with Sand as Upper Soil Layer, Lines Represent where Wastewater Effluent Stopped at the End of Day

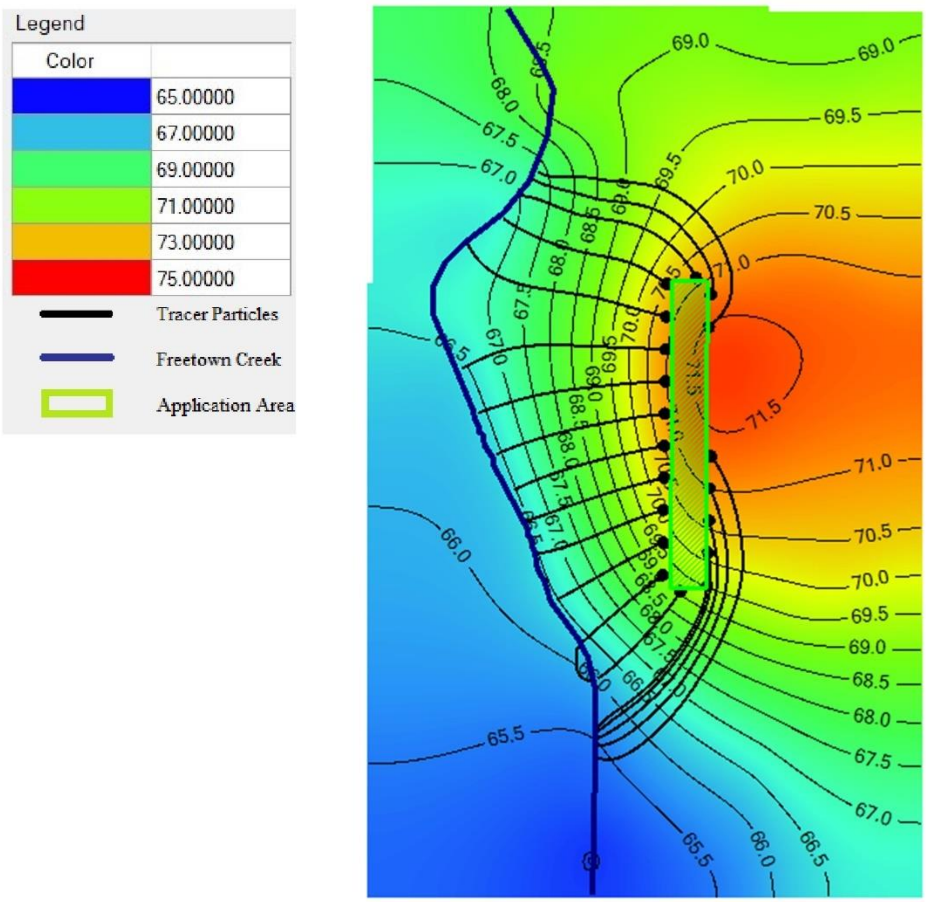


Figure 3-8: Travel of Wastewater Effluent At Steady State in MODFlow with Sand as Upper Layer with Contours Representing Water Table Elevation

Steady state was able to be achieved due to the soil conductivity being increased by almost two orders of magnitude from 7.07 x 10^{-7} m s^{-1} to 5 x 10^{-5} m s^{-1}. **Figures 3-7** and **3-8** also show the only path for sustainable drainage is if the wastewater effluent travels to Freetown Creek. Steady state was able to be achieved only when the loading rate of the recharge area is the same as the loading rate of Freetown Creek. If wastewater effluent does not travel to Freetown Creek, then ponding would occur resulting in a failed spray field. Freetown Creek in 2017 was found to have an average flow rate of 12,500 m^3 d^{-1} (5.11 cfs) and a 7Q10 of 0 (ADEM, 2022a).

The 7Q10 is the lowest seven day average that occurs once every ten years. A 7Q10 of 0 indicates that there is recorded data that Freetown Creek has been dry for a seven day period. This is a concern for the loading rate of the creek due to the low assimilation capacity.

The change in soil conductivity to achieve sufficient drainage shows the extent of failure by the existing spray field design. Due to the impracticality of replacing the entire first soil layer with sand, the discharge permit was incrementally decreased to determine a more adequate discharge permit based on the existing spray field design. The discharge permit at 1,893 $m^3\ d^{-1}$ has been shown by **Figures 3-5** and **3-6** to be too much wastewater effluent allowed to be discharged. The testing was done until steady state was achieved with no ponding occurring within the site. Determining the actual loading capabilities of the spray field will assist in designing enhancements for the spray field.

Figure 3-9 shows the incremental decrease of the discharge permit with the corresponding time until ponding occurred. The spray field’s ponding took longer to occur as the permitted discharge was lowered. At 852 $m^3\ d^{-1}$ (225,000 gallons d^{-1}), 45% of the current discharge permit, the spray field was able to achieve steady state with no ponding. **Figure 3-10** shows how the wastewater effluent traveled through the spray field over time. **Figure 3-10** is similar to **Figure 3-7** in that wastewater effluent stopped traveling in the north, east, and south directions, but continued west towards Freetown Creek. The distance traveled by the wastewater effluent in the existing soil conditions was greater than the fine sand soil conditions. This is due to wastewater effluent taking longer to move throughout the subsurface and creating greater hydraulic heads that are near the application area. **Figure 3-10** confirms that the only possible way for the spray field to function sustainably is if the wastewater effluent travels to Freetown Creek.

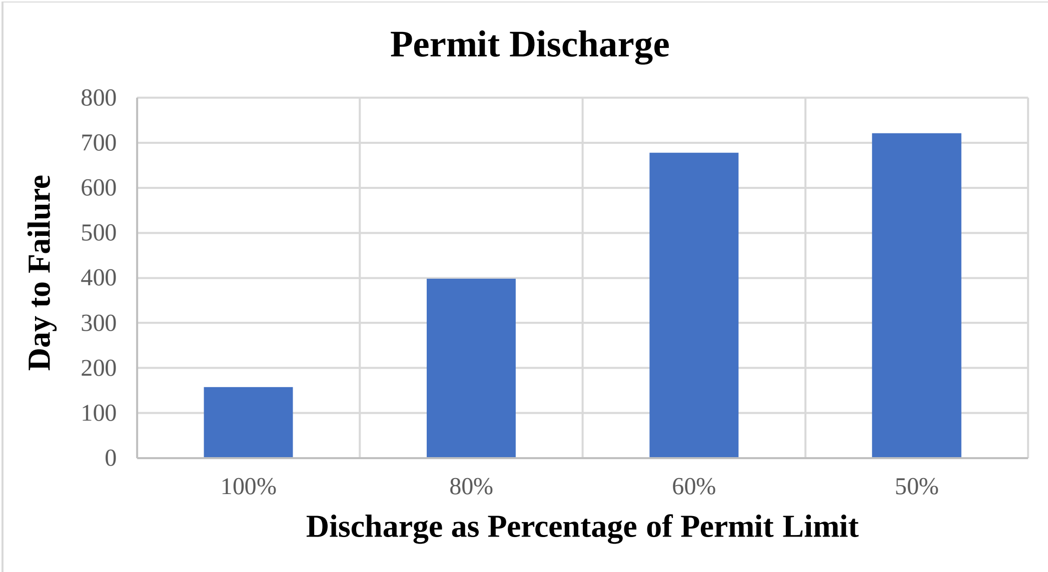


Figure 3-9: Time to Failure Versus Percentage of Permitted Discharge

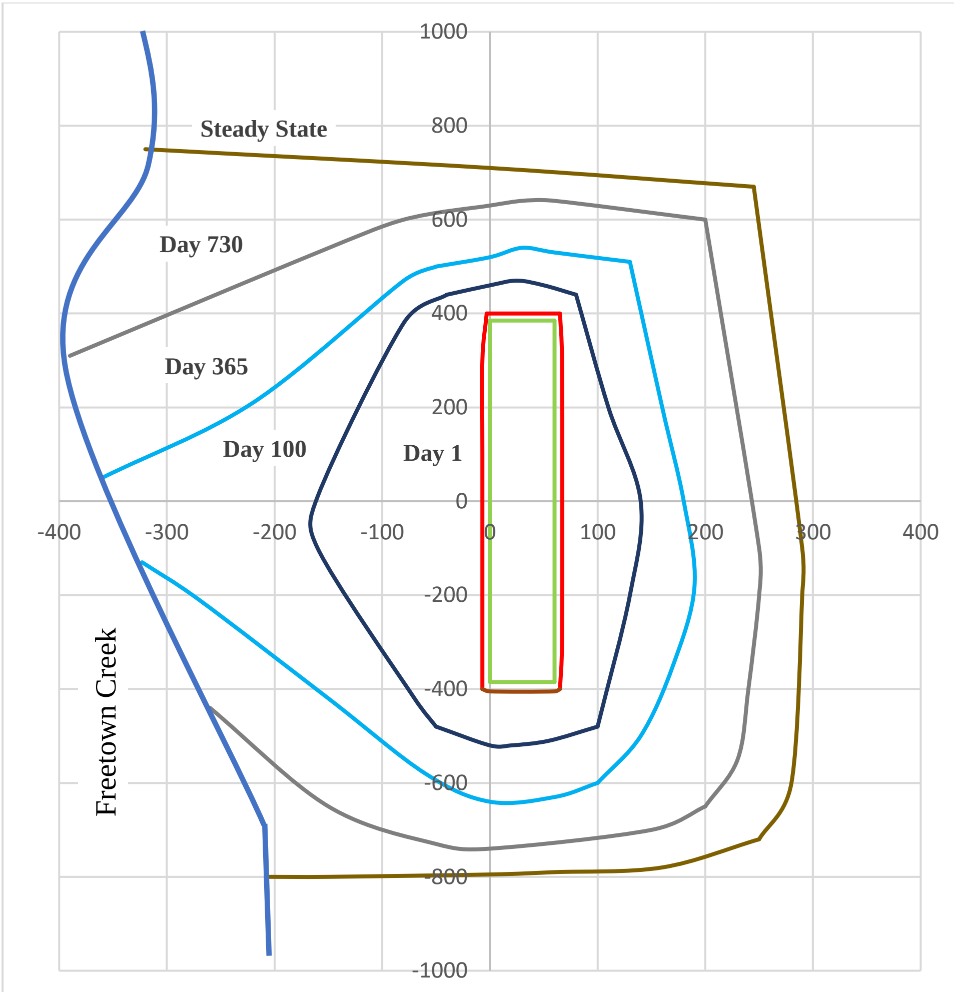


Figure 3-10: Travel of Wastewater Effluent Over Time with the Discharge Being Reduced to 946 m^3 d^{-1} (250,000 gallons per day), Lines Represent where Wastewater Effluent Stopped at the End of Day

Figure 3-11 shows the spray field conditions at steady state with inserted tracer particles and the corresponding path lines. **Figure 3-11** shows an increased water table elevation compared to **Figure 3-8**. The increased water table elevation and hydraulic head causes the wastewater effluent to take a longer path from the eastern side of the application area. The path lines in **Figure 3-11** can be seen to be noticeably wider than those of **Figure 3-8**. The simulation found **w**astewater effluent began to arrive at Freetown Creek on day 196.

