The Role of Centralized Wastewater Treatment in the Rural Alabama Black Belt

by

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

Auburn, Alabama
May 6, 2023

Keywords: Wastewater, Centralized,
Treatment, Alabama Black Belt

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Abstract

Centralized and decentralized wastewater treatment systems play a major role in protecting human health and U.S. waters from contamination. However, failing wastewater treatment in the rural Alabama Black Belt has become a prominent issue. In the Black Belt, the status and role of decentralized systems have become well documented. However, there is a lack of research about centralized systems in the Black Belt. Due to the scarcity of research and available literature, this thesis encapsulates the role and status of centralized treatment systems in the rural Black Belt, which excludes Montgomery County since the majority (~87%) of the population is from a metropolitan area.

Overall, centralized treatment plays an important role since approximately half (~51%) of the rural Black Belt is served by centralized systems. Additionally, the recent performance of centralized treatment in the Black Belt was evaluated by using 2020 and 2021 quarterly noncompliance violations from the U.S. EPA ECHO (Enforcement and Compliance History Online) database. The performance of small community centralized systems was significantly ($p < 0.05$) worse in the Black Belt than centralized systems that served the remainder of Alabama. Using a multivariable regression model, the percent of service population in poverty and the type of treatment facility (aerated lagoons, stabilization ponds, or mechanical treatment plants) were determined to be the most significant predictor variables that influenced the recent performance of small community centralized systems in the Black Belt. The other technical variables of treatment facilities (e.g., age of system, flow, annual design flow, method of discharge, service population,

size of system, bypasses, and sanitary overflows) and nontechnical characteristics of municipal sewered areas (e.g., median household income, percent black, percent white, percent eighteen years or older, percent sixty-five years or older, percent households below $15,000, percent no high school, percent bachelor's degree or higher, and other socio-demographic variables) had no significant effect on the performance of these systems in the model.

Acknowledgments

The author would like to recognize his advisor, Dr. Mark Barnett, for the incredible support and guidance that was received. Without his advising, the author would never be able to excel in the graduate school at Auburn University. Additional gratitude is expressed to the author's co-advisor, Dr. Stephanie Rogers, for the inspiring instruction and support. In addition, the author wants to thank committee member, Dr. Joel Hayworth, and other Auburn faculty in the Civil and Environmental Engineering Department for their knowledge and time during the author's graduate career. The author would like to thank his colleague, Carey Clark, for his advice and support. Finally, the author express's gratitude for his friends and family that supported him throughout his graduate studies at Auburn University. This research was funded by the U.S. Department of Agriculture's (USDA) Technical Assistance and Training for Innovative Regional Wastewater Treatment Solutions Grant Pilot Program.

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Chapter One.

Introduction

1.1 Problem Statement

Wastewater treatment is one of the most essential types of infrastructure for a functioning and prosperous community. It is estimated that over 75% of the United States (U.S.) population is connected to a centralized sewer system (U.S. EPA, 2004a; ASCE, 2017). Typically, centralized wastewater treatment is provided by a municipality, a “publicly owned treatment works” (POTW) (Bipartisan Policy Center, 2017; U.S. EPA, 2004b). The purpose of centralized wastewater treatment is to remove pollutants from municipal wastewater and provide clean effluent that is discharged to a receiving body of water or groundwater via land application site (U.S. EPA, 2004a). Within a centralized sewer system, municipal (e.g., city or town) wastewater is collected from all households, businesses, and industries inside the municipality’s service area. The collected wastewater is then processed at a central wastewater treatment facility (WWTF). Once the wastewater is processed at the treatment facility, the treated effluent is discharged at a designated outfall. Typically, centralized wastewater treatment facilities include at least one of the following processes: so-called mechanical treatment (e.g., activated sludge or fixed-films systems), aerated lagoons, or stabilization ponds. All three types of processes incorporate different combinations of physical, chemical, and biological mechanisms to treat wastewater.

When centralized treatment is not available, an alternative is decentralized wastewater treatment. Decentralized systems include isolated onsite systems that serve the individual owner or cluster systems that serve two or more households (U.S. EPA, 2003). Decentralized systems are most often onsite wastewater treatment systems (e.g., septic systems). Onsite systems are more common in smaller communities that are less densely populated since these systems are a more cost-effective option in comparison to centralized treatment facilities (U.S. EPA, 1997), which are capital intensive and require continuous monitoring.

An area of the U.S. that has garnered significant attention due to its inadequate wastewater infrastructure is the Alabama Black Belt, which had the 5th highest usage rate for onsite systems in 1990 and still relies on onsite systems today (He et al., 2011). Historically, the residents within the Alabama Black belt have been characterized by elevated rates of unemployment, lower median household incomes, prevalent poverty, and difficulties maintaining adequate infrastructure and health services (Wimberly and Morris, 2002). However, in the early 1800s, this region was one of the wealthiest areas in the U.S. due its rich "Blackland Prairie" soil and enslaved African American population that supported cotton plantations throughout the Black Belt (University of Alabama Center for Economic Development; Tullos, 2004). Due to the legacy of plantation culture and racial repression from Jim Crow laws, the Black Belt has been stuck in a state of economic depression since the early 1900s (University of Alabama Center for Economic Development; Tullos, 2004). The term "Black Belt" originated from the region's native "Blackland Prairie" soils. The Alabama Black Belt region (Figure 1.1) spans central Alabama from Sumter County to Russell County.

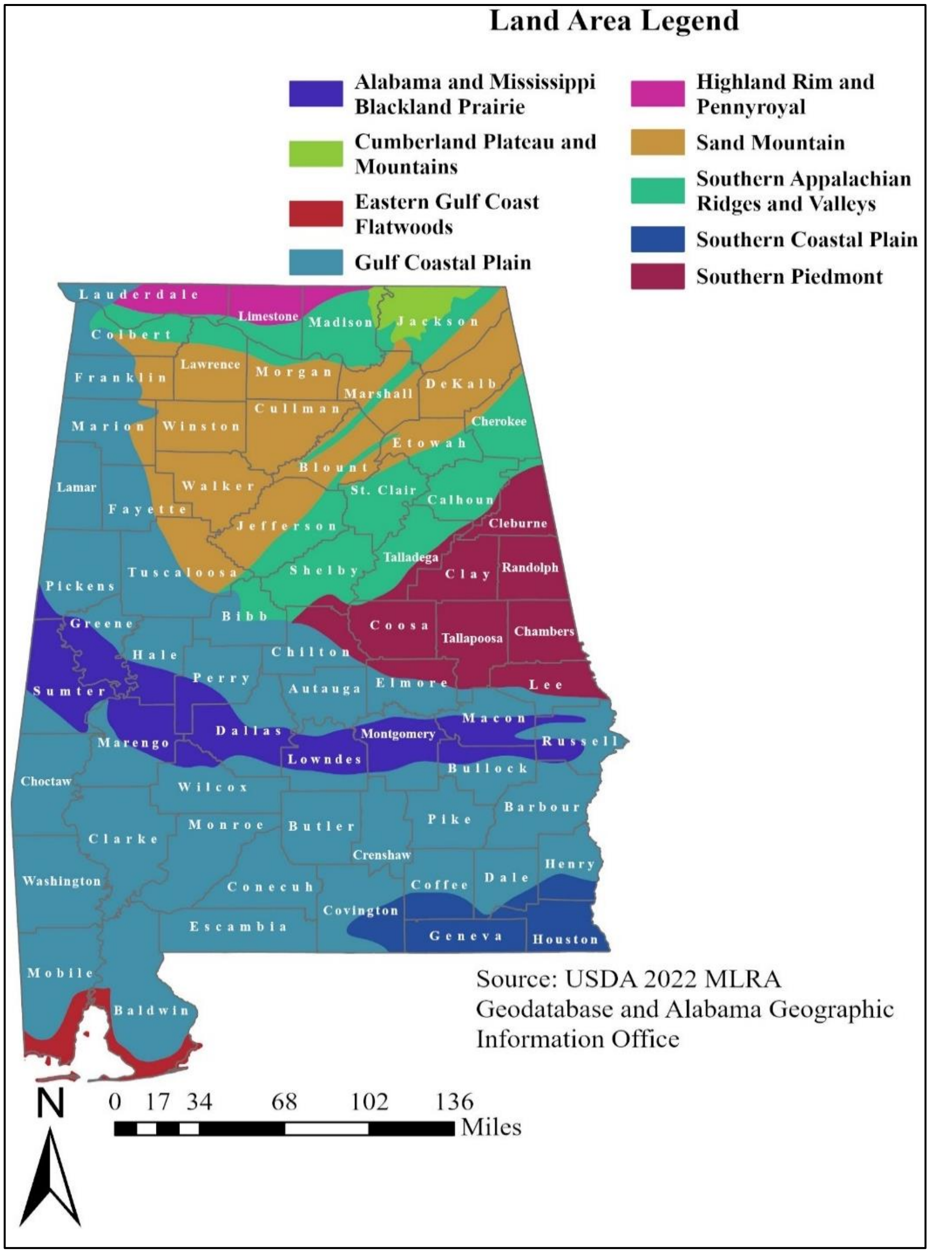

Figure 1.1 Major Land Resource Areas of Alabama. Adapted from U.S. Department of Agriculture.

Although the Black Belt has favorable agricultural properties, septic systems frequently fail due to impermeable soils high in clay content (He et al., 2011; Maxcy-Brown et al., 2021; U.S. EPA, 2021; Winkler et al., 2017). Some residents within the Black Belt have resorted to directly discharging untreated wastewater from a household to a surface trench or vegetated area, referred to as “straight piping”, since onsite systems are susceptible to failure and are not affordable (Maxcy-Brown et al., 2021). There are numerous concerns with straight piping since it can directly impact human health and the environment due to presence of raw sewage on the open ground. Untreated wastewater contains human pathogens, including viruses, bacteria *(e.g., Escherichia coli (E. coli))*, worms, and contaminants such as nutrients (e.g., nitrogen and phosphorus) that can ecologically impact surface waters. The concerns regarding straight piping and septic systems in the Black Belt have been widely reported, and research is being conducted to find innovative methods to assist residents that own decentralized systems in Black Belt (Maxcy-Brown et al., 2021; U.S. EPA, 2021).