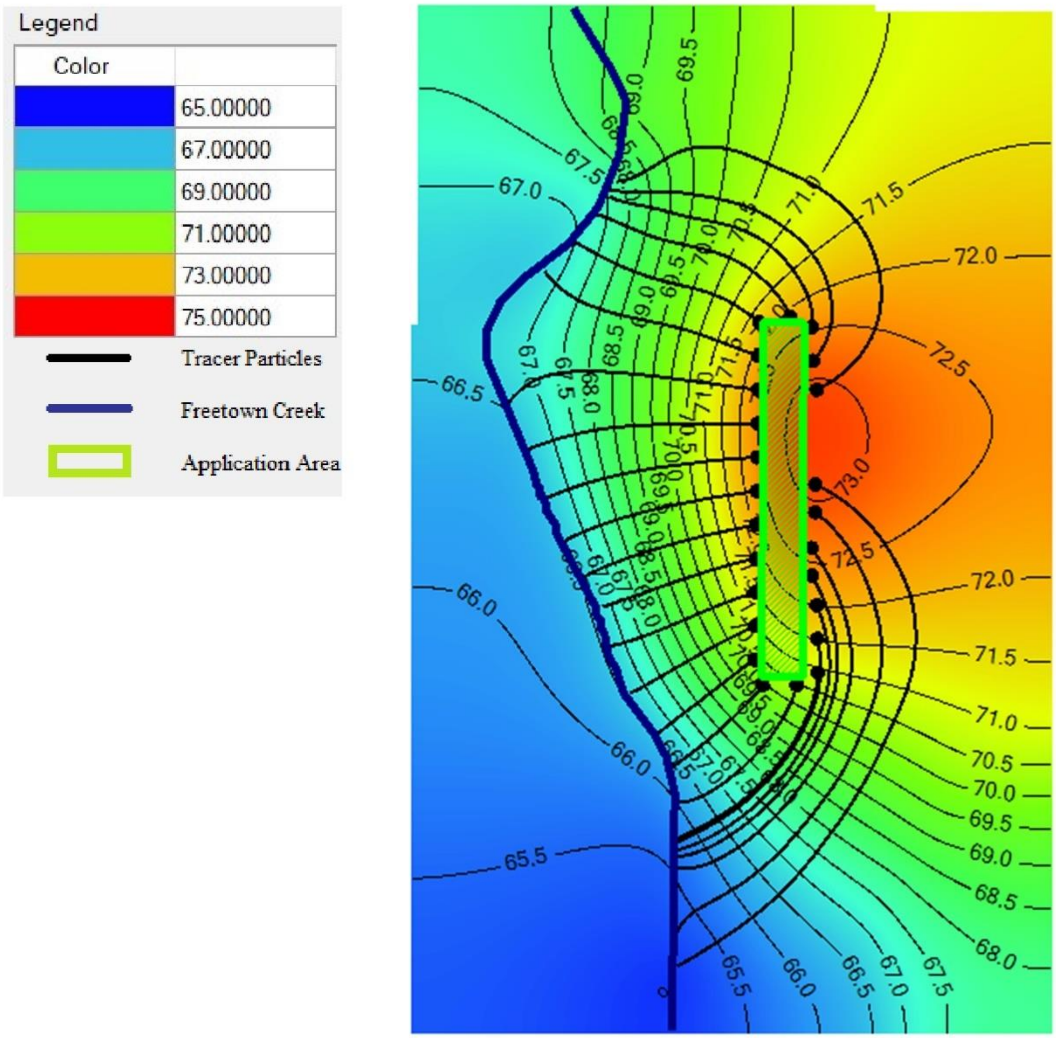


Figure 3-11: Travel of Wastewater Effluent At Steady State in MODFlow with Sand as Upper Layer with Contours Representing Water Table Elevation

The 852 m^3 d^{-1} (225,000 gallons d^{-1}) reduced discharge permit is a conservative value given continuous operation of the sprinklers and assumed even application throughout the recharge area. A permitted discharge of 852 m^3 d^{-1} in Uniontown with a population of 2,107 (Census, 2020b), would allow for 0.40 m^3 d^{-1} (107 gallons d^{-1}) per resident. A study conducted in

2022 found the average person in the United States uses 0.38 m^3 d^{-1} (101 gallons d^{-1}) (Swistock and Sharpe, 2022). Based on Uniontown's population, a 852 m^3 d^{-1} permit discharge would be close to sufficient for the city's needs. The original 1,893 m^3 d^{-1} (500,000 gallons d^{-1}) discharge permit is too high for the existing system and more than double the estimated city's needs.

The findings of the spray field's inadequate sizing and excessive permit discharge are also congruent with the EPA's land application design manual (EPA, 2006). The appropriate land requirement ranges from 0.23 – 3.45 km^2 per 3785 m^3 d^{-1} (23 – 345 hectaraes per MGD) (EPA, 2006). A spray field with maximum infiltration at a permitted discharge of 1,893 m^3 d^{-1} (500,000 gallons d^{-1}), would require a land area of 0.12 km^2 (30 acres). The EPA design manual recommends using an approximate infiltration rate of 3.8 cm wk^{-1} or a loading rate that is below 6 m yr^{-1}. The infiltration rate and loading rate comes from a design manual that has been used throughout the wastewater design industry (Crites, 2000). Currently, the applied field area is 0.037 km^2 (9.24 acres) and the loading rate is 18.6 m yr^{-1}. Given the conditions of the soil conductivity and permeability throughout the site and precipitation and evaporation data found in **Table 3-4** and **3-5**, the infiltration rate is safe to assume lower than the maximum infiltration considered in design recommendations. The existing spray field area is also a conservative value given the ten meters around the two sprinkler lines to account for the sprinkler discharge landing outside of the sprinkler lines. The existing spray field area is more than three times to small of the estimated required size for a spray field based on the design criteria and existing discharge permit.

3.3.b Potential Engineering Modification to Enhance Drainage

Based on the results in **Section 3.3.a**, increasing the spray field area and increasing the hydraulic conductivity within the site would increase the loading capability of the spray field.

The EPA's design manual also recommends cultivating vegetation with the spray field site to increase drainage by increasing evapotranspiration (EPA, 2006). In **Section 3.2.a**, evaporation and precipitation were not incorporated due to how little evaporation and precipitation would impact the model relative to the amount of wastewater effluent being discharged. The spray field was assumed to be in equilibrium with Freetown Creek under the assumption the spray field was able to sustainably drain precipitation without ponding occurring. Evapotranspiration from cultivated vegetation was modeled to see how an increased evapotranspiration would impact the spray field. Alfalfa grass and hay were used due to the high evapotranspiration rates and prevalence throughout the southeast United States. The evapotranspiration rates of alfalfa grass and hay can be found in **Table 3-7**. The increased evapotranspiration was only applied within the application area. The model found ponding began to occur on day 171. The spray field began ponding on day 158 without evapotranspiration from the vegetation. The increased evapotranspiration only prolonged ponding by thirteen days and evapotranspiration was found to have a minimal effect on draining the spray field. Due to the minimal effect, cultivated vegetation and an increased evapotranspiration were not used in the engineered proposed designs.

Month	Alfalfa Grass (m/month)	Alfalfa Hay (m/month)	Cumulative (m/month)	Cumulative (m/d)
January	0.022	0.019	0.041	0.0013
February	0.061	0.051	0.112	0.0040
March	0.095	0.079	0.174	0.0058
April	0.157	0.130	0.287	0.0093
May	0.203	0.170	0.373	0.0120
June	0.229	0.186	0.415	0.0138
July	0.237	0.198	0.435	0.0140
August	0.214	0.176	0.390	0.0126
September	0.153	0.131	0.284	0.0095
October	0.116	0.092	0.208	0.0067
November	0.049	0.041	0.090	0.0030
December	0.018	0.015	0.033	0.0011

Table 3-7: Evapotranspiration Rates from Vegetation (EPA, 2006)

Multiple different designs were preliminary tested to determine how the spray field might best be able to drain the wastewater effluent. Implementing sand trenches and installing additional sprinkler lines to increase the field area were found to have the greatest effect on the spray field.

Sand trenches were found to have the biggest impact on wastewater effluent drainage within the site. Sand with a hydraulic conductivity of 5×10^{-4} m s^{-1} was assumed for the sand trenches. Sand's hydraulic conductivity is directly dependent on pore size thus making sand's hydraulic conductivity difficult to determine for large quantities (Cabalar & Akbulut, 2016). A conservative hydraulic conductivity value was used to better predict the impact and sustainability of the drainage. Six sand trenches were shown to have the best impact on the drainage of the spray field. The conceptual design of the sand trenches within the spray field can be seen in **Figure 3-12**. The sand trenches were fifty meters wide by 200 meters long by four meters deep. The sand trenches were spaced fifty meters apart.

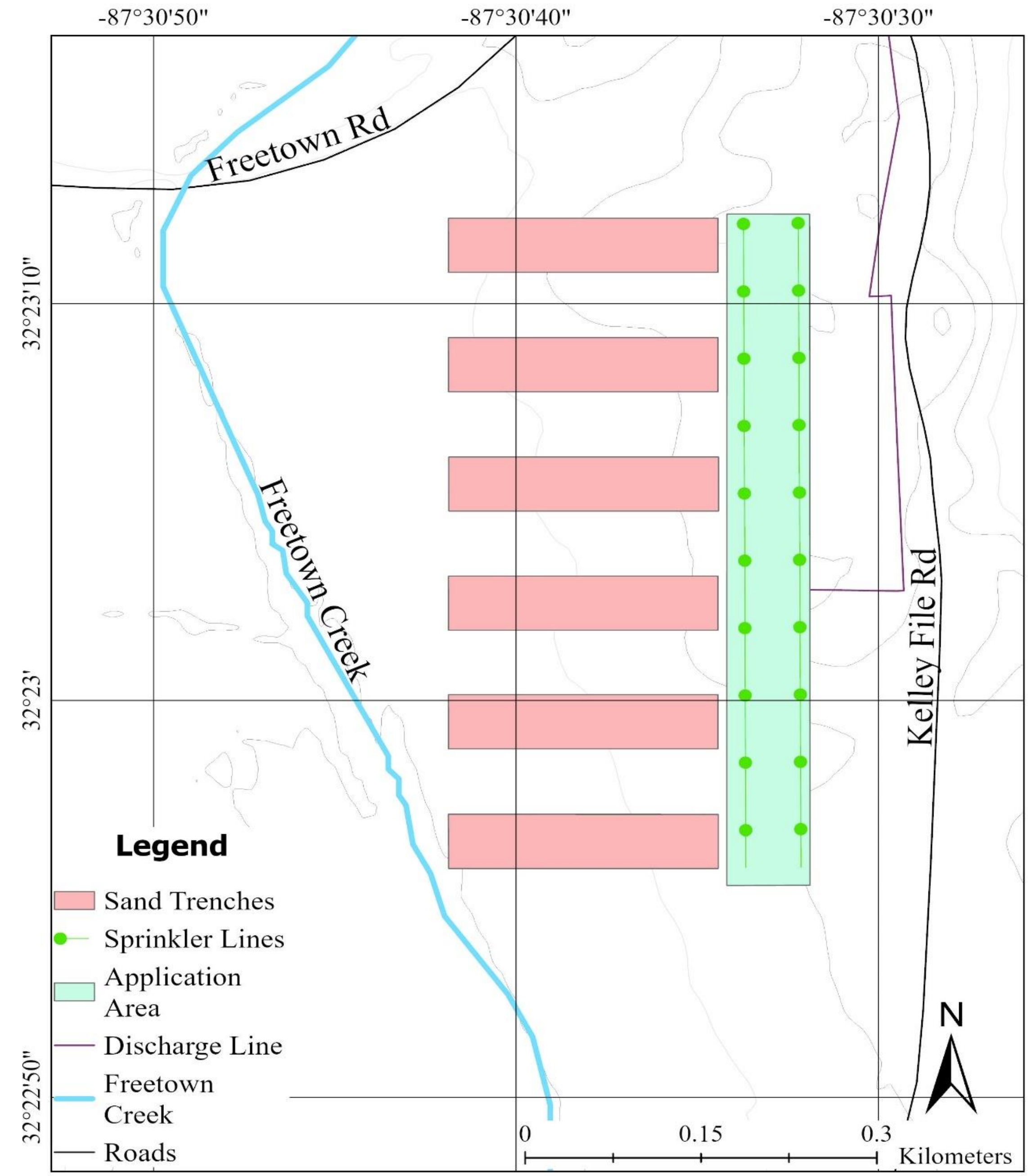


Figure 3-12: Conceptual Sand Trench Design with Existing Sprinklers

The result of the implementation of the sand trenches can be seen in **Figure 3-13**. The wastewater effluent was able to achieve steady state with no ponding occurring within the spray field site under the existing discharge permit of 1,893 m^3 d^{-1}. Tracer particles were inserted around the border of the application area to determine the path wastewater effluent traveled to arrive at Freetown Creek. The tracer particles inserted on the western side of the application area can be seen traveling to a sand trench and then traveling across the spray field to Freetown Creek in **Figure 3-13**. Wastewater effluent began arriving at Freetown Creek by day forty three on the shortest path from the recharge area to Freetown Creek. The portion at the bottom right of **Figure 3-13** shows the inactive, dry cells due to no wastewater effluent traveling that far to the southeastern part of the model area.

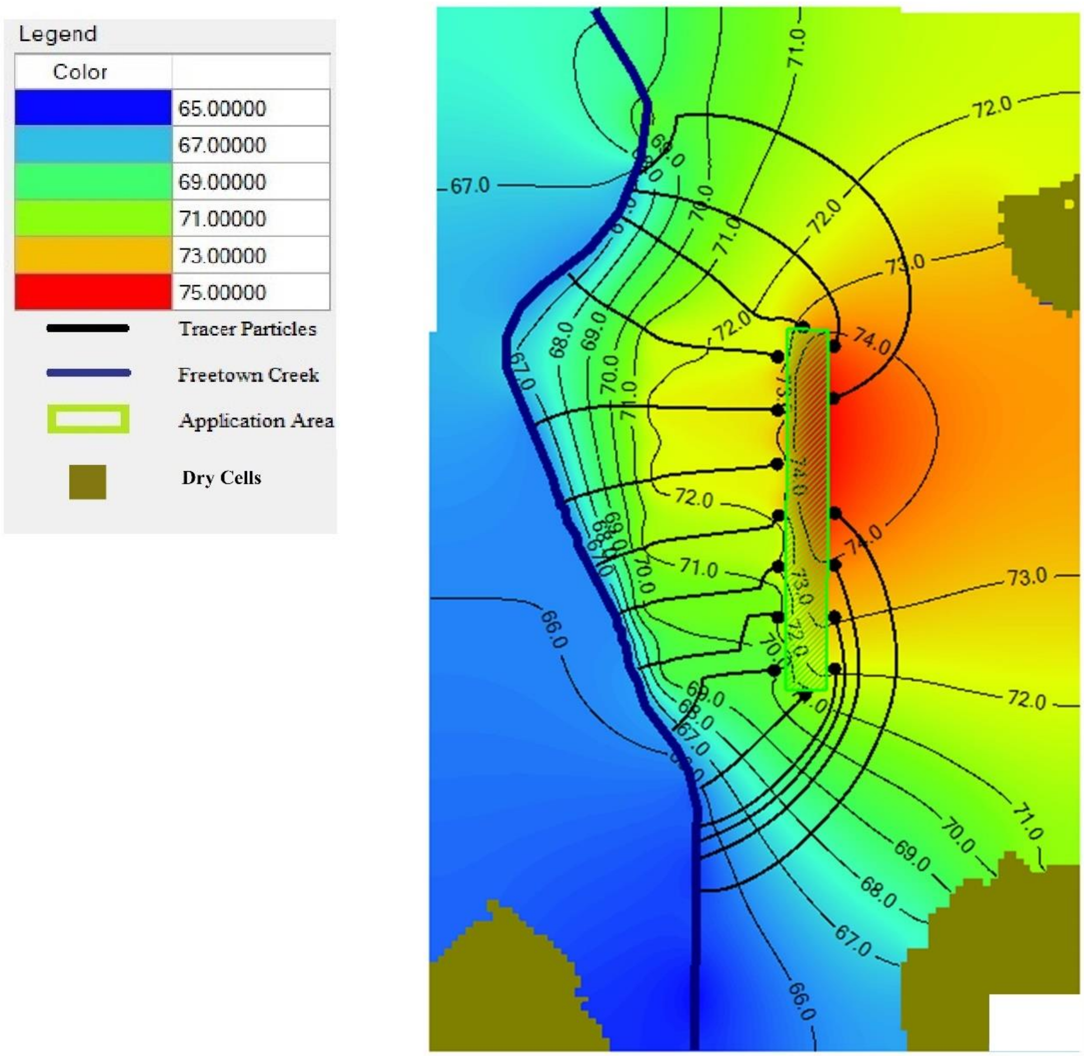


Figure 3-13: MODFlow Steady State Run with Sand Trench Design with Tracer Particles Represented by Path Lines and Contours Representing Water Table Height

Based on EPA's design manual and the results from **Figures 3-9**, the existing field area was severely undersized based on the existing permit discharge. The EPA design manual recommends an approximate field area of 194,000 m^2 (48 acres) based on the approximate infiltration rate and discharge permit. The design manual recommends the loading of the wastewater effluent onto the spray field be between 0.5 – 6 m yr^{-1} (EPA, 2006). The resized spray field area would have a loading of 3.4 m yr^{-1} compared to a loading of 18.6 m yr^{-1} with the existing field area.

The spray field would need an additional five sprinkler lines, identical to the already installed sprinkler lines, spaced every fifty meters apart to reach 198,000 m^2 (49 acres). This is assuming a ten meter buffer zone around the sprinkler lines to account for wastewater effluent falling outside of sprinkler lines and even application between the sprinkler lines. The conceptual design of the new sprinkler lines can be seen in **Figure 3-14**.

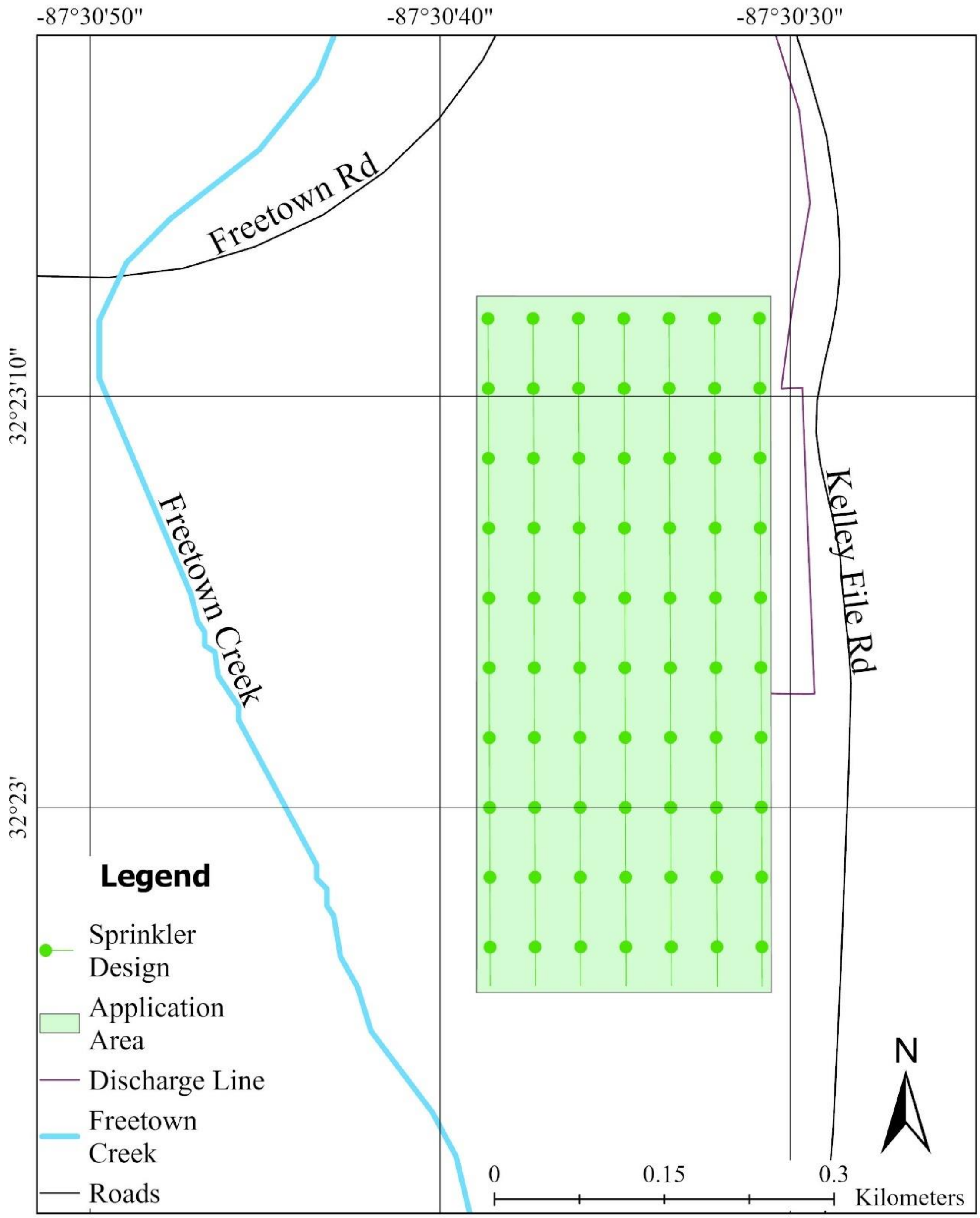


Figure 3-14: Conceptual Expanded Sprinkler Configuration

The spray field began to pond on day 412 of the simulation when applied with the permitted discharge of 1,893 m^3 d^{-1}. The increased spray field area from 37,200 m^2 to the recommended 198,000 m^2 did not achieve steady state. A perched water table began to form due to the Selma Chalk and water mounding within the middle of the application area led to the ponding. Water mounding of the spray field was consistent with **Figures 3-5** and **3-6**. Due to the Selma Chalk acting as an impermeable layer, the 1,893 m^3 d^{-1} permitted discharge is to much wastewater effluent being discharged relative to the Selma Chalk's depth from surface elevation. The Selma Chalk depth would need to increase to be able to achieve sufficient drainage. Wastewater effluent did begin to arrive at Freetown Creek on day 49 before ponding occurred.