Despite the attention that decentralized systems have received, there are also significant concerns with centralized treatment systems in the Black Belt. For example, a chronically “failing” WWTF in Uniontown, AL has been mentioned in national media and national environmental organizations (Environmental Policy Innovation Center, 2022). The Uniontown WWTF consists of a system of aerated lagoons (Figure 1.2) and a land application site where treated effluent is applied (Figure 1.3), which is commonly referred to as a so-called “sprayfield” (Schwetschenau et al., 2022).

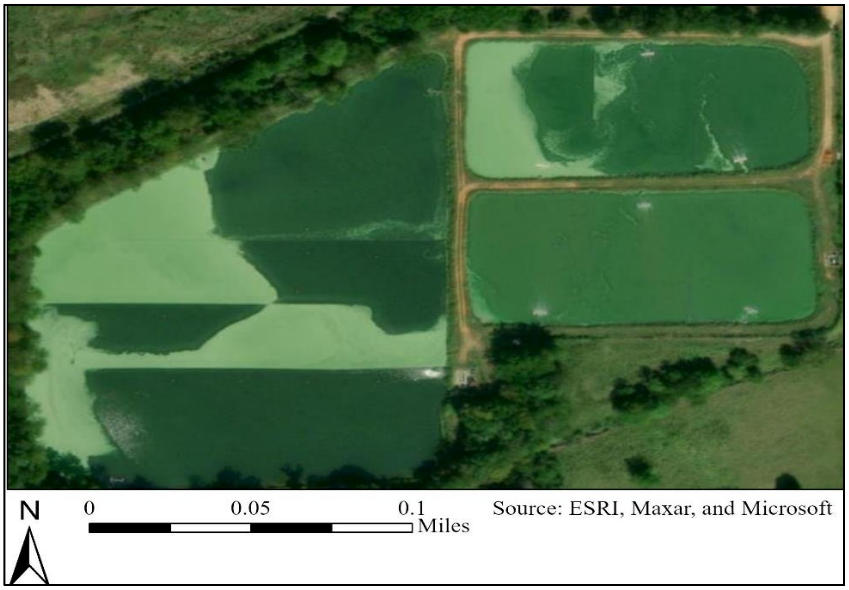

Figure 1.2 Uniontown Lagoon System

Figure 1.3 Uniontown Land Application Site “Sprayfield”

Currently, the treatment system is failing and cannot provide adequate treatment for residential and commercial clients, which includes a catfish farm and cheese manufacturing facility (Sobol, 2019). The facility has exceeded the flow capacity and effluent limits for the five-day biochemical oxygen demand (BOD_5) and *E. coli* (Sentell Engineering, 2018). Additionally, Uniontown and other Black Belt municipal areas (Figure 1.4) (e.g. Akron, Cuba, Demopolis, Hayneville, Linden, Livingston, Marion, and York) with centralized treatment facilities have been subject to regulatory/legal enforcement actions due to performance issues prior to 2008 (ADEM, 2008; ADEM, 2011a; ADEM, 2011b; ADEM, 2012a; ADEM, 2012b, ADEM, 2013; ADEM, 2016 ADEM, 2018a; ADEM, 2018b).

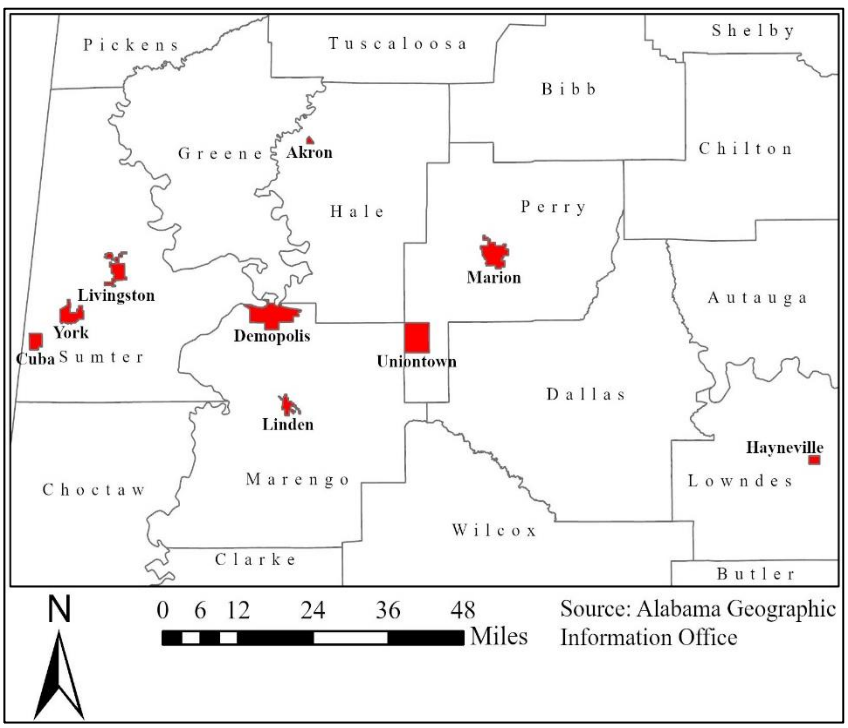

Figure 1.4 Black Belt Municipal Areas with Legal Enforcement Action

Unlike decentralized systems, which are regulated by the health department, centralized treatment systems are regulated at the federal level by the 1972 Clean Water Act (CWA) National Pollutant Discharge Elimination System (NPDES). The NPDES program was established by the

U.S. EPA to regulate performance (i.e., regulate effluent limits and standards) of public, private, and industrial wastewater treatment facilities. The regulations from the NPDES program are implemented to prevent performance violations, referred to as noncompliance violations, that could negatively impact bodies of water within the U.S. Although the CWA sets minimum federal standards, they are typically enforced by authorized tribal, territorial, and state government agencies. In Alabama, the CWA/NPDES primacy agency is the Alabama Department of Environmental Management (ADEM). The NPDES program requires dischargers, referred to as permittees, to report on a quarterly basis their compliance status.

Typically, noncompliance refers to the following types of general violations: effluent limitations, schedule, and reporting. The effluent limitations include monthly average, weekly average, daily maximum, and daily minimum effluent limitations of specific pollutants (e.g., suspended solid and BOD_5). Schedule violations represent failure to give an account of scheduled milestones, such as following guidelines to prevent ongoing pollution, by 90 or more days. Noncompliance also occurs when a discharger fails to submit required documentation or reports within 30 days. If there are repetitive trends for similar noncompliance violations or effluent limits are severely exceeded, noncompliance violations can be elevated to “significant noncompliance” violations since they pose serious risks to health and the environment (U.S. EPA, 2010a). If not properly addressed, noncompliance violations can lead to further action such as litigation and fines (U.S. EPA, 2010b). Every municipality is required to minimize noncompliance violations, and when they do occur, identify, and address their causes.

Meeting stringent permit standards is a challenge for centralized treatment systems in the U.S. (Drinan et al., 2012), particularly small community systems (10,000 or fewer people) (U.S. EPA, 1999; Jones et al., 2001; U.S. EPA, 2016; U.S. EPA, 2022a). Performance issues at small community centralized treatment systems can result from numerous underlying causes such as accepting industrial wastewater and septage, poor maintenance and design of the facility, financial limitations, inability to have hire and retain operators, and lack of managerial training (Moran, 2017; U.S. EPA, 2022b; U.S. EPA 2022c; U.S. EPA, 2022d). Similarly, some of the small community Black Belt facilities, such as the one in Uniontown, AL, are incapable of achieving compliance due to resource scarcity and operational problems. Additionally, Schwetschenau (2022) claims that the demographic profile and wastewater treatment issues of Uniontown are representative of wastewater issues across the Black Belt region. However, it is unclear whether factors, such as non-technical characteristics of municipal sewered area (e.g., median household income, percent black, percent white, percent eighteen years or older, percent sixty-five years or older, percent households below $15,000, percent no high school, percent bachelor's degree or higher, and other socio-demographic variables) and technical characteristics of treatment facilities (age of system, flow, annual design flow, method of discharge, type of treatment, population, size of system, bypasses, and sanitary overflows), significantly contribute to poor performance of centralized systems throughout the Black Belt region.

Although the failures of decentralized treatment systems in the Black Belt have garnered significant attention, the sewered population and performance of centralized treatment have not been widely discussed or studied. Therefore, research must be conducted to understand the severity of performance and the population served by centralized treatment systems. The overall centralized sewer population can be used to determine if these systems serve a minor or major portion of the Black Belt population. While the performance can be analyzed by using noncompliance violations to determine how centralized facilities perform in the Black Belt relative to other small communities throughout Alabama. Further investigation should also be conducted to better understand how centralized wastewater treatment systems perform in the Black Belt relative to state and national performance standards. In addition, non-technical characteristics and technical characteristics that effect the performance of centralized systems in the Black Belt need to be identified since it can ensure municipalities provide adequate sanitation and minimize the possibility of a "failing" treatment system.

1.2 Objectives

The key objectives of this thesis are 1) to determine the importance of centralized treatment systems in the Black Belt by using the population of the sewer service areas, 2) determine whether centralized systems for small communities in the Black Belt perform better or worse than those in similar small communities throughout the state of Alabama, and 3) determine whether factors, such as non-technical characteristics of centralized sewer areas or technical characteristics of wastewater treatment facilities, explain performance by using noncompliance violations.

1.3 Organization

This report is organized to meet the criteria for a publication-style thesis, which is outlined in the Guide to Preparation and of Theses and Dissertations by the Auburn University Graduate School. This thesis includes a total of four chapters: 1) introduction, 2) literature review, 3) evaluation of centralized wastewater treatment in the Black Belt with methodology, results, and discussion, and 4) conclusions and recommendations. The introduction, chapter one, identifies the significant problems and main objectives of the study. A detailed literature review of background information is presented in chapter two. Chapter three includes the methodology, results, and discussion from evaluating the role of centralized wastewater treatment systems. This chapter is formatted as a draft manuscript to be submitted for publication in a peer-reviewed journal. The conclusions and recommendations for future work are outlined in chapter four. Additional supporting information is found in the appendices.

Chapter Two.