Chapter Four.

Conclusion

4.1. Conclusions for the Existing Spray Field

The spray field located within Uniontown, AL has failed due to severe ponding. The spray field is severely undersized, and the permitted discharge is too great for the system. The system will fail at the permitted loading rate. Based on the modeling conducted in **Section 3.3.a**, the failure is due to the low conductivity of the upper soil layer and the Selma Chalk relative to the loading rate of the spray field. The Selma Chalk acts as an impermeable layer and creates a perched water table once infiltrated wastewater effluent reached the Selma Chalk. The perched water table restricts deeper wastewater effluent infiltration and movement throughout the spray field. Based on the existing permit discharge of 1,893 m^3 d^{-1}, the spray field would begin ponding on day 158.

The spray field was found to have sustainable drainage and achieve steady state if two factors could change. The first would be if the permitted discharge was decreased to 852 m^3 d^{-1} (225,000 gallons d^{-1}) from 1,893 m^3 d^{-1} (500,000 gallons d^{-1}). Decreasing the loading rate to 852 m^3 d^{-1} would allow the system to function sustainably and achieve steady state. Wastewater effluent began arriving at Freetown Creek on day 196. The reduction is half of the existing permitted discharge.

Previous discharge records show consistent exceedance of the discharge permit occurring within recent years. Thirty one out of thirty six months between the years 2018 – 2020 reported an exceedance of the permitted discharge. The highest recorded daily average discharge was reported at 6,224 m^3 d^{-1} (1,660,000 gallons d^{-1}). The consistent exceedance of the permitted discharge has led to an acceleration and amplification of the spray field's failure. The population of Uniontown is only 2,107 people. Based on the highest average daily discharge of 6,224 m^3 d^{-1}, each resident would have to use an average water use of 2.95 m^3 d^{-1} (788 gallons d^{-1}). The U.S. citizen average water use is 0.38 m^3 d^{-1} (101 gallons d^{-1}) (Swistock and Sharpe, 2022). Based on the average water use, an average monthly discharge of 801 m^3 d^{-1} (212,000 gallons d^{-1}) would be sustainable for Uniontown's population.

The second way the spray field would be able to sustainably drain and achieve steady state would be by replacing the entire first soil layer with fine sand. This is not feasible for application but displays the disproportionate loading of wastewater effluent relative to the hydraulic conductivity of the soil. The hydraulic conductivity of the upper soil layer was increased to 5 x 10^{-5} m s^{-1} from the existing 7.07 x 10^{-7} m s^{-1}. Almost two orders of magnitude increase was necessary to ensure no ponding would occur. The wastewater effluent that was discharged traveled to Freetown Creek via the subsurface. Wastewater effluent began arriving at Freetown Creek on day 113. This result shows that if the spray field was working correctly, discharged wastewater effluent would be draining to Freetown Creek. One area of concern is how low the 7Q10 of Freetown Creek was found to be in 2017. The low 7Q10 shows that at points during the year, Freetown Creek does not have any water flowing. Freetown Creek begins to feed Chilatchee Creek 6.63 km (4.12 miles) from where wastewater effluent enters the creek. The Chilatchee Creek eventually feeds the Alabama River, a major river within Alabama.

4.2. Conclusions for Preliminary Engineered Solutions

Several different preliminary engineering modifications were modeled to determine the most effective methods to achieve sustainable drainage. Based on the results from **Section 3.3.b**, designing applications that increase the spray field area and increase the hydraulic conductivity throughout the site were considered in the design. Cultivated vegetation throughout the spray field was found to have a minimal impact due to the amount of wastewater effluent being discharged. The evapotranspiration only prolonged ponding from occurring by twenty three days with the existing permit discharge.

Sand trenches and expanding the sprinkler application area were found to have the greatest impact on increasing the loading capability of the spray field. Sand trenches were found to be able to achieve sustainable drainage at the permitted discharge. The sand trench configuration found in **Figure 3-9**, assuming a hydraulic conductivity of 5×10^{-4} m s^{-1}, was able to achieve steady state with no ponding. Wastewater effluent began arriving at Freetown Creek on day forty three. The spray field was closest to ponding near Freetown Creek and not within the application area, due to the elevation sloping at a steeper grade than the water mound accumulating in the subsurface.

Installing an additional five sprinkler lines, found in **Figure 3-14**, would increase the application area from 37,200 m^2 to 198,000 m^2 and decrease the loading rate from 18.6 m yr^{-1} to 3.4 m yr^{-1}. Increasing the sprinkler application area to the design recommendation would still not allow for a permitted discharge of 1,893 m^3 d^{-1}. The sprinkler line expansion would cause wastewater effluent to begin arriving at Freetown Creek within 49 days.

References

Abu Ghunmi, L., Zeeman, G., Fayyad, M., & van Lier, J. B. (2010). Grey water treatment in a series anaerobic - Aerobic system for irrigation. *Bioresource Technology*, *101*(1), 41-50. https://doi.org/10.1016/j.biortech.2009.07.056

ADEM. (2007). *Administrative and Engineering Guidelines Industrial Waste Land Treatment Facilities*. Montgomery, AL

ADEM. (2018). *National Pollutant Discharge Elimination Sytem - General Permit*. (ALG640000). Retrieved from https://adem.alabama.gov/programs/water/permits/ALG640000WaterTreat.pdf

ADEM. (2021). *Uniontown Wastewater Treatment System Update as of September 2021*. https://adem.alabama.gov/newsEvents/reports/UniontownWWTPReport.pdf

ADEM. (2022a). *E-File*. (AL0063657). Alabama Department of Environmental Management Retrieved from http://app.adem.alabama.gov/efile/

ADEM. (2022b). *Municipal Wastewater Treatment Facility Outfalls* http://gis.adem.alabama.gov/mun/index.html

ADEM. (2023). *Underground Injection Control (UIC) Program*. Montgomery, AL Retrieved from https://adem.alabama.gov/programs/water/uicprogram.cnt

ADPH. (2018). *Infant Mortality*. Retrieved from https://www.alabamapublichealth.gov/perinatal/infant-mortality.html

AGSCS. (1981). *Land Resources and Major Land Resource Areas of the United States*. Retrieved from http://soilphysics.okstate.edu/S257/south/mlra/135.htm

Ahmad, N. (1983). Vertisols. In *Developments in soil science* (Vol. 11, pp. 91-123). Elsevier.

Angelakis, A. N., Asano, T., Bahri, A., Jimenez, B. E., & Tchobanoglous, G. (2018). Water Reuse: From Ancient to Modern Times and the Future. *Frontiers in Environmental Science*, *6*, Article 26. https://doi.org/10.3389/fenvs.2018.00026

Aydin, M. E., & Ozcan, S. (2008, Oct 08-11). SUSTAINABLE ADOPTED WASTEWATER TREATMENT AND REUSE IN AGRICULTURE.*NATO Science for Peace and Security Series C - Environmental Security* [Role of ecological chemistry in pollution research and sustainable development]. NATO Advanced Research Workshop on Role of Ecological Chemistry in Pollution Research and Sustainable Development, Chisinau, MOLDOVA.

Bandyopadhyay, K. K., Mohanty, M., Painuli, D. K., Misra, A. K., Hati, K. M., Mandal, K. G., Ghosh, P. K., Chaudhary, R. S., & Acharya, C. L. (2003). Influence of tillage practices and nutrient management on crack parameters in a Vertisol of central India. *Soil & Tillage Research*, *71*(2), 133-142. https://doi.org/10.1016/s0167-1987(03)00043-6

Bastian, R. K. (2005). Interpreting science in the real world for sustainable land application. *Journal of Environmental Quality*, *34*(1), 174-183. https://doi.org/10.2134/jeq2005.0174

Bond, W. J. (1998). Effluent irrigation - an environmental challenge for soil science. *Australian Journal of Soil Research*, *36*(4), 543-555. https://doi.org/10.1071/s98017

Bouwer, H. (1999). Artificial recharge of groundwater: systems, design, and management. *Hydraulic design handbook*, *24*, 44.

Bouwer, H., Bauer, W. J., & Dryden, F. D. (1978). LAND TREATMENT OF WASTEWATER IN TODAYS SOCIETY. *Civil Engineering*, *48*(1), 78-81. <Go to ISI>://WOS:A1978EK97800011

Bureau, U. S. C. (2021). *Poverty in the United States: 2021*. Retrieved from https://www.census.gov/library/publications/2022/demo/p60-277.html

Butler, J. J., Bohling, G. C., Whittemore, D. O., & Wilson, B. B. (2020). Charting Pathways Toward Sustainability for Aquifers Supporting Irrigated Agriculture. *Water Resources Research*, *56*(10), Article e2020WR027961. https://doi.org/10.1029/2020wr027961

Cabalar, A. F., & Akbulut, N. (2016). Evaluation of actual and estimated hydraulic conductivity of sands with different gradation and shape. *SpringerPlus*, *5*(1), 1-16.

CDC. (2015). *Outpatient Antibiotic Prescriptions - United States, 2015*. https://www.cdc.gov/antibiotic-use/data/report-2015.html

Census, U. S. (2020a). *Income in the Past 12 Months (Inflation Adjusted Dollars)*. Washington D.C.

Census, U. S. (2020b). *Total Population*. Washington D.C.

Cetecioglu, Z., & Atasoy, M. (2018). Biodegradation and Inhibitory Effects of Antibiotics on Biological Wastewater Treatment Systems. In E. D. Bidoia & R. N. Montagnolli (Eds.), *Toxicity and Biodegradation Testing* (pp. 29-55). https://doi.org/10.1007/978-1-4939-7425-2_2

Chan, Y. J., Chong, M. F., Law, C. L., & Hassell, D. G. (2009). A review on anaerobic-aerobic treatment of industrial and municipal wastewater. *Chemical Engineering Journal*, *155*(1-2), 1-18. https://doi.org/10.1016/j.cej.2009.06.041

Coleman, C. H. (2011). *Do Physicians' Legal Duties to Patients Conflict with Public Health Values? The Case of Antibiotic Overprescription*. https://doi.org/10.1007/s11673-009-9155-4

County of Maui, Hawaii v. Hawaii Wildlife Fund, U.S. 1-51 (Supreme Court 2020). https://www.supremecourt.gov/opinions/19pdf/18-260_jifl.pdf

Crites, R. W. (2000). *Land treatment systems for municipal and industrial wastes*. McGraw-Hill Education.

Dao, K. C., Yang, C. C., Chen, K. F., & Tsai, Y. P. (2020). Recent Trends in Removal Pharmaceuticals and Personal Care Products by Electrochemical Oxidation and Combined Systems. *Water*, *12*(4), Article 1043. https://doi.org/10.3390/w12041043

de Bustamante, I., Lillo, F. J., Sanz, J. M., de Miguel, A., Garcia, E., Carreno, F., Gomez, D., Martin, T., Martinez, F., & Corvea, J. L. (2009). A comparison of different methodologies for designing land application systems: Case study at the Reduena WWTP. *Desalination and Water Treatment*, *4*(1-3), 98-102. https://doi.org/10.5004/dwt.2009.362

Deblonde, T., Cossu-Leguille, C., & Hartemann, P. (2011). Emerging pollutants in wastewater: A review of the literature. *International Journal of Hygiene and Environmental Health*, *214*(6), 442-448. https://doi.org/10.1016/j.ijheh.2011.08.002

Dewsnup, R. L., Jensen, D. W., & Swenson, R. W. (1973). *A summary-digest of State water laws*. National Water Commission.

Dillon, P., Escalante, E. F., Megdal, S. B., & Massmann, G. (2020). Managed Aquifer Recharge for Water Resilience. *Water*, *12*(7), Article 1846. https://doi.org/10.3390/w12071846

Diop, A., & Fraser, R. (2009). A community-based forestry approach to poverty alleviation in Alabama's Black Belt Region. *International Forestry Review*, *11*(2), 186-196. https://doi.org/10.1505/ifor.11.2.186

Downing, D. M., Winer, C., & Wood, L. D. (2003). Navigating through Clean Water Act jurisdiction: A legal review. *Wetlands*, *23*(3), 475-493. https://doi.org/10.1672/0277-5212(2003)023[0475:Ntcwaj]2.0.Co;2

Duan, R., Fedler, C. B., & Sheppard, C. D. (2010). Nitrogen leaching losses from a wastewater land application system. *Water Environment Research*, *82*(3), 227-235.

Duan, R. B., & Fedler, C. B. (2016). Denitrification Field Study at a Wastewater Land Application Site. *Journal of Irrigation and Drainage Engineering*, *142*(2), Article 05015011. https://doi.org/10.1061/(asce)ir.1943-4774.0000980

Duan, R. B., Sheppard, C. D., & Fedler, C. B. (2010). Short-Term Effects of Wastewater Land Application on Soil Chemical Properties. *Water Air and Soil Pollution*, *211*(1-4), 165-176. https://doi.org/10.1007/s11270-009-0290-7

EPA. (1974a). *Evaluation of Land Application Systems*. (430/9-74-015). Washington D.C. Retrieved from https://nepis.epa.gov/Exe/ZyNET.exe/2000C13H.TXT?ZyActionD=ZyDocument&Client=EPA&Ind

ex=Prior+to+1976&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C70thru75%5CTxt%5C00000000%5C2000C13H.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL#

EPA. (1974b). *Land Application of Wastewater*. (903-9-75-017). Chicago, IL Retrieved from https://nepis.epa.gov/Exe/ZyNET.exe/20007Y59.txt?ZyActionD=ZyDocument&Client=EPA&Index=Prior%20to%201976&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C70THRU75%5CTXT%5C00000000%5C20007Y59.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=2

EPA. (2002). *Federal Water Pollution Control Act*. Washington D.C.: United States of America

EPA. (2006). *Land Treatment of Municipal Wastewater Effluents*. (625/R-06/016). Cincinati, OH Retrieved from https://nepis.epa.gov/Exe/ZyNET.exe/2000C13H.TXT?ZyActionD=ZyDocument&Client=EPA&Index=Prior+to+1976&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C70thru75%5CTxt%5C00000000%5C2000C13H.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL#

EPA. (2015a). *Connectivity of Streams & Wetlands to Downstream Wataers: A review & Synthesis of the Scientific Evidence*. Washington D.C.: Environmental Protection Agency Retrieved from https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=296414

EPA. (2015b). *Technical Support Document for the Clean Water Rule: Waters of the United States*. Retrieved from https://www.epa.gov/sites/default/files/2015-05/documents/technical_support_document_for_the_clean_water_rule_1.pdf

EPA. (2020). *History of the Effects of Litigation Over Recent Definitions of "Waters of the United States"*. Washington D.C. Retrieved from https://www.epa.gov/system/files/documents/2022-12/History%20of%20the%20Effects%20of%20Litigation.pdf

EPA. (2022a). *Learn About Small Wastewater Systems*. https://www.epa.gov/small-and-rural-wastewater-systems/learn-about-small-wastewater-systems#wastewater

EPA. (2022b). *Summary fo the Clean Water Act*. Environmental Protection Agency Retrieved from https://www.epa.gov/laws-regulations/summary-clean-water-act

Ewing, T., Babauta, J. T., Atci, E., Tang, N., Orellana, J., Heo, D., & Beyenal, H. (2014). Self-powered wastewater treatment for the enhanced operation of a facultative lagoon. *Journal of Power Sources*, *269*, 284-292. https://doi.org/10.1016/j.jpowsour.2014.06.114

Fedler, C. B. (2021). Design of Land Application Systems for Water Reuse. *Water*, *13*(15), Article 2120. https://doi.org/10.3390/w13152120

Fraser, R. F., Gyawali, B. R., & Schelhas, J. (2005). Blacks in space: Land tenure and well-being in Perry County, Alabama. *Small-Scale Forest Economics, Management and Policy*, *4*, 21-33.

Galegar, W. C., Harlin, C. C., & Enfield, C. G. (1980). DRAINAGE REQUIREMENTS FOR LAND APPLICATION WASTEWATER-TREATMENT. *Transactions of the Asae*, *23*(2), 343-&. <Go to ISI>://WOS:A1980JY82500015

Gharaibeh, M., Eltaif, N., & Al-Abdullah, B. (2007). Impact of field application of treated wastewater on hydraulic properties of vertisols. *Water, Air, and Soil Pollution*, *184*, 347-353.

Gohil, M. (2000). *Land Treatment of Waste Water*. New Age International.

Grehs, B. W. N., Linton, M. A. O., Clasen, B., de Oliveira Silveira, A., & Carissimi, E. (2021). Antibiotic resistance in wastewater treatment plants: understanding the problem and future perspectives. *Archives of Microbiology*, *203*(3), 1009-1020. https://doi.org/10.1007/s00203-020-02093-6

Grehs, B. W. N., Linton, M. A. O., Clasen, B., Silveira, A. D., & Carissimi, E. (2021). Antibiotic resistance in wastewater treatment plants: understanding the problem and future perspectives. *Archives of Microbiology*, *203*(3), 1009-1020. https://doi.org/10.1007/s00203-020-02093-6

Guettaf, M., Maoui, A., & Ihdene, Z. (2017). Assessment of water quality: a case study of the Seybouse River (North East of Algeria). *Applied Water Science*, *7*(1), 295-307. https://doi.org/10.1007/s13201-014-0245-z

Hawaii Wildlife Fund v. County of Maui, U.S. (United States Court of Appeals, Ninth Circuit. 2018).

Hawaii Wildlife Fund V. County of Mauii, U.S. (United States District Court, D. Hawai`i 2014). https://www.leagle.com/decision/inadvfdco150313000199

He, J. J., Dougherty, M., Arriaga, F. J., Fulton, J. P., Wood, C. W., Shaw, J. N., & Lange, C. R. (2013). Short-term soil nutrient impact in a real-time drain field soil moisture-controlled SDI wastewater disposal system. *Irrigation Science*, *31*(1), 59-67. https://doi.org/10.1007/s00271-011-0292-2

He, J. J., Dougherty, M., & Chen, Z. B. (2021). Numerical assessment of a soil moisture controlled wastewater SDI disposal system in Alabama Black Belt Prairie. *Chemosphere*, *263*, Article 128210. https://doi.org/10.1016/j.chemosphere.2020.128210

He, J. J., Dougherty, M., Shaw, J., Fulton, J., & Arriaga, F. (2011). Hydraulic management of a soil moisture controlled SDI wastewater dispersal system in an Alabama Black Belt soil. *Journal of Environmental Management*, *92*(10), 2479-2485. https://doi.org/10.1016/j.jenvman.2011.05.009

He, J. J., Dougherty, M., Zellmer, R., & Martin, G. (2011). Assessing the Status of Onsite Wastewater Treatment Systems in the Alabama Black Belt Soil Area. *Environmental Engineering Science*, *28*(10), 693-699. https://doi.org/10.1089/ees.2011.0047

Heilweil, V. M., & Watt, D. E. (2011). Trench infiltration for managed aquifer recharge to permeable bedrock. *Hydrological Processes*, *25*(1), 141-151. https://doi.org/10.1002/hyp.7833

Huang, C., Huang, Z. Y., Hu, Y., Li, Z. X., Wu, Y., & Gao, J. (2021). Treatment of wastewater generated from traditional Chinese medicine processing and utilization: Recent advances and future outlook. *Journal of Cleaner Production*, *291*, Article 125927. https://doi.org/10.1016/j.jclepro.2021.125927

Huang, Y. S., Li, P., Li, H., Zhang, B., & He, Y. L. (2021). To centralize or to decentralize? A systematic framework for optimizing rural wastewater treatment planning. *Journal of Environmental Management*, *300*, Article 113673. https://doi.org/10.1016/j.jenvman.2021.113673

Jia, Z., Evans, R. O., & Smith, J. T. (2006). Effect of controlled drainage and vegetative buffers on drainage water quality from wastewater irrigated fields. *Journal of Irrigation and Drainage Engineering*, *132*(2), 159-170. https://doi.org/10.1061/(asce)0733-9437(2006)132:2(159)

King, L. D. (1982). LAND APPLICATION OF UNTREATED INDUSTRIAL-WASTE WATER. *Journal of Environmental Quality*, *11*(4), 638-644. https://doi.org/10.2134/jeq1982.00472425001100040016x

Kunhikannan, S., Thomas, C. J., Franks, A. E., Mahadevaiah, S., Kumar, S., & Petrovski, S. (2021). Environmental hotspots for antibiotic resistance genes. *Microbiologyopen*, *10*(3), Article e1197. https://doi.org/10.1002/mbo3.1197

Lapworth, D. J., Baran, N., Stuart, M. E., & Ward, R. S. (2012). Emerging organic contaminants in groundwater: A review of sources, fate and occurrence. *Environmental Pollution*, *163*, 287-303. https://doi.org/10.1016/j.envpol.2011.12.034

Lee, J. (2020). Clean Water Act Jurisdiction over Groundwater Discharges after County of Maui v. Hawaii Wildlife Fund. *Fordham L. Rev.*, *89*, 2773.