Literature Review

2.1 Small Community Wastewater Systems

Based on the U.S. EPA, a small community has a population of 10,000 or fewer (U.S. EPA, 1999; U.S. EPA 2016; U.S. EPA, 2022a). Within a small community, there are two types of systems that treat wastewater: centralized and decentralized. Centralized treatment systems collect municipal (e.g., city or town) wastewater from multiple households, businesses, and industries within a public sewer and treat the wastewater at a central facility (U.S. EPA, 2004a, U.S. EPA, 2004b). After the wastewater has been treated, the effluent is discharged to surface water or groundwater via land application. The alternative to centralized treatment is decentralized treatment systems. Decentralized treatment includes isolated onsite systems (e.g., septic systems) that treat wastewater from individual households or cluster systems that treat wastewater from multiple households or unincorporated communities (Crites and Tchobanoglous, 1998; U.S. EPA, 2003, U.S. EPA, 2012). Both types of treatment systems are important since these systems protect the environment and public health in a small community. However, small communities have limited economic resources and limited experience to manage wastewater systems (Nelson and Dow, 1994 in Crites and Tchobanoglous, 1998; Thompson et al., 2020). Therefore, it is important for small communities to be knowledgeable about wastewater treatment systems.

2.2 Centralized Wastewater Systems

Centralized wastewater systems serve a significant majority (~ ≥75%) of the U.S population (ASCE, 2017; U.S. EPA, 2004a). These systems can vary in design due to cost, raw wastewater characteristics, system reliability, location limitations, and reliability (Davis, 2019). These systems can vary based on the type of sewer, treatment technology, and method of discharge. Centralized systems can either have combined sewers or separate sewers. Combined sewers collect both sewage and stormwater. This type of sewer system is less common in the U.S. (i.e., combined sewer systems serve about 40 million people in the U.S.) since stormwater causes overwhelmingly overflows, which can harm human health (Burian et. al, 2000; Tibbetts, 2005). Due to the issues with combined sewers, separate sewer systems are more common for modern sewer systems since only municipal sewage is collected. Once the wastewater has been collected in a combined or separate sewer, the wastewater is treated at a centralized facility.

A centralized treatment facility treats wastewater using chemical, physical, and biological mechanisms. However, the mechanisms that treat wastewater can be incorporated differently because of the various types of facilities. The general type of facilities includes mechanical treatment and wastewater treatment ponds (Thompson et al., 2022). Mechanical treatment plants have a series of tanks, basins, or clarifiers with other mechanical treatment technologies (e.g., tanks, basins, clarifiers, pumps, blowers, screens, or grinders) to treat wastewater (ADEM Water Division, 2020; Moussavi et al., 2021). Additionally, a mechanical treatment plant includes one or more of the following treatment processes listed below in Table 2.1.

Table 2.1: Mechanical Treatment Processes. Adapted from Davis (2019) and Barry (2012).

Type of Process	Description
Activated Sludge	Wastewater is treated in an aerated tank and later the sludge is separated from the effluent. Some of the sludge is returned to increase the bacteria in the treatment system and the rest is disposed.
Contact Stabilization	Modified activated sludge process that reaerates the returned sludge before adding it to the initial treatment tank.
Extended Aeration	Modified activated sludge process where wastewater is treated longer (e.g., 24 hours or longer) in an aerated tank.
MBR	Modified activated sludge process where the membrane filter separates and filters the sludge rather using additional settling tanks.
Oxidation Ditch	Modified activated sludge process that uses an oval basin instead of rectangular tank.
RBC	Wastewater is treated by a rotating shaft that has several large plastic media discs. During rotation, the film of bacteria on the disks treats the wastewater.
SBR	Modified activated sludge process that uses a singular batch reactor to fill, aerate, settle, and remove most of wastewater instead using a series of tanks similarly as in conventional activated sludge treatment.
Trickling Filters	Wastewater is sprayed into a fixed bed of media (e.g., rocks or plastic material), where the film of bacteria on the media treats the wastewater.
Vertical Loop Reactor	A variation of an oxidation ditch that circulates wastewater in a vertical plane rather than a horizontal plane.

Note: The mechanical treatment processes in Table 2.1 were based on the different types of technologies listed for mechanical treatment plants from the ADEM water division (2020).
Abbreviations: MBR- Membrane Bioreactor, SBR- Sequencing Batch Reactor, and RBC- Rotating Biological Contactors

Typically, mechanical treatment plants have a high cost and require more skilled operators (Muga et al., 2008; Thompson, 2020). Thus, wastewater ponds (i.e., oxidation ponds) are a more affordable option. Oxidation ponds refer to open earthen basins that use natural processes to treat wastewater. The term “pond” and “lagoon” are similar terms (Crites and Tchobanoglous, 1998; Davis, 2019). However, as indicated in table 2.2 adapted from Caldwell et. al (1973) in Davis (2019), “lagoons” will reference aerated ponds and “ponds” will reference non-aerated ponds.

Table 2.2: Wastewater Ponds. Adapted from Caldwell et al. (1973) in Davis (2019).

Type of Process	Description
Aerated Lagoon	Treats wastewater in an earthen basin that uses mechanical or diffused aerators to provide oxygen, which allows bacteria to degrade organics aerobically.
Aerobic Pond	Treats wastewater in a shallow basin (one between two feet) that promote algae growth and increased oxygen, which allows bacteria to degrade organics aerobically
Anaerobic Pond	Treats wastewater in a deep basin (greater than 8 feet) to remove dissolved oxygen and allow bacteria to degrade organics anaerobically
Facultative Pond	Treats wastewater from bacteria in the upper aerobic layer, lower anaerobic layer, and facultative middle layer, which has a total depth between three to eight feet. The aerobic layer provides oxidation, the anaerobic layer allows sludge to settle, and the facultative middle layer is combination of both anaerobic and aerobic conditions.
Polishing Pond	After the effluent has been treated by other biological processes, the pond is used to provide additional dissolved oxygen and surface reaeration

Additionally, ponds and lagoons can have a continuous (i.e., frequent discharges) or controlled discharge (i.e., periodic discharges at specified times) (Crites and Tchobanoglous, 1998). A hydrograph controlled release (HCR) pond or lagoon is a variation of controlled discharge, which discharges during acceptable stream flow conditions (Crites and Tchobanoglous, 1998). In comparison to continuously discharging facilities, HCR ponds or lagoons are beneficial for low-flow streams that may be more impacted from discharges.

The most common type of pond is a facultative pond (Davis, 2019), which is mostly referred to as a stabilization pond (Crites and Tchobanoglous, 1998). However, aerated lagoons are useful when a stabilization pond is not able to provide enough oxygen for proper wastewater treatment. In comparison to using a singular pond or lagoon, a combination of ponds or lagoons can be used to treat wastewater since it can be more energy efficient and provide better effluent quality (Butler et al., 2017; Crites and Tchobanoglous, 1998). Depending on the size and the number of ponds and lagoons, these types of facilities generally require a large area. However, ponds and lagoons require relatively minimal maintenance to operate and minimal funding (Crites and Tchobanoglous, 1998;

Gloyna, 1971 in Thompson et al., 2022). Thus, ponds and lagoons are located primarily in smaller communities.

Once the wastewater has been treated at a centralized facility, the effluent is either discharged to surface water or a land application site. Surface water discharges includes any discharge that enters any surface water source located in the U.S (U.S. EPA, 2010a). Alternatively, land application discharges generally use spray irrigation to dispose of wastewater onto land surface, which is commonly referred to as a “sprayfield” (Schreffler et al., 2005; U.S. EPA, 2006). The wastewater on the “sprayfield” either percolates through the soil and is recharged to groundwater or evaporates into the air. In some cases, land application sites have been shown to be a more effective method of wastewater disposal since the landscape can filter nitrogen in comparison to surface water (Schreffler et al., 2005). Due to land application sites requiring large amounts of land space, centralized facilities commonly discharge to surface water within more urbanized communities.

Centralized systems are preferred in urbanized communities since it promotes pollution control and is an affordable option for larger densely populated communities (Burian et. al, 2000). However, some small communities are served by centralized systems. In comparison to centralized systems in large communities, small community centralized systems are more likely to have poor performance due to inadequate funding and expertise to maintain these systems (Jones et al., 2001). A poor performing centralized system can negatively impact human health and the environment. Thus, the performance of centralized facilities is monitored and regulated by the U.S. EPA National Pollutant Discharge Elimination System (NPDES) program (Code of Federal Regulations, 2021).

2.2.1 Performance Monitoring of Centralized Treatment Facilities

The NPDES program was established by the U.S. EPA to regulate any discharger that could potentially release pollutants to U.S. waters (U.S. EPA, 2004a, U.S. EPA, 2010a). The NPDES program uses compliance monitoring to enforce effluent limits and standards, which indicates proper performance of a treatment facility (Schaeffer et. al, 1988). If the effluent limits or standards are violated, the facility is noncompliant. Noncompliance violations are reported on a quarterly (three month) basis, and each quarter can have one or more of the following general violations in table 2.3.

Table 2.3: NPDES General Violations. Adapted from U.S. EPA (2010a).

Type of Violation	Description
Effluent Limitations	Exceeding treated wastewater monthly, weekly, and daily parameters, which includes conventional[1], unconventional[2], and toxic pollutants[3]. Additionally, includes any other effluent violation that can impact water quality or health.
Schedule	Failure to achieve or give an account of scheduled compliance milestones by 90 days or more (e.g., failure to make corrective actions that could prevent ongoing pollution)
Reporting	Failure to submit compliance schedule[4] progress report or discharge monitoring report[5] by 30 days or more (e.g., failure to submit any effluent parameters or failure to report updates about corrective actions that can fix previous and ongoing pollution)

[1]Conventional pollutants include five day biochemical oxygen demand (BOD_5), total suspended solids (TSS), fecal coliform (e.g., *E. coli*), pH, oil and grease
[2]Uncoventional pollutants include nutrients (e.g., nitrogen and phosphorus)
[3]Toxic pollutants include metals (e.g., iron) and manmade organics (e.g., Per- and polyfluoroalkyl (PFAS))
[4]Compliance schedules allow dischargers to achieve compliance within 90 days.
[5]Discharge monitoring reports (DMR) include the monthly weekly, and daily parameters effluent parameters.