Li, H. N., Shi, Z. W., & Zhu, C. X. (2014). Trends in Research on Electrochemical Oxidation. *Croatica Chemica Acta*, *87*(2), 185-194. https://doi.org/10.5562/cca2446

Li, Y., Robinson, L. E., Carter, W. M., & Gupta, R. (2015). Childhood obesity and community food environments in Alabama's Black Belt region. *Child Care Health and Development*, *41*(5), 668-676. https://doi.org/10.1111/cch.12204

Liang, X., & Yue, X. (2021). Challenges facing the management of wastewater treatment systems in Chinese rural areas. *Water Science and Technology*, *84*(6), 1518-1526. https://doi.org/10.2166/wst.2021.332

Lichtenstein, B. (2007). Illicit drug use and the social context of HIV/AIDS in Alabama's Black Belt. *Journal of Rural Health*, *23*, 68-72. https://doi.org/10.1111/j.1748-0361.2007.00126.x

Lin, H. S., McInnes, K. J., Wilding, L. P., & Hallmark, C. T. (1998). Macroporosity and initial moisture effects on infiltration rates in vertisols and vertic intergrades. *Soil Science*, *163*(1), 2-8. https://doi.org/10.1097/00010694-199801000-00002

Liu, Y. J., Hu, C. Y., & Lo, S. L. (2019). Direct and indirect electrochemical oxidation of amine-containing pharmaceuticals using graphite electrodes. *Journal of Hazardous Materials*, *366*, 592-605. https://doi.org/10.1016/j.jhazmat.2018.12.037

Luthin, J. N. (1971). *Drainage engineering*.

Ma, J. W., Cui, Y. B., Li, A. M., Zou, X. J., Ma, C. D., & Chen, Z. B. (2022). Antibiotics and antibiotic resistance genes from wastewater treated in constructed wetlands. *Ecological Engineering*, *177*, Article 106548. https://doi.org/10.1016/j.ecoleng.2022.106548

Mann, B., & Rogers, A. (2021). Segregation Now, Segregation Tomorrow, Segregation Forever? Racial and Economic Isolation and Dissimilarity in Rural Black Belt Schools in Alabama*. *Rural Sociology*, *86*(3), 523-558. https://doi.org/10.1111/ruso.12384

Martinez-Huitle, C. A., Hernandez, F., Ferro, S., Alfaro, M. A. Q., & de Battisti, A. (2006). Electrochemical oxidation: An alternative for the wastewater treatment with organic pollutants agents. *Afinidad*, *62*(521), 26-34. <Go to ISI>://WOS:000240721100005

Matosic, M., Crnek, V., Jakopovic, H. K., & Mijatovic, I. (2009). MUNICIPAL WASTEWATER TREATMENT IN A MEMBRANE BIOREACTOR. *Fresenius Environmental Bulletin*, *18*(12), 2275-2281. <Go to ISI>://WOS:000274093100003

Mauck, B., & Winter, K. (2021). Assessing the potential for managed aquifer recharge (MAR) of the Cape Flats Aquifer. *Water Sa*, *47*(4), 505-514. https://doi.org/10.17159/wsa/2021.v47.i4.3801

Mazeikiene, A. (2019). Improving small-scale wastewater treatment plant performance by using a filtering tertiary treatment unit. *Journal of Environmental Management*, *232*, 336-341. https://doi.org/10.1016/j.jenvman.2018.11.076

McCardell, A., Davison, L., & Edwards, A. (2005). The effect of nitrogen loading on on-site system design: a model for determining land application area size. *Water Science and Technology*, *51*(10), 259-266. https://doi.org/10.2166/wst.2005.0374

Michael-Kordatou, I., Michael, C., Duan, X., He, X., Dionysiou, D. D., Mills, M. A., & Fatta-Kassinos, D. (2015). Dissolved effluent organic matter: Characteristics and potential implications in

wastewater treatment and reuse applications. *Water Research*, *77*, 213-248. https://doi.org/10.1016/j.watres.2015.03.011
Miron, A. R., Chivu, A. M. A., Rikabi, A., & Albu, P. C. (2014). Pharmaceutical Industry Wastewater Treatment through Electrocoagulation. *Revista De Chimie*, *65*(12), 1399-1406. <Go to ISI>://WOS:000345946400002
Mitchell, C., & Buehring, N. (2009). Alabama and Mississippi Blackland Prairie Case Studies. In S. Outreach (Ed.), *Conservation Tillage Systems in the Southeast* (pp. 241-250).
Mitchell, C. C. (2008). *Soils of Alabama*.
Monnett, G. T., Reneau, R. B., & Hagedorn, C. (1996). Evaluation of spray irrigation for on-site wastewater treatment and disposal on marginal soils. *Water Environment Research*, *68*(1), 11-18. https://doi.org/10.2175/106143096x127163
Moser, M. (1978). A Method for Preliminary Evaluation of Soil Series Characteristics to Determine the Potential for Land Treatment Processes. Proceedings of Symposium on Land Treatment of Wastewater, Hanover, NH,
Muga, H. E., & Mihelcic, J. R. (2008). Sustainability of wastewater treatment technologies. *Journal of Environmental Management*, *88*(3), 437-447. https://doi.org/10.1016/j.jenvman.2007.03.008
Murphy, O. J., Hitchens, G. D., Kaba, L., & Verostko, C. E. (1992). DIRECT ELECTROCHEMICAL OXIDATION OF ORGANICS FOR WASTE-WATER TREATMENT. *Water Research*, *26*(4), 443-451. https://doi.org/10.1016/0043-1354(92)90044-5
NOAA. (2023). *Local Climatological Data*. https://www.ncei.noaa.gov/cdo-web/datatools/lcd
NRCS. (2023). *Geospatial Gateway*. https://datagateway.nrcs.usda.gov/GDGOrder.aspx
Page, D., Bekele, E., Vanderzalm, J., & Sidhu, J. (2018). Managed Aquifer Recharge (MAR) in Sustainable Urban Water Management. *Water*, *10*(3), Article 239. https://doi.org/10.3390/w10030239
Paranychianakis, N. V., Angelakis, A. N., Leverenz, H., & Tchobanoglous, G. (2006). Treatment of wastewater with slow rate systems: A review of treatment processes and plant functions. *Critical Reviews in Environmental Science and Technology*, *36*(3), 187-259. https://doi.org/10.1080/10643380500542756
Payer, F. S., & Weil, R. R. (1987). PHOSPHORUS RENOVATION OF WASTE-WATER BY OVERLAND-FLOW LAND APPLICATION. *Journal of Environmental Quality*, *16*(4), 391-397. https://doi.org/10.2134/jeq1987.00472425001600040017x
Powers, A. (2023). Federal Water Pollution Control Act. In *Major Acts of Congress*: Encylopedia.com.
Prior, J. W., & Wong, D. W. S. (2022). Exploring different dimensions in defining the Alabama Black Belt. *Geojournal*, *87*(3), 1525-1542. https://doi.org/10.1007/s10708-020-10325-x
Rad, M. R., Araya, A., & Zambreski, Z. T. (2020). Downside risk of aquifer depletion. *Irrigation Science*, *38*(5-6), 577-591. https://doi.org/10.1007/s00271-020-00688-x
Ramachandran, P., Rachuri, N. K., Martha, S., Shakthivel, R., Gundala, A., & Battu, T. S. (2019). Implications of Overprescription of Antibiotics A Cross-Sectional Study. *Journal of Pharmacy and Bioallied Sciences*, *11*, S434-S437. https://doi.org/10.4103/jpbs.JPBS_62_19
Rapanos v. United States, U.S. 1-65 (Supreme Court 2006). https://supreme.justia.com/cases/federal/us/547/04-1034/index.pdf
Drip Dispersal Systems Technology Assessment and Design Guidance, 1-82 (2007).
Rhoades, M. B., Parker, D. B., Sweeten, J. M., Cole, N. A., Brown, M. S., & Asae. (2003, Oct 12-15). Land application of beef feedyard effluent to forage sorghum and winter wheat.*Asae Publication* [Animal, agricultural and food processing wastes ix, proceedings]. 9th International Symposium on Animal, Agricultural and Food Processing Wastes, Raleigh, NC.
Sackett v. Environmental Protection Agency, Supreme Court U.S. 1-82 (Washington D.C. 2023). https://www.supremecourt.gov/opinions/22pdf/21-454_4g15.pdf

Sadler, L. Y. a. D., C. S. (1996). Effects of Organic Liquids on the Permeability of Selma Chalk. *Hazardous Waste and Hazardous Materials*, *13*(3), 351-361. https://doi.org/10.1089/hwm.1996.13.351
Sanspree, M. J., Allison, C., Goldblatt, S. H., & Pevsner, D. (2008). Alabama Black Belt eye care—optometry giving back. *Optometry-Journal of the American Optometric Association*, *79*(12), 724-729.
Sanz, J. M., de Miguel, A., de Bustamante, I., de Tomas, A., & Goy, J. L. (2014). Technical, financial and location criteria for the design of land application system treatment. *Environmental Earth Sciences*, *71*(1), 13-21. https://doi.org/10.1007/s12665-013-2685-4
Shakeel, M., Arshad, M., & Aslam, M. U. (2018). THE RATIONAL USE OF ANTIBIOTICS MEDICINE. *Indo American Journal of Pharmaceutical Sciences*, *5*(10), 10075-10078. https://doi.org/10.5281/zenodo.1463056
Stathatou, P. M., Gad, F. K., Kampragou, E., Grigoropoulou, H., & Assimacopoulos, D. (2015). Treated wastewater reuse potential: mitigating water scarcity problems in the Aegean islands. *Desalination and Water Treatment*, *53*(12), 3272-3282. https://doi.org/10.1080/19443994.2014.934108
Steiner, J. L., Devlin, D. L., Perkins, S., Aguilar, J. P., Golden, B., Santos, E. A., & Unruh, M. (2021). Policy, Technology, and Management Options for Water Conservation in the Ogallala Aquifer in Kansas, USA. *Water*, *13*(23), Article 3406. https://doi.org/10.3390/w13233406
Stoler, J., Jepson, W., Wutich, A., Velasco, C. A., Thomson, P., Staddon, C., & Westerhoff, P. (2022). Modular, adaptive, and decentralised water infrastructure: promises and perils for water justice. *Current Opinion in Environmental Sustainability*, *57*, 101202. https://doi.org/https://doi.org/10.1016/j.cosust.2022.101202
Swistock, B., & Sharpe, W. (2022). Water System Planning: Estimating Water Needs. *Penn State Extension*, 1-4. https://extension.psu.edu/water-system-planning-estimating-water-needs
Teow, Y. H., Ghani, M. S. H., Hamdan, W., Rosnan, N. A., Mazuki, N. I. M., & Ho, K. C. (2017). Application of Membrane Technology towards The Reusability of Lake Water, Mine Water, and Tube Well Water. *Jurnal Kejuruteraan*, *29*(2), 131-137. https://doi.org/10.17576/jkukm-2017-29(2)-09
Thoma, K., Baker, P. A., & Allender, E. B. (1993). DESIGN METHODS FOR THE DEVELOPMENT OF WASTE-WATER LAND DISPOSAL SYSTEMS. *Water Science and Technology*, *27*(1), 77-86. https://doi.org/10.2166/wst.1993.0020
Tripathi, V., & Tripathi, P. (2017). Antibiotic Resistance Genes: An Emerging Environmental Pollutant. In K. K. Kesari (Ed.), *Perspectives in Environmental Toxicology* (pp. 183-201). https://doi.org/10.1007/978-3-319-46248-6_9
Tzanakakis, V. E., Paranychianaki, N. V., & Angelakis, A. N. (2006, Oct 28-30). Soil as a wastewater treatment system: historical development.*Water Science and Technology: Water Supply* [Insights into water management: Lessons from water and wastewater technologies in ancient civilizations]. 1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilization, Iraklio, GREECE.
U.S. (2020). *County of Maui v. Hawaii Wildlife Fund*. Washington D.C. Retrieved from https://www.supremecourt.gov/opinions/19pdf/18-260_jifl.pdf
United-Nations. (2015). *The Human Right to Water and Sanitation*. U.-W. D. P. o. A. a. Communication. https://www.un.org/waterforlifedecade/pdf/human_right_to_water_and_sanitation_milestones.pdf
USDA. (2023). *Web Soil Survey*. United States Department of Agriculture. Retrieved May 1 from https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx
van Voorthuizen, E., Zwijnenburg, A., van der Meer, W., & Temmink, H. (2008). Biological black water treatment combined with membrane separation. *Water Research*, *42*(16), 4334-4340. https://doi.org/10.1016/j.watres.2008.06.012