Additionally, a facility can be noncompliant without a general violation occurring. This type of noncompliance occurrence is a single event violation, which includes unauthorized sampling, unpermitted discharges, or failure to renew NPDES permit (U.S. EPA, 2008). If there are repetitive trends for similar noncompliance violations or effluent limits are severely exceeded, noncompliance violations can be elevated to “significant noncompliance” since these violations pose high risks to human health and the environment (U.S. EPA, 2010a). However, “significant noncompliance” is a discretionary definition (U.S. EPA, 2010a). As the NPDES program prioritizes the latest noncompliance issues, the definition of “significant noncompliance” constantly changes. (U.S. EPA, 2010a). “Significant noncompliance” is supposed to be indicator for legal enforcement (U.S. EPA, 2010a). However, a discharger with any type of noncompliance violation can lead to enforcement action (Konisky et al., 2010). The types of enforcement action include informal enforcement (i.e., notice of violation) and formal enforcement action (i.e., judicial litigation with potential fines) (U.S. EPA, 2010b). Thus, centralized facilities should fix performance issues immediately to avoid any legal consequences.

In 1999, over ninety percent of all NPDES noncompliance violations came from small community sewer systems (Jones et al., 2001). Considering many of these small community sewer systems discharge to low flow streams (Jones et al., 2001), the local environmental impacts might be disproportionally high. Currently, the noncompliance status for small community centralized sewer systems has not been well documented. However, recently the U.S. EPA has issued a compliance advisory for small public and private wastewater treatment facilities (i.e., facilities that serves a population of 10,000 or fewer and have a flowrate of less than 1 million gallons per day) since these facilities contributed to 60% of all “significant noncompliance” violations, which includes facilities that served some small communities (U.S. EPA, 2022b; U.S. EPA, 2022c). Thus, noncompliance violations for small communities are an on-going issue.

Performance issues for small community centralized treatment systems can result from numerous underlying causes such as accepting industrial wastewater and septage, poor maintenance and design of the facility, financial limitations, inability to have hire and retain operators, and lack of managerial training (Moran, 2017; U.S. EPA, 2022b; U.S. EPA 2022c; U.S.

EPA, 2022d). However, identifying the root cause of performance issues can be difficult (AWWA, 2017, U.S. EPA, 2017). Due to complexity of performance issues and cost with centralized systems, decentralized systems can be a better option for some small communities.

2.3 The Alabama Black Belt

The Alabama Black Belt is a region that is geographically defined to have rich "Blackland Prairie" soil, which is used to grow corn, cotton, soybeans, and small grains (Mitchell et al., 2020). The term "Black Belt" originated from the region's native "Blackland Prairie" soils, which is shown in Figure 2.1.

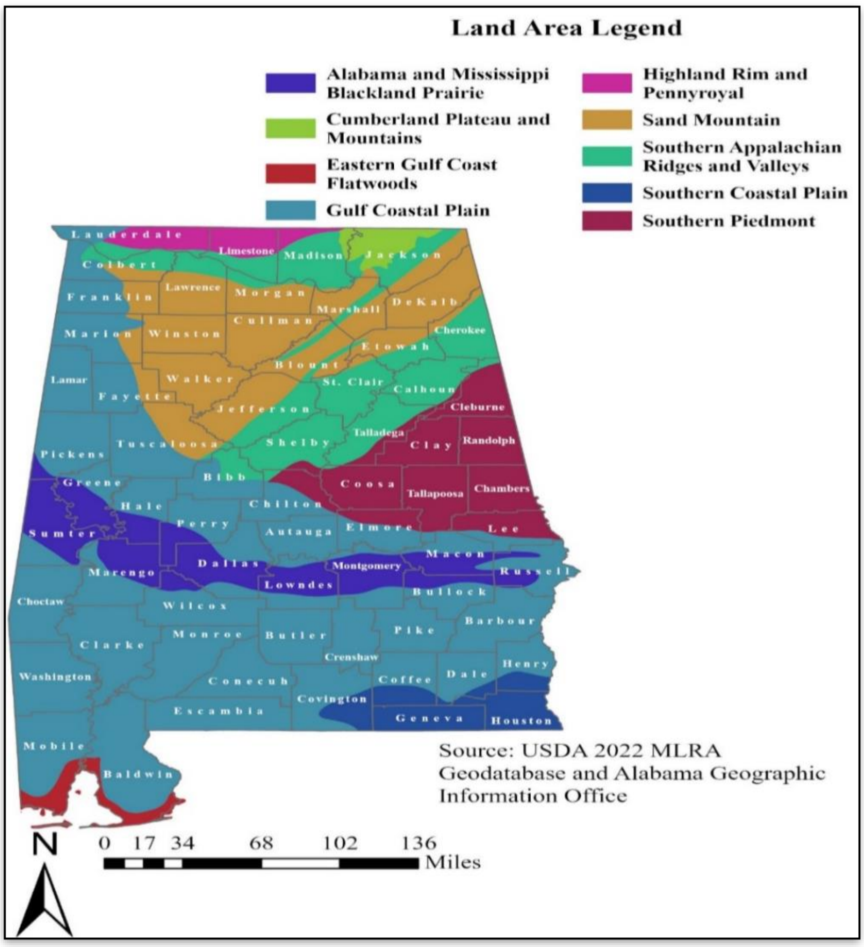

Figure 2.1 Major Land Resource Areas of Alabama. Adapted from U.S. Department of Agriculture.

Historically, the residents within the Alabama Black belt have been characterized by elevated rates of unemployment, lower median household incomes, prevalent poverty, and difficulties maintaining adequate infrastructure and health services (Wimberly and Morris, 2002). In addition, the Alabama Black Belt has been known to have inadequate centralized and decentralized wastewater systems (Schwetschenau, 2022; Winkler et al., 2017).

Regarding decentralized systems, the Black Belt had the 5th highest usage rate of onsite systems and still relies on these systems currently (He et al., 2011). However, onsite systems (e.g., septic systems) frequently fail due to the Black Belt soil (i.e., Blackland Prairie soil), which is high in clay content, becoming impermeable when wet (He et al., 2011, Izenberg et al., 2013; Maxcy-Brown et al., 2021). In addition, poor maintenance is another cause of failing onsite systems in the Black Belt (Cook Wedgworth et al., 2013). Poor maintenance of onsite systems is likely exacerbated by rural poverty. Due to the unfavorable geological conditions, poor maintenance, and unsewered areas, some residents have resorted to discharging untreated wastewater from their household to the surface, which is generally referred to as “straight piping”. In comparisons to onsite systems that are regulated by the Alabama Department of Public Health (ADPH), “straight piping” is unregulated and can directly impact the environment. Due to the issue of “straight piping” and failing septic systems, there has been ongoing research to find alternative technologies (e.g., mound systems and sand filters) for onsite treatment (U.S. EPA, 2021). One alternative strategy is to use subsurface drip irrigation (SDI) rather than a drainfield to dispose of wastewater from a septic system (He et al., 2013; He et al., 2021). Due to recent publicity, the role and status of decentralized wastewater systems in the Black Belt has been well documented.

In comparison to decentralized sewer systems, the role and status of centralized sewer systems in the Black Belt is less known. The Alabama Department of Environmental Management

(ADEM) enforces the NPDES compliance monitoring program for all centralized systems in the Black Belt. However, accessing the information regarding the performance and sewered populations of these systems in not easy to obtain. In 1990, 18% of Lowndes County was connected to public sewers (Winkler et al., 2017). However, this study only focused on Lowndes County and not the entire Black Belt. In 2021, the University of South Alabama conducted a study for the Delta Regional Authority (DRA) that included the population that was served by a wastewater provider in the Black Belt (DRA, 2021). However, this study does not identify which populations are served by only centralized treatment system. Additionally, the population estimates might be inaccurate since some of these facilities were not in operation (e.g., Mosses in Lowndes County) or the population was not listed (e.g., Uniontown in Perry County). Thus, there is need to determine the current population that is served by centralized systems in the Black Belt.

Regarding the performance of centralized systems in the Black Belt, nothing has been documented in peer-reviewed literature except for the Uniontown treatment facility (Sobol, 2019; Schwetschenau, 2022). The city of Uniontown is in Perry County, has a predominantly African American population (~90%) with low income (~$17,000 median per capita annual income) (Schwetschenau, 2022). The treatment facility for Uniontown consists of a lagoon treatment system that disposes of wastewater by land application (e.g,. sprayfield). However, the system is failing due to the lagoons and the sprayfield overflowing (Sobol, 2019, Schwetschenau, 2022). The lagoons overflow due to infiltration and inflow from stormwater entering the sewer system. Due to excessive peak flows, the high clay content swells underneath the sprayfield, which causes the field to overflow. When accessing the ADEMs e-file database, additional information is provided from Sentell Engineering that the facility has performance issues with treating BOD_5 and *E. coli* (Sentell Engineering, 2018).

Prior to 2008, ADEM has additional documentation that indicates Uniontown and other Black Belt facilities have been subjected to legal enforcement actions due to performance issues, including Akron, Cuba, Demopolis, Linden Livingston, Hayneville, Marion, and York (ADEM, 2008; ADEM, 2011a; ADEM, 2011b, ADEM, 2012a; ADEM, 2012b; ADEM, 2013; ADEM, 2016 ADEM, 2018a; ADEM, 2018b). The magnitude and cause of these performance issues are not known, but Schwetschenau (2022) states that the demographic profile and wastewater treatment issues of Uniontown are representative of wastewater issues across the Black Belt region. Due to the previous performance issues of Uniontown and other Black Belt municipalities, the recent performance of these small community centralized facilities needs to be analyzed. In addition, the role of technical characteristics of treatment facilities (e.g., age of system, annual flow, flow design capacity, type of treatment, method of discharge, population, size of system, bypass, and sanitary overflows) and non-technical characteristics of municipal sewered areas (e.g., median household income, percent black, percent white, percent eighteen years or older, percent sixty-five years or older, percent households below $15,000, percent no high school, percent bachelor's degree or higher, and other socio-demographic variables) of these systems is unclear.

Chapter Three.

The Role of Centralized Wastewater Treatment in the Rural Alabama Black Belt

This chapter is written as a draft manuscript. It will be submitted later for publication in a peer- reviewed scientific journal.