Voeks, J. H., McClure, L. A., Go, R. C., Prineas, R. J., Cushman, M., Kissela, B. M., & Roseman, J. M. (2008). Regional differences in diabetes as a possible contributor to the geographic disparity in stroke mortality: the REasons for Geographic And Racial Differences in Stroke Study. *Stroke*, *39*(6), 1675-1680.

Wanner, J. (2021). The development in biological wastewater treatment over the last 50 years. *Water Science and Technology*, *84*(2), 274-283. https://doi.org/10.2166/wst.2021.095

Waqas, S., Bilad, M. R., Man, Z. B., Klaysom, C., Jaafar, J., & Khan, A. L. (2020). An integrated rotating biological contactor and membrane separation process for domestic wastewater treatment. *Alexandria Engineering Journal*, *59*(6), 4257-4265. https://doi.org/10.1016/j.aej.2020.07.029

Wax, C. L., & Pote, J. W. (1996). Influence of climate on design of systems for land application of wastewater. *Climate Research*, *6*(1), 71-78. https://doi.org/10.3354/cr006071

Webster, G. R., & Bowman, J. (2008). Quantitatively Delineating the Black Belt Geographic Region. *Southeastern Geographer*, *48*(1), 3-18. https://doi.org/10.1353/sgo.0.0007

Wedgworth, J. C., & Brown, J. (2013). Limited Access to Safe Drinking Water and Sanitation in Alabama's Black Belt: A Cross-Sectional Case Study. *Water Quality Exposure and Health*, *5*(2), 69-74. https://doi.org/10.1007/s12403-013-0088-0

Wenten, I. G., Friatnasary, D. L., Khoiruddin, K., Setiadi, T., & Boopathy, R. (2020). Extractive membrane bioreactor (EMBR): Recent advances and applications. *Bioresource Technology*, *297*, Article 122424. https://doi.org/10.1016/j.biortech.2019.122424

Westphalen, A. P. C., Corcao, G., & Benetti, A. D. (2016). Use of biological activated carbon for drinking water treatment. *Engenharia Sanitaria E Ambiental*, *21*(3), 425-436. https://doi.org/10.1590/s1413-41522016143108

WHO/UNICEF. (2021). *Progress on household drinking water, sanitation and hygiene 2000 - 2020* (SDG 6 Monitoring, SDG 6 Progress Reports, Issue. https://www.unwater.org/publications/who/unicef-joint-monitoring-program-water-supply-sanitation-and-hygiene-jmp-progress-0#:~:text=Only%2081%20per%20cent%20of,facilities%2C%20leaving%201.9%20billion%20without.

Woody, T. W., Rubin, A. R., & Frederick, D. (1997, Jan 16-17). Surface irrigation design considerations to facilitate system performance, operation, and maintenance at one effluent reuse system in North Carolina. [Site characterization and design of on-site septic systems]. Symposium on the Site Characterization and Design of On-Site Septic Systems, New Orleans, La.

Wu, Y. X., Du, H. X., Li, F. S., Su, H. N., Bhat, S. A., Hudori, H., Rosadi, M. Y., Arsyad, F., Lu, Y. Q., & Wu, H. F. (2020). Effect of Adding Drinking Water Treatment Sludge on Excess Activated Sludge Digestion Process. *Sustainability*, *12*(17), Article 6953. https://doi.org/10.3390/su12176953

Yadav, K. K., Gupta, N., Kumar, V., Khan, S. A., & Kumar, A. (2018). A review of emerging adsorbents and current demand for defluoridation of water: Bright future in water sustainability. *Environment International*, *111*, 80-108. https://doi.org/10.1016/j.envint.2017.11.014

Yeganeh, A., Nabi-Bidhendi, G., Rashedi, H., & Hosseinzadeh, M. (2020). Development of Membrane Bioreactor to Membrane Electro-bioreactor for Advanced Treatment of Wastewater. *Pollution*, *6*(1), 197-210. https://doi.org/10.22059/poll.2019.281006.622

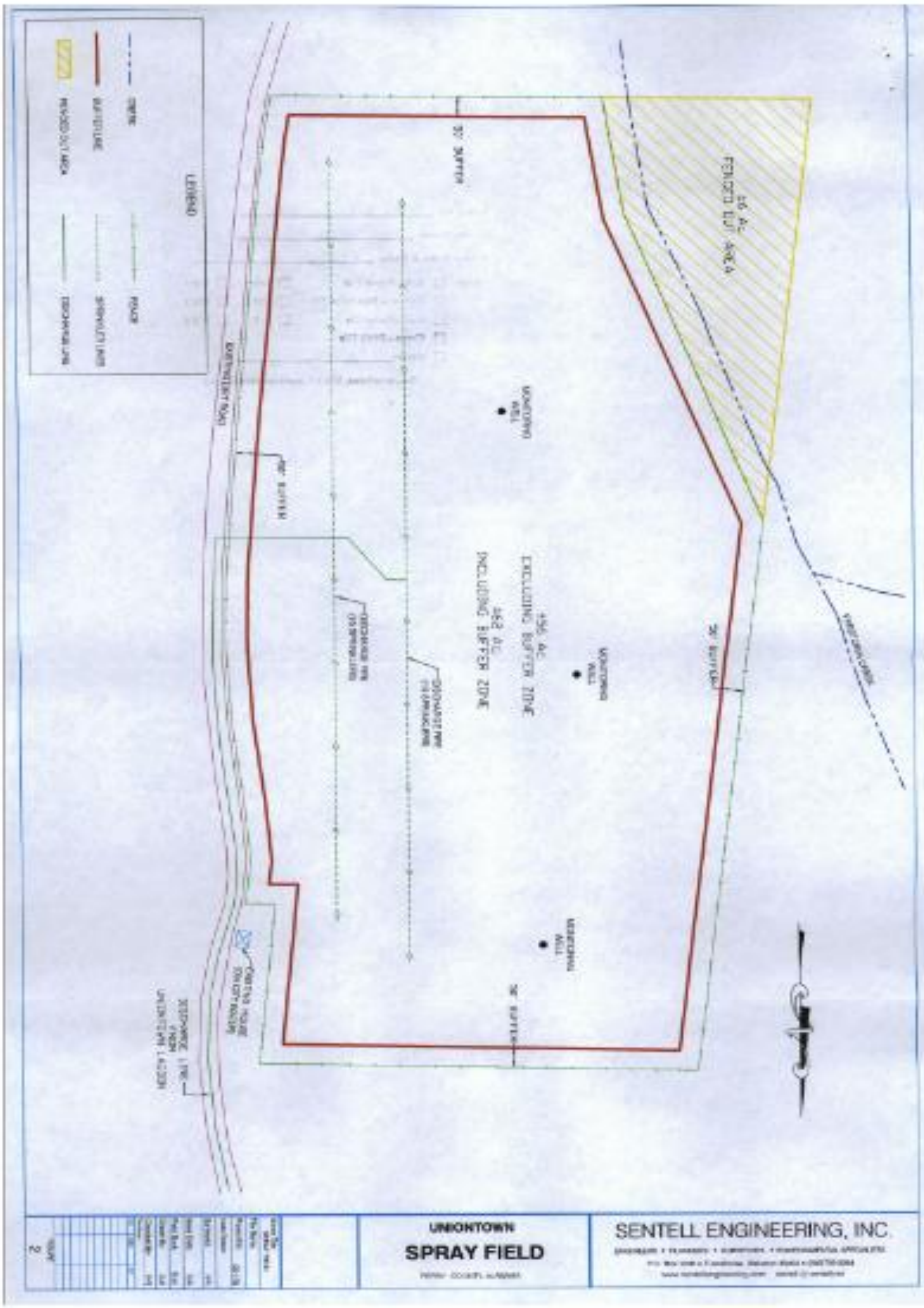
Young, C. E., & Epp, D. J. (1980). Land treatment of municipal wastewater in small communities. *American Journal of Agricultural Economics*, *62*(2), 238-243.

Zekri, S., Ahmed, M., Chaieb, R., & Ghaffour, N. (2014). Managed aquifer recharge using quaternary-treated wastewater: an economic perspective. *International Journal of Water Resources Development*, *30*(2), 246-261. https://doi.org/10.1080/07900627.2013.837370

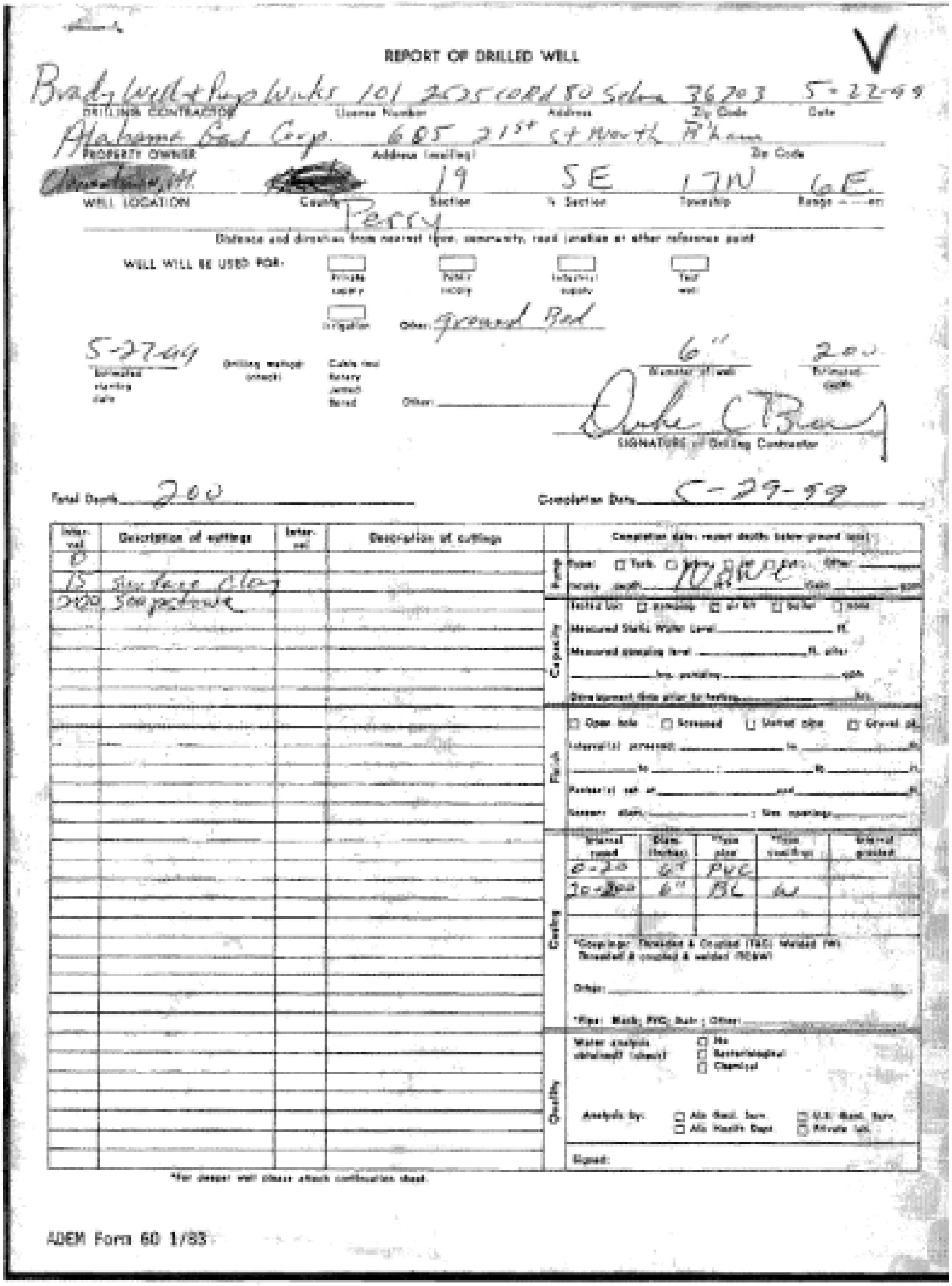
Zhang, C. Y., Yu, Z. S., & Wang, X. Y. (2022). A review of electrochemical oxidation technology for advanced treatment of medical wastewater. *Frontiers in Chemistry*, *10*, Article 1002038. https://doi.org/10.3389/fchem.2022.1002038

Zhang, S. Y., Hopkins, I., Guo, L., & Lin, H. (2019). Dynamics of Infiltration Rate and Field-Saturated Soil Hydraulic Conductivity in a Wastewater-Irrigated Cropland. *Water*, *11*(8), Article 1632. https://doi.org/10.3390/w11081632

Appendix



Appendix A: Original Design of Uniontown Spray Field



REPORT OF DRILLED WELL

Brady Well & Pump Works 101 2025 Ward 80 Selma 36703 5-22-59
DRILLING CONTRACTOR — License Number — Address — Zip Code — Date

Alabama Gas Corp. 605 21st St North B'ham
PROPERTY OWNER — Address (mailing) — Zip Code

WELL LOCATION — County: Perry — Section: 19 — ¼ Section: SE — Township: 17N — Range: 6E

Distance and direction from nearest town, community, road junction or other reference point

WELL WILL BE USED FOR: Private supply / Public supply / Industrial supply / Test well / Irrigation / Other: Ground Bed

Estimated starting date: 5-27-59 — Drilling method (check): Cable tool / Rotary / Jetted / Bored — Other:

Diameter of well: 6" — Estimated depth: 200

SIGNATURE of Drilling Contractor

Total Depth: 200 — Completion Date: 5-29-59

Interval	Description of cuttings	Interval	Description of cuttings
0			
15	Surface clay		
200	Soapstone		

Completion data: record depths below ground level

Pump — Type: Turb. / Jet / Sub. / Other — Intake depth — gpm: NONE

Capacity — Tested by: pumping / air lift / bailer / none — Measured Static Water Level — ft. — Measured pumping level — ft. after — hrs. pumping — gpm — Development time prior to testing — hrs.

Finish — Open hole / Screened / Slotted pipe / Gravel pk — Interval(s) screened: to — ft. — Packer(s) set at — and — ft. — Screen: diam. — ; Size openings

Interval cased	Diam. (inches)	*Type pipe	*Type couplings	Interval grouted
0-20	6"	PVC		
20-200	6"	BL	W	

Casing — *Couplings: Threaded & Coupled (T&C); Welded (W); Threaded & coupled & welded (TC&W) — Other: — *Pipe: Black; PVC; Galv.; Other:

Quality — Water analysis obtained? (check): No / Bacteriological / Chemical — Analysis by: Ala. Geol. Surv. / Ala. Health Dept. / U.S. Geol. Surv. / Private lab.

Signed:

*For deeper well please attach continuation sheet.

ADEM Form 60 1/83

Appendix B: Soil Boring Data Log

REPORT OF DRILLED WELL

Allen & Willis	#453	Jemison	36738	4-2-01
DRILLING CONTRACTOR	License Number	Address	Zip Code	Date

Mary F. Jones
PROPERTY OWNER — Address (mailing) — Zip Code

Perry		17		T17N	R6E
WELL LOCATION	County	Section	¼ Section	Township	Range

½ mi S of Uniontown
Distance and direction from nearest town, community, road junction or other reference point

WELL WILL BE USED FOR: [X] Private supply [ ] Public supply [ ] Industrial supply [ ] Test well [ ] Irrigation Other: ______

Estimated starting date ______ Drilling method (check): Cable tool, (Rotary), Jetted, Bored Other: ______

5" Diameter of well — 800 Estimated depth

Thomas B. Willis
SIGNATURE of Drilling Contractor

Total Depth 740 — Completion Date 4/30/01

Interval	Description of cuttings	Interval	Description of cuttings
0-7	Top Clay		
-595	Selma chalk		
-740	Sand + Clay layered		

Completion data: report depths below ground level

Pump: Type: [ ] Turb. [X] Subm. [ ] Jet [ ] Cent. Other: ______ Intake depth 220 H.P. 3/4 Yield 10 gpm

Capacity: Tested by: [ ] pumping [ ] air lift [ ] bailer [ ] none. Measured Static Water Level 175 ft. Measured pumping level ______ ft. after ______ hrs. pumping ______ gpm. Development time prior to testing ______ hrs.

Finish: [ ] Open hole [X] Screened [ ] Slotted pipe [ ] Gravel pk. Interval(s) screened: 680 to 740 ft. ______ to ______; ______ to ______ ft. Packer(s) set at ______ and ______ ft. Screen: diam. ______; Size openings ______

Casing:

Interval cased	Diam. (inches)	*Type pipe	*Type couplings	Interval grouted
0-20	5"	PVC		

*Couplings: Threaded & Coupled (T&C) Welded (W) Threaded & coupled & welded (TC&W)
Other: ______
*Pipe: Black; PVC; Galv.; Other: ______

Quality: Water analysis obtained? (check) [ ] No [ ] Bacteriological [ ] Chemical
Analysis by: [ ] Ala. Geol. Surv. [ ] Ala. Health Dept. [ ] U.S. Geol. Surv. [ ] Private Lab.
Signed: ______

*For deeper well please attach continuation sheet.

ADEM FORM 63 12/89

Appendix C: Soil Boring Data Log

Sentell Engineering Inc.

"Turning Ideas Into Reality Since 1957"

Engineers
Planners
Surveyors
Environmental Specialists

August 8, 2013

Ms. Sandra Lee
ADEM Municipal Section
1400 Coliseum Blvd.
Montgomery, Alabama 36110

Dear Ms. Lee:

Re: City of Uniontown
New Sprayfield

As requested, I made a site visit for the purpose of performing 4 soil borings at a depth of 6" over the entire spray field site in Uniontown, AL. The list below shows my results.

If you have any questions, please call us at (205) 752-5564.

Sincerely,

SENTELL ENGINEERING, INC.

Christopher G. Sentell, P.L.S.

East Spray Field:

#1 East — Lat - 32-25'21.5" Long - 87-31"11.5"
0"-3" 2.5Y 4/2 Dark Grayish Brown Silty Clay
3"-6" 2.5Y 4/4 Olive Brown Silty Clay

#2 East — Lat - 32-25'10.1" Long - 87-31"11.1"
0"-3" 2.5Y 4/2 Dark Grayish Brown Silty Clay
3"-6" 2.5Y 4/4 Olive Brown Silty Clay

West Spray Field:

#1 West — Lat - 32-25'19.6" Long - 87-31"21.2"
0"-3" 2.5Y 4/4 Olive Brown Silty Clay
3"-6" 2.5Y 3/3 Dark Olive Brown Silty Clay

#2 West — Lat - 32-25'17.8" Long - 87-31'22.1"
0"-3" 2.5Y 2/3 Dark Grayish Brown Silty Clay
3"-6" 2.5Y 3/3 Dark Olive Brown Silty Clay

P.O. BOX 1238 · 639 BLACK BEARS WAY · TUSCALOOSA, ALABAMA 35403 · 205.752.5564 · FAX 205.752.5569
www.sentell.net

Appendix D: Soil Boring Data Log

Waste Load Allocation Summary

Page 2

Annual Effluent Limits

Qw		MGD
CBOD5		
NH3-N		
TKN		
D.O.		

Conventional Parameters

Qw	1	MGD	Qw	1	MGD
Season	Summer		Season	Winter	
From	May		From	Dec	
Through	Nov		Through	Apr	
CBOD5	6		CBOD5	9	
NH3-N	1		NH3-N	3	
TKN			TKN		
D.O.	7		D.O.	7	

Other Parameters

Qw		MGD	Qw		MGD
Season			Season		
From			From		
Through			Through		
TP			TP		
TN			TN		
TSS			TSS		

"Monitor Only" Parameters for Effluent:

Parameter	Frequency	Parameter	Frequency
TP	Monthly		
TKN	Monthly		
NO2+NO3-N	Monthly		

Water Quality Characteristics Immediately Upstream of Discharge

Parameter	Summer		Winter	
CBODu	2	mg/l	2	mg/l
NH3-N	0.11	mg/l	0.11	mg/l
Temperature	30	°C	20	°C
pH	7	su	7	su

Hydrology at Discharge Location

Drainage Area Qualifier: Exact

			Method Used to Calculate
Drainage Area	4.26	sq mi	
Stream 7Q10	0	cfs	ADEM Estimate w/USGS Gage Data
Stream 1Q10	0	cfs	75%of 7Q10
Stream 7Q2	0	cfs	ADEM Estimate w/USGS Gage Data
Annual Average	5.11	cfs	ADEM Estimate w/USGS Gage Data

Comments and/or Notations: This WLA is for a proposed discharge to Freetown Creek.

Appendix E: Waste Load Allocation Summary for Freetown Creek