3.1 Introduction

In the Black Belt, the role and status of decentralized wastewater systems has been researched and is well documented (He et al., 2011, Cook Wedgworth et al., 2013; Izenberg et al., 2013; Winkler et al., 2017; Maxcy-Brown et al., 2021). However, there is a lack of research and information concerning the role of centralized wastewater systems in the region. Centralized systems play an important role in treating domestic wastewater across the U.S. Additionally, the performance of these systems is vital to ensure local tributaries are not being polluted and to protect the environment. Thus, the following objectives in this study are to 1) to determine the importance of centralized treatment systems in the Black Belt by using the population of the sewer service areas, 2) determine whether centralized systems for small communities in the Black Belt perform better or worse than those in similar small communities throughout the state of Alabama, and 3) determine whether factors, such as non-technical characteristics of centralized sewer areas or technical characteristics of wastewater treatment facilities, explain performance by using noncompliance violations.

3.2 Materials and Methods

The conceptual framework (Figure 3.1) was developed to obtain results for the objectives of this study.

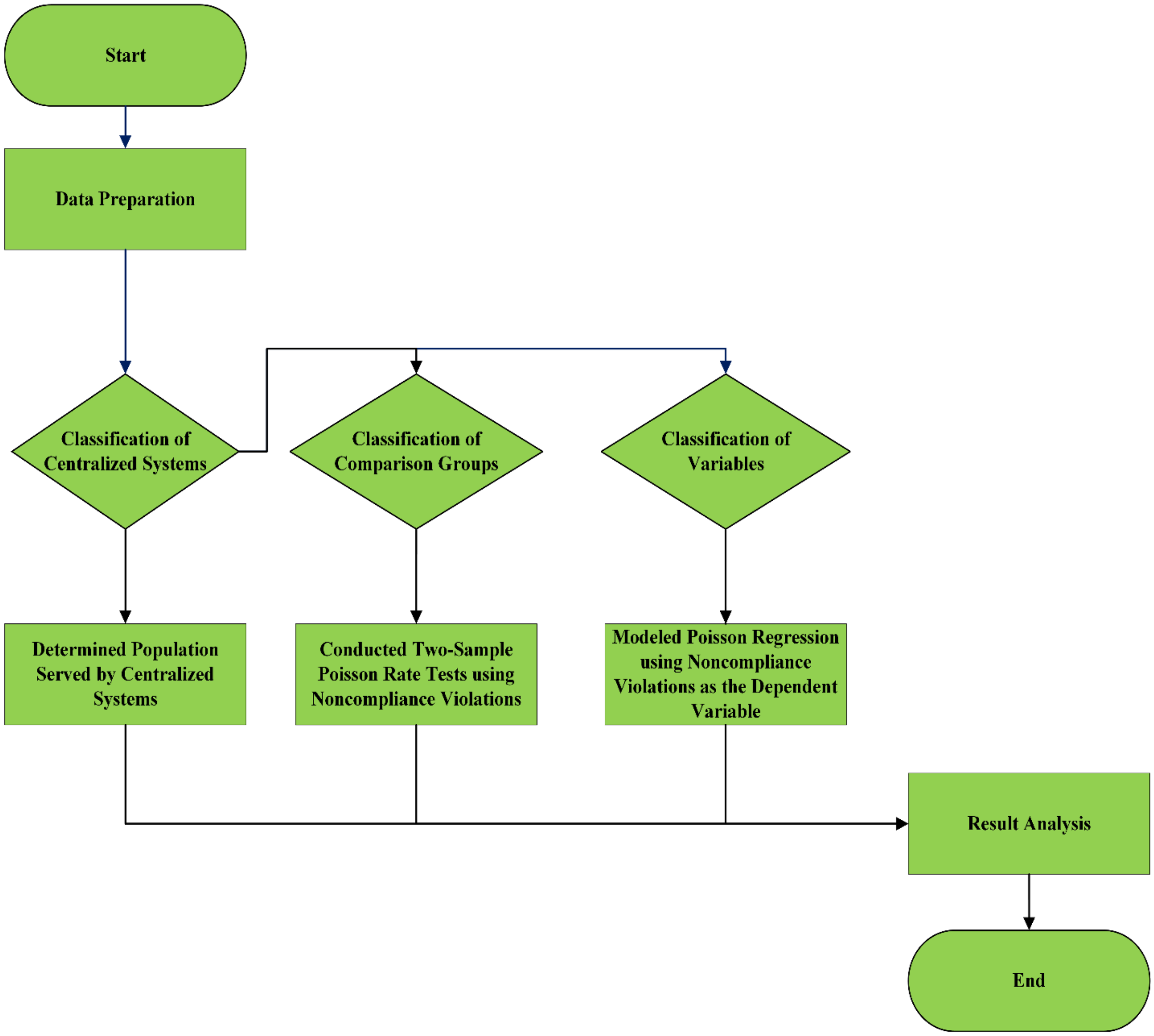

Figure 3.1: Conceptual Framework of the Materials and Methods

Based on the conceptual framework, data preparation was used to classify the centralized sewer systems for the Black Belt study area, control area, and baseline area for the remainder of Alabama. Further classification of the comparisons groups was needed to assess the performance of centralized treatment in small Black Belt communities. In addition, the independent and dependent variables were classified prior to conducting a regression analysis to determine the factors that affect the performance of centralized treatment in small Black Belt communities.

Afterwards, the population that was served by centralized treatment systems in the Black Belt was determined. Using noncompliance violations to indicate performance of centralized systems, the performance of centralized facilities in the Black Belt was compared to the control area and baseline area using a two-sample Poisson rate test. Additionally, a Poisson regression analysis was performed to determine whether factors, (e.g., nontechnical characteristics of municipal sewered areas or technical characteristics of wastewater treatment facilities) effect the performance of these systems.

3.2.1 Data Preparation

For this research, 12 counties have been included in our definition of the Alabama Black Belt since each County had Blackland Prairie soil. However, Montgomery County was removed since most (~87.4%) of the county's population lives in the city of Montgomery which is a major metropolitan area and does not fit the criteria of small Black Belt communities for this study. Thus, the Black Belt study area included 11 counties in this study. The control area was defined to include all 18 Alabama Counties that were south of the Alabama Black Belt. The counties for the control area were selected since these counties are nearby the Black Belt. In Figure 3.1, the counties for Black Belt and control area in Alabama are shown.

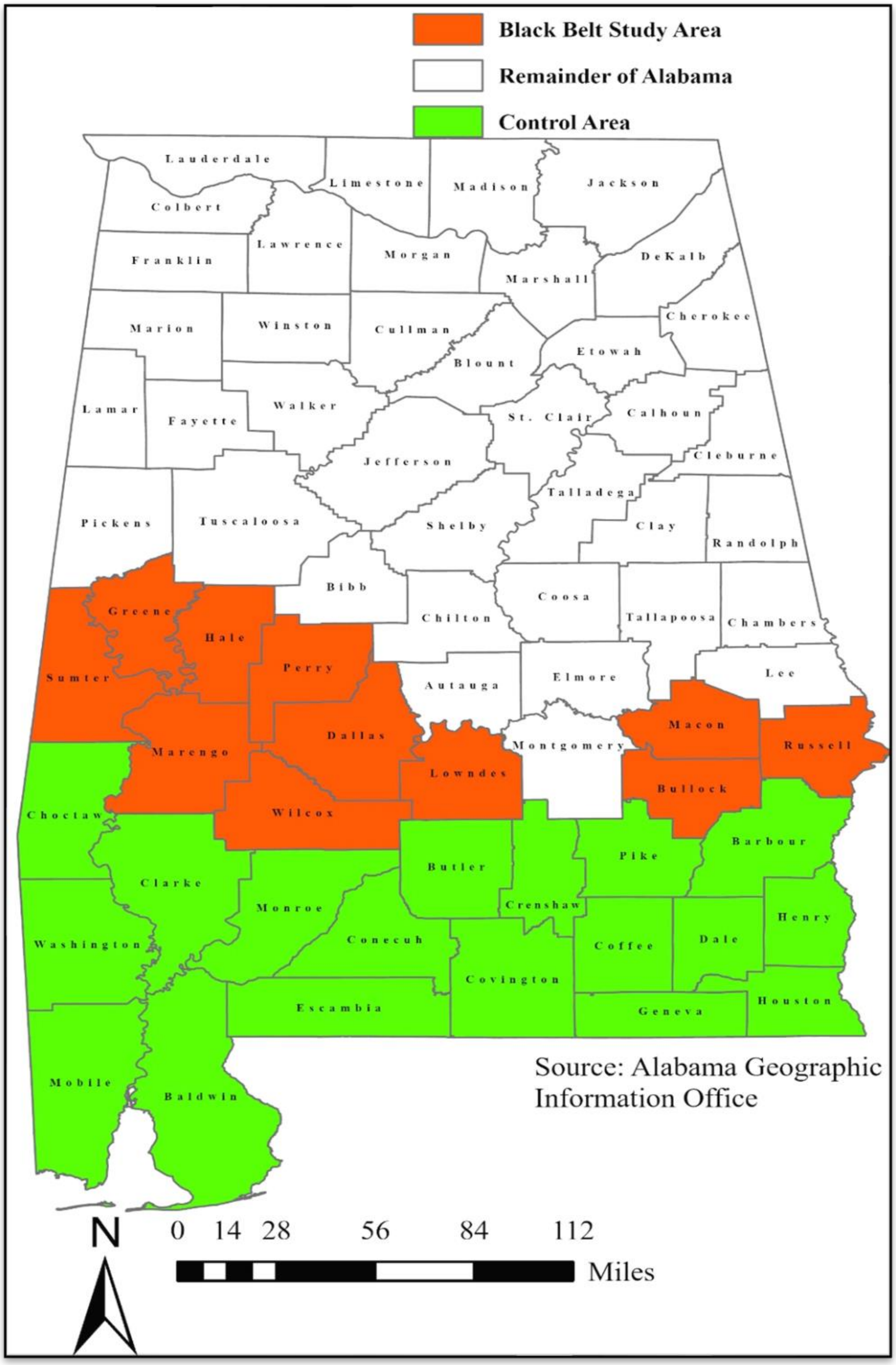

Figure 3.2: Black Belt Study Area and Control Area Counties

Additionally, a baseline area with 56 counties was defined in this study to include every Alabama County except the 11 counties within the Black Belt study area. The purpose of the baseline was to include small and large communities to determine the performance of all centralized treatment systems outside of the Black Belt study area. After defining the Black Belt study area, control area, and the baseline for the State of Alabama, the following sources in Table 1 were used to identify and collect data about the different centralized sewer systems.

Table 3.1: Sources for Data Collection

Source	**Purpose for Data Collection**	**Data Manipulation**
U.S. EPA ECHO[1]	• Identify and collected 2020 and 2021 noncompliance history for public wastewater treatment facilities (i.e., POTW) in the State of Alabama	Using the detailed facility reports, the noncompliance data for each POTW was collected and sorted in Excel for the respective comparison groups in Alabama
ADEM efile[2]	• Reviewed NPDES permit to collect the sewer service area and population, which indicates whether a centralized system is small or large • Reviewed MWPP reports to determine the technical characteristics[4] of the treatment facility	Collected the data from the permits and reports respective to each facility and recorded the data in Excel
U.S. Census[3]	• Collected the total county population estimate for July 1st, 2021, which was used to assess the percentage of the Black Belt served by centralized sewer systems • Collected the 2021 ACS five-year estimates values for municipal areas (i.e., incorporated place), which was used to assess the nontechnical characteristics of Black Belt sewer service areas	Collected tabulated data and used the data respectively for different Black Belt counties or municipal areas

Note: All facilities that did not serve a municipal area (i.e., incorporated place) or did not have a MWWP report were removed since these facilities these do not fit the study criteria of centralized treatment facility.
Abbreviations: ACS- American Community Survey, ADEM- Alabama Department of Environmental Management, U.S. EPA ECHO- United States Environmental Protection Agency Environmental Compliance and History Online, NPDES- National Pollutant Discharge Elimination System, POTW- publicly owned treatment works and MWPP- Municipal Wastewater Prevention Plan

[1]Link: https://echo.epa.gov/facilities/facility-search

[2]Link: http://app.adem.alabama.gov/efile/

[3]Link: https://www.census.gov/data.html

[4]Techincal Characteristics includes type of treatment process (e.g., mechanical treatment plant, stabilization pond, or aerated lagoon), annual flow, age of system, bypasses/sanitary overflows, and method of discharge.

The centralized facilities in the Black Belt, control area, and the baseline of Alabama were categorized as small or large to represent the size of the treatment facilities. The sewer service area, population, and the annual design capacity from the National Pollutant Permit Discharge Elimination Systems (NPDES) permits were used to categorize each facility. According to the United States Environmental Protection Agency (U.S. EPA), a small wastewater treatment system serves a community with 10,000 people or fewer and has annual design flow of less than one million gallons per day (U.S. EPA, 2022d). A large wastewater system serves a population of more than 10,000 or has annual design flow of one million or more gallons per day. Only municipal systems that served an incorporated place (e.g., city, town, or village) and had a Municipal Pollution Prevention (MWPP) report were considered for this study since these facilities fit the study criteria of a centralized treatment facility (i.e., a facility that treats wastewater from multiple households, businesses, or industries within a municipal sewer system). Without the MWPP Report, the type of treatment facility (e.g., mechanical treatment plant, stabilization pond, or aerated lagoon), annual average flow, age of system, method of discharge (e.g., surface water or land application) bypasses/sanitary overflows, and other technical characteristics could not be determined. Additionally, all facilities that had nonactive discharges in 2020 and 2021 were removed from the study.

3.2.2 Determining the Black Belt Population Served by Centralized Systems

In this section of the study, it was determined there were 18 small, centralized wastewater systems and six large, centralized wastewater systems that served incorporated places (i.e., municipal areas) in 2020 and 2021. Using the respective population for each municipal sewer area, the total population served by centralized systems in each Black Belt County was determined. After total population was obtained, the 2021 United States (U.S.) Census population estimates for each Black Belt County was used to calculate the percentage of population that was served by centralized systems.

3.2.3 Comparison of Black Belt Noncompliance Occurrences in 2020 and 2021

In this section of the study, the Black Belt and the control area only included centralized sewer systems that were managed by a municipality that served only small communities (i.e., sewer systems that served a community with 10,000 or fewer). However, the baseline included centralized systems that served communities of all sizes (i.e., communities with both small (10,000 or fewer) and large (more than 10,000) populations). If two or more facilities served the same small community sewer area, they were not included since the extent (e.g., subdivision, school, correctional facility, industrial park, or incorporated place) of the municipal area that was served by each system could not be determined. However, the centralized treatment facilities that had the same sewer service areas for large communities (e.g., urbanized cities) were not removed since these systems are more complex and require more than one facility to serve a more densely populated municipal area. Both small and large municipal treatment facilities were used to calculate the rate of all noncompliance occurrences during 2020 and 2021. It was determined there were 19 facilities that served small communities in the Black Belt and 45 facilities that served small communities in the control area. The baseline included 215 facilities that served both small and large communities.

Once all facilities in the Black Belt and control area were identified, the performance of the wastewater systems was indicated by NPDES (i.e., noncompliance) violations. The U.S. EPA Environmental Compliance and History Online (ECHO) database was used to collect all noncompliance violation occurrences (i.e., all violations, which is not limited to only major violations, were collected) for the Black Belt and the control area. Considering ECHO shows noncompliance violations for the previous 3 years (12 quarters), the noncompliance data from 2019 and 2022 was disregarded due to the data being incomplete. However, the noncompliance violations for the two most recent years 2020 and 2021 (8 quarters) were used.

In addition to determining the average occurrence rate of noncompliance for small and large treatment facilities in the Black Belt, control area, and baseline area, the average percent of quarterly violations for both small and large treatment facilities using an aerated lagoon, mechanical treatment plant, or stabilization pond were determined for all facilities. Within the Black Belt, the average quarterly percent of noncompliance violations were calculated to determine if there was difference in violations based on the type of treatment facility.

The rate of occurrence for violations in the Black Belt, control area, and the baseline of Alabama followed a Poisson distribution since the occurrence rate of violations used a count measure, which was indicated as an integer based on each quarterly violation (Illowsky and Dean, 2023). The statistical testing that was conducted used a two sample-Poisson rate test based on the exact method (Przyborowski and Wilenski, 1939). The null hypothesis of the two-sample Poisson rate test based on the exact method is that the rate of quarterly violations between two populations are not different, and the null hypothesis can only be rejected if the probability value (p-value) is less than a 0.1%, 1%, 5%, and 10% significance level. Using the Poisson rate test and the different datasets for the violation occurrences, it was determined if there was any statistically significant difference of violations in comparison to control area or the baseline of Alabama.

3.2.4 Regression Analysis of Violations, Nontechnical Characteristics, and Technical Characteristics of Black Belt Facilities

Using the nineteen Black Belt facilities that were categorized as small and large municipal systems in section 3.2.2, the following dependent (e.g., quarterly noncompliance violations) and independent variables (e.g., nontechnical characteristics of the municipal sewered areas and technical characteristics of the treatment facilities) were identified, which are shown in the Tables 3.2, 3.3, and 3.4.

Table 3.2: Dependent Variable

Variable Name	Variable Description
2020 and 2021 Noncompliance(1)	All noncompliance violations for 2020 and 2021

[1]Source: U.S. EPA ECHO Database

Table 3.3: Nontechnical Characteristic Variables of Municipal Sewered Areas

Variable Name and Source	Variable Description
MHI(1)	Median household income
Percent Asian(2)	Percent of population that is Asian
Percent 17 Years or Under(2)	Percent of Population 17 years and younger
Percent 18 Years or Older(2)	Percent of Population 18 years and older
Percent 65 Years or Older(2)	Percent of Population 65 years and older
Percent American Indian(2)	Percent of population that is American Indian and Alaska Native
Percent Associate Degree(3)	Percent of population 25 years and over whose highest education completed is an associate degree
Percent Bachelor's Degree or Higher(3)	Percent of population 25 years and over whose highest education completed is a bachelor's degree or higher
Percent Below Poverty4 (1)	Percent of all people below the poverty level
Percent Black(2)	Percent of population that is black or African American
Percent of Hawaiian Islander(2)	Percent of population that is native Hawaiian and other pacific islander
Percent Hispanic or Latino(2)	Percent of population that is Hispanic or Latino in 2020
Percent Highschool or General Education Diploma(3)	Percent of population 25 years and over whose highest education completed is high school or GED
Percent Highschool with No Diploma(3)	Percent of population 25 years and over whose highest education 9th through 12th grade with no diploma
Percent No Highschool(3)	Percent of population 25 years and over whose highest education less than 9th grader
Percent Households below $15,000(1)	Percent of Household below a $15,000 income
Percent Households between $15,000 and $75,000(1)	Percent of Households between a $15,000 and $75,000 income
Percent Households above $75,000(1)	Percent of Households above a $75,000 income
Percent Some College(3)	Percent of population 25 years and over whose highest education was some college

Percent Some Other Race[(2)]	Percent of population that is some other race
Percent Two or More Races[(2)]	Percent of population that is two races or more
Percent White[(2)]	Percent of population that is white
Unemployment Rate[(1)]	Unemployment Rate

Note: The nontechnical characteristic values for the City of Eutaw Lagoon only included the City of Eutaw since the system served a population of 3175 (~90%) in Eutaw and 300 (~10%) in Boligee.
[1]Source: 2021 ACS 5-Year Estimates Data Profile (DP03-Selected Economic Characteristics)
[2]Source: 2021 ACS 5-Year Estimates Data Profile (DP05-ACS Demographic and Housing Estimates)
[3]Source: 2021 ACS 5-Year Estimates Data Profile (DP02-ACS Selected Social Characteristics in the US)
[4]Poverty is a set dollar value that is varies by the size, age, and family status of people that live in a household together, which is defined by the U.S. Census (2022) for the American Community Survey.

Table 3.4: Technical Characteristic Variables of Treatment Facilities

Variable Name and Source	**Variable Description**
Age[(2)]	Age of facility for 2020 and 2021 since being constructed or reconstructed
Average Annual Flow[(1,2,4)]	Annual Average Monthly Flowrate for 2020 and 2021
Bypass/Overflow due to Equipment Failure[(2,3)]	Bypass or overflow events in 2020 and 2021 at facility due to equipment failure
Bypass/Overflow due to Heavy Rain[(2,3)]	Bypass or overflow events in 2020 and 2021 at facility due to heavy rain
Annual Design Flow[(1)]	Annual Design Flowrate of Sewer Service Area (MGD)[5]
Method of Discharge[(2)]	Method of discharging treated wastewater
Percent Average Flow at Capacity[(1,2)]	Percentage of Annual Average Monthly Flowrate (MGD)[5] for 2020 and 2021 at the design capacity
Population[(1)]	Population of Municipal Sewer Service Area
Size of System[(1)]	Size of System determined by population and design capacity
Type of Treatment[(2)]	Type of Treatment Process at Facility

[1]Source: ADEM NPDES Permit
[2]Source: ADEM MWPP Annual Report
[3]Source: SSO Reports
[4]Source: DMR Reports
[5]Million Gallons Per Day

In Table 3.2, the 2020 and 2021 noncompliance violations were chosen to be the dependent variable since this variable explains the performance of a facility. The detailed facility reports from the U.S. EPA ECHO (2022) database were used to collect the noncompliance violations. Additionally, the detailed facility reports were used to identify the different types of nontechnical characteristics (e.g., age, education, income, and race) associated with sewer service areas, which are shown in Table 3.3. MHI was included because this variable is commonly used when assessing the affordability of centralized sewer services for small communities (U.S. Conference of Mayors, American Water Works Association, and Water Environment Federation, 2013). Additionally, the percent below poverty and unemployment rate were selected as nontechnical variables since these are other alternative parameters to assess the affordability of sewer services (U.S. Conference of Mayors, American Water Works Association, and Water Environment Federation, 2013). After identifying the different variables in Table 3.3, the 2021 U.S. Census Bureau American Community Survey (ACS) five-year estimates based on municipal areas (i.e., incorporated places) were used to collect the numerical values for each variable. In Table 3.4, these variables were based on underlying causes for performance issues and technical characteristics that are associated with wastewater treatment facilities (US EPA, 2022b; US EPA, 2022c). All numerical values for the technical characteristics of each treatment facility were collected from the 2020 and 2021 Municipal Wastewater Pollution Prevention (MWPP) annual reports. If the annual average flowrate or the sanitary bypasses/overflow due to heavy rain and equipment failure were not included in the MWPP annual reports, the monthly discharge monitoring reports were used to calculate the annual average flowrate and the sanitary sewer overflow reports were used to determine the number of bypasses/overflows due to heavy rain and equipment failure.

In this study, most of the independent variables are continuous numerical variables. However, the size of system (e.g., small and large), type of treatment (e.g., aerated lagoons, mechanical treatment plants, and stabilization ponds), and method of discharge (e.g., surface water or land application) are categorical variables. Continuous variables are those that have an infinite range of numerical values. However, categorical variables have a finite number of different group categories. In the analysis, a coding scheme was used in Minitab Statistical Software to quantitively analyze the different categorical variables. An effect coding scheme was applied since the main effects (i.e., coefficients) of all categories are determined by assigning numerical values (e.g., negative one, zero, or positive one) to each group member (Alkharusi, 2012).

Using Minitab Statistical Software, a Poisson regression model with a forward selection algorithm was performed to identify the nontechnical and technical characteristics that were associated with noncompliance violations. Poisson log-linear model was determined to be the most appropriate regression model since the dependent variable used a count measure (Frome, 1983). The Poisson log-linear model uses equation 1 below:

$$\lambda(\mathrm{x}_i, \beta) = \exp\,(\mathrm{x}_i \beta) \qquad (1)$$

Where, $\lambda(\mathrm{x}_{i,}\beta)$ - predicted rate of occurrence, x_i- predictor(s), and β- predictor(s) coefficient are the following abbreviations.

In equation 1, $\lambda(\mathrm{x}_{i,}\beta)$ is the predicted number of violations and x_i includes a series of covariates (i.e., one or more independent variables from Table 3.3 and 3.4) with a respective coefficient, β, for each individual variable.

A forward selection algorithm was used to identify the most significant independent variables (Famoye & Rothe, 2003). In a forward selection algorithm, the method starts with an empty model and then adds the most significant term at each step. During each step, the significance of the overall variables was assessed by performing a Wald test with a 5% significance level. The null hypothesis of a Wald test determines whether a set of parameters are simultaneously zero and which parameters significantly affect the fit of the model (Wald, 1943; Lishinski, 2018)). Additionally, the Wald test was used to identify whether different categorical levels within an overall variable are simultaneously zero. If the probability value of the Wald test is significant, the overall variable is significant since it improves the model (Lishinski, 2018). A Pearson and deviance goodness-of-fit test was performed to determine if the observed data fit the model. If the goodness-of-fit tests have a significant probability value, the null hypothesis (i.e., the predicted values fit the model) is rejected.

3.3 Results and Discussion

3.3.1 Determining the Black Belt Population Served by Centralized Systems

Using the population for the centralized municipal systems and the 2021 U.S. Census County population estimates, the absolute population and the percentage of the population served by small wastewater systems, large wastewater systems, and both type of wastewater systems was determined for each Black Belt County. The absolute population and percentage of population served by centralized wastewater systems is shown below in Table 3.5 and 3.6 respectively:

Table 3.5: Absolute Population Served by Centralized Municipal Systems in Black Belt Counties

County	County Population	Number of Small Centralized Wastewater Facilities	Number of Large Centralized Wastewater Facilities	Small Centralized Wastewater Systems Population	Large Centralized Wastewater System Population	Centralized Wastewater System Population
Bullock	10,320	1	1	499	4,800	5,299
Dallas	37,619	0	1	0	19,000	19,000
Greene	7,629	1	0	3,475	0	3,475
Hale	14,754	2	1	2,815	3,300	6,115
Lowndes	9,965	2	0	2,000	0	2,000
Macon	18,895	2	1	775	10,000	10,775
Marengo	18,996	1	1	1,898	7,700	9,598
Perry	8,355	2	0	4,795	0	4,795
Russell	58,722	1	1	335	36,000	36,335
Sumter	12,164	3	0	3,500	0	3,500
Wilcox	10,446	3	0	5,160	0	5,160
Total	207,865	18	6	25,252	80,800	106,052

Note: ADEM considers the large facility (i.e., Union Springs Wastewater Treatment Plants and Land Application) in Bullock County to be one facility instead of two separate facilities centralized facilities.

Table 3.6: Percentage of Population Served by Centralized Municipal Systems in Black Belt Counties

County	Percentage Served by Small Centralized Systems	Percentage Served by Large Centralized Systems	Percentage Served by Centralized Systems
Bullock	4.8%	46.5%	51.3%
Dallas	0.0%	50.5%	50.5%
Greene	45.5%	0.0%	45.5%
Hale	19.1%	22.4%	41.4%
Lowndes	20.1%	0.0%	20.1%
Macon	4.1%	52.9%	57.0%
Marengo	10.0%	40.5%	50.5%
Perry	57.4%	0.0%	57.4%
Russell	0.6%	61.3%	61.9%
Sumter	28.8%	0.0%	28.8%
Wilcox	49.4%	0.0%	49.4%
Total	12.1%	38.9%	51.0%

Based on Table 3.6, the 11 Black Belt counties had ~ 51% of the populations wastewater treated by centralized sewer systems. The other half of the population can be assumed to be on decentralized systems or straight pipes (Maxcy-Brown et al., 2021). More of the population in the eleven Black Belt counties was served by large, centralized sewer systems (38.9%) in comparison to small, centralized sewer systems (12.1%).

Overall, there is not a major lack of centralized sewer systems since over half of the Black Belt population is served by centralized systems. When comparing to the percentage of Alabama (54.5%) that was served by public sewer systems in 1990 (U.S. Census, 2021), the percentage of the Black Belt served by centralized systems is not major difference. Additionally, centralized sewer systems arguably play a more important role than decentralized systems since some of these centralized facilities accept septage, which comes mainly from septic tanks. If Montgomery County was included as part of the Black Belt, centralized sewer systems would have a more important role since most of Montgomery County's Population (~87.7%) is served by Centralized Sewer Systems. However, it should be acknowledged that some Black Belt counties, such as Lowndes County and Sumter County, had a lack of access to centralized sewer systems (Winkler et al., 2017).

3.3.2 Comparison of Black Belt Noncompliance Occurrences in 2020 and 2021

Using the rate of violation occurrence for each facility, the averages were calculated for the facility being an aerated lagoon, mechanical treatment plant, or stabilization pond in the Black Belt, control area, and baseline for the State of Alabama, which is shown in Table 3.7.

Table 3.7: The 2020 and 2021 Rate of Noncompliance Violations in the Black Belt Study Area, Control Area, and the Baseline Area of Alabama

Study Area	Number of Facilities	Average Quarters in Noncompliance 2020-2021			
		Aerated Lagoon	**Mechanical Treatment**	**Stabilization Pond**	**Overall Average**
Black Belt	19	4.30 (53.8%)	5.00 (62.5%)	1.00 (12.5%)	3.58 (44.7%)
Small Black Belt Facilities	16	4.22 (52.8%)	5.50 (68.8%)	1.00 (12.5%)	3.38 (42.2%)
Large Black Belt Facilities	3	5.00 (62.5%)	4.50 (56.3%)	NA	4.67 (58.3%)
Control Area	45	3.38 (42.3%)	2.52 (31.5%)	3.18 (39.8%)	2.93 (36.7%)
Control Area Small Facilities	38	2.9 (36.3%)	2.47 (30.9%)	3.18 (39.8%)	2.79 (34.9%)
Control Area Large Facilities	7	5.00 (62.5%)	2.75 (34.4%)	NA	3.71 (46.4%)
State of Alabama Excluding the Black Belt	215	3.59 (44.8%)	2.13 (26.6%)	3.24 (40.5%)	2.54 (31.7%)

Note: The percentages in the parentheses indicates the average percent of quarters in noncompliance from 2020 and 2021.
Abbreviation: NA-Not Applicable

The two sample Poisson rate test based on the exact method was performed for all statistical comparisons, which are shown in Table 3.8 and 3.9 below.

Table 3.8: Statistical Comparisons for Violations in the Black Belt Study Area, Control Area, and the Baseline Area of Alabama

	BB	**SBB**	**LBB**	**CA**	**SCA**	**LCA**	**AL**
BB	NA	N	N	N	N	N	**Y***
SBB		NA	N	N	N	N	**Y**
LBB			NA	N	N	N	**Y**
CA				NA	N	N	N
SCA					NA	N	N
LCA						NA	**Y**
AL							NA

Note: The Black Belt and control area includes centralized treatment facilities that serve only small municipal communities. However, the baseline for Alabama includes facilities that serves both small and large municipal

communities.
Abbreviations: BB- Black Belt Facilities, SBB- Small Black Belt Facilities, LBB- Large Black Belt Facilities, CA- Control Area Facilities, SCA- Small Control Area Facilities, LCA- Large Control Area Facilities, AL- Baseline of Alabama Facilities, N- No statistical difference, NA- Not Applicable, Y*- Statistical difference at a 5% significance level, Y- Statistical difference at a 10% significance level

Table 3.9: Statistical Comparisons for Violations with Respect to the Different Types of Treatment Facilities in the Black Belt Study Area and the Baseline Area of Alabama

	BB (L)	**BB (M)**	**BB (P)**	**AL (L)**	**AL (M)**	**AL (P)**
BB (L)	NA	N	**Y*****	N	**Y*****	**N**
BB (M)		NA	**Y****	N	**Y****	**N**
BB (P)			NA	**Y****	**N**	**Y****
AL (L)				NA	**Y*****	**N**
AL (M)					NA	**Y****
AL(P)						NA

Note: The Black Belt includes centralized treatment facilities that serve only small communities. However, the baseline for Alabama includes facilities that serves both small and large municipal communities.
Abbreviations: BB (L)- Black Belt Aerated Lagoons, BB (M)- Black Belt Mechanical Treatment, BB (P)- Black Belt Stabilization Ponds, AL (L)- Baseline of Alabama Aerated Lagoons, AL (M)- Baseline of Alabama Mechanical Treatment, AL (P)- Baseline of Alabama Stabilization Ponds, NA- Not Applicable, N- No statistical difference, Y***- Statistical difference at a 0.1% significance level, Y**- Statistical difference at a 1% significance level

Based on Table 3.7, and 3.8, it was determined that the rate of violations occurrences was not significantly higher for small communities in the Black Belt in comparison to other small communities in the control area. However, the centralized facilities in small Black Belt communities were significantly higher in comparison to the remainder of all small and large communities for the State of Alabama. Additionally, it was observed in Table 3.7 and 3.9 that Black Belt mechanical treatment plants had more frequent violations in comparison to remainder of mechanical treatment plants in Alabama. Within the Black Belt, it was determined that all the aerated lagoons and mechanical treatment plants had higher rates of violations in comparison to the stabilization ponds.

Based on the statistical comparisons of noncompliance violations, small community treatment facilities, especially those utilizing mechanical treatment, performed worse in the Black Belt compared to the remainder of Alabama. This could be due, for example, to these small communities having potential financial limitations, lack of managerial training, and the inability to hire and retain experienced operators (U.S. EPA, 2022b; U.S. EPA, 2022d). Additionally, stabilization ponds might have performed better than the other type of treatment processes in the Black Belt since ponds are a simpler type of treatment process that typically require less funding and less maintenance.

3.3.3 Regression Analysis of Violations, Nontechnical Characteristics, and Technical Characteristics of Black Belt Facilities

Using the frequency of violations and the Poisson regression model, the best passing variables were the type of treatment and percent below poverty shown in Table 3.10.

Table 3.10: Poisson Regression Model Results

Deviance Adjusted R-Sqr[1] =.4108		**AICc[2]=85.34**		**P value<0.05**
Term	**Value**	**Standard error**	**P value[3]**	**VIF[4]**
Constant	0.469	0.316	0.137	NA[5]
Percent Below Poverty	2.11×10^{-2}	9.68×10^{-3}	0.029	1.31
Type of Treatment				
Aerated Lagoon	0.260	0.217	0.231	1.26
Mechanical Treatment Plant	0.665	0.221	0.003	1.06
Stabilization Pond	-0.925	0.316	0.003	NA[5]

[1]Deviance Adjusted R-Sqr is a measure of goodness of fit to determine if adding a new term improves the model
[2] AICc (Akaike's Information Criterion with Correction for small sample size) indicates less bias in the model
[3]P Value (probability value) indicates the coefficients that are statistically significant
[4]VIF (Variance Inflation Factor) is a measure of collinearity, and a value of 1 indicates no redundant information
[5]NA-Not Applicable

Based on Table 3.10, the percent below poverty had a positive relationship with the predicted violation occurrences (i.e., the higher the poverty level had a greater number of violations). Additionally, there was a positive relationship between violations and the facility having aerated lagoons or mechanical treatment. However, stabilization ponds had an inverse relationship between the number of violations (i.e., stabilization ponds had a smaller number of violations). The individual coefficient for aerated lagoons was not significant. However, the overall significance for the type of treatment was evaluated using a Wald test (Wald, 1943; Lishinski, 2018). It was determined that the type of treatment, which included aerated lagoons, mechanical treatment plants, and stabilizations ponds, was significant in Table 3.11.

Table 3.11: Overall Significance of Model and Independent Variable (P value < 0.05)

Term	**P value**
Regression Model	0.001
Percent Below Poverty	0.029
Type of Treatment	0.006

Note: P value (probability value) indicates the variables that are statistically significant.

The aerated lagoons were not removed since the overall variable (e.g., type of treatment) improved the model. Additionally, the fit of the model was assessed using the Deviance and Pearson goodness of fit test (Pearson, 1900; Nedler and Wedderburn, 1972) and the results are shown in Table 3.12.

Table 3.12: Goodness of Fit (P value < 0.05)

Term	**P value**
Deviance	0.089
Pearson	0.213

Note: P value (probability value) indicates the goodness of fit for the model.

Based on Table 3.12, the deviance residual and Pearson goodness of fit test was insignificant. Therefore, the null hypothesis failed to be rejected, and the observed number of violations fits the actual number of violations reasonably well. Using the independent categorical and numerical values for each facility and equation 2 below, the predicted values could be determined in Table 3.13.

$$NC = \exp(0.469 + 0.02112(\%\ BP) + 0.26(L) + 0.665(M) - 0.925(P)) \quad (2)$$

Where, NC-Predicted Violations, % BP-Percent Below Poverty, L-Aerated Lagoon, M-Mechanical Treatment Plant, and P-Stabilization Pond are the respective abbreviations. Note: A value of 1 is associated with the respective type of treatment

Table 3.13: List of Independent and Dependent Variable Values for Black Belt Facilities

Facility	Type of Treatment	% Below Poverty	Predicted NC	NC
Akron Lagoon	Aerated Lagoon	15.6	2.88	2
Fort Deposit WWTF	Aerated Lagoon	32	4.07	3
Greensboro Lagoon	Aerated Lagoon	28	3.74	5
Hayneville HCR Lagoon	Aerated Lagoon	23.9	3.43	8
Livingston Lagoon	Aerated Lagoon	50.2	5.98	6
Midway Land Application	Aerated Lagoon	22.9	3.36	4
Moundville Lagoon	Aerated Lagoon	18.1	3.04	3
Pine Hill Lagoon	Aerated Lagoon	44.9	5.35	5
Uniontown WWTP	Aerated Lagoon	60.9	7.50	7
York Lagoon	Aerated Lagoon	26.5	3.63	0
Cuba WWTP	Mechanical Treatment Plant	17.2	4.47	3
Demopolis WWTP	Mechanical Treatment Plant	21.5	4.90	1
Marion WWTP	Mechanical Treatment Plant	21.7	4.92	8
Tuskegee North WPCP	Mechanical Treatment Plant	28.8	5.72	8
City of Eutaw Lagoon	Stabilization Pond	30.2	1.20	1
Hurtsboro HCR Lagoon	Stabilization Pond	11.4	0.81	0
City of Linden HCR Lagoon	Stabilization Pond	21.7	1.00	1
Notasulga WWTF	Stabilization Pond	23.2	1.03	2
Shorter WWTF	Stabilization Pond	19.6	0.96	1

Abbreviations: NC-Noncompliance Violations, HCR-Hydrograph Controlled Release, WPCP- Water Pollution Control Plant, WWTF-Wastewater Treatment Facility, and WWTP- Wastewater Treatment Plant

Using the predicted and actual noncompliance violations from Table 13, the relationship is shown in Figure 3.3.

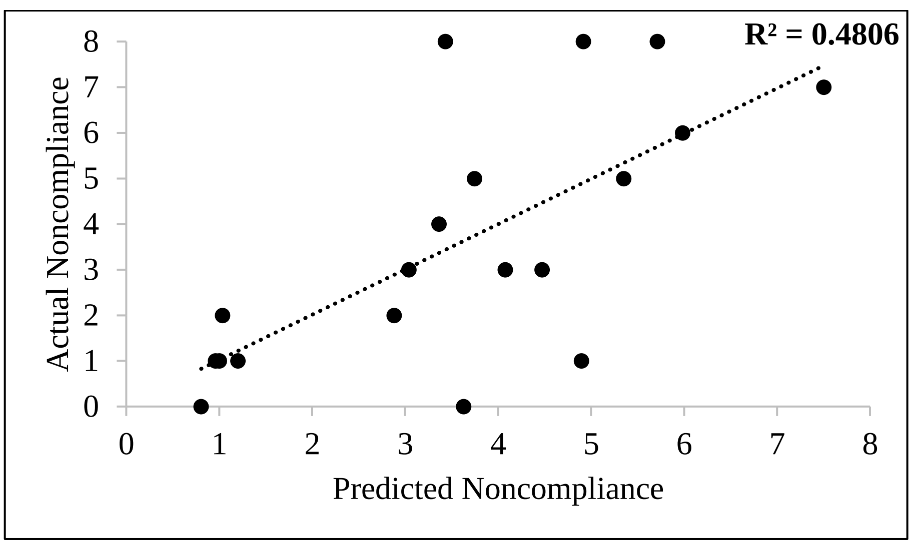

Figure 3.3: Number of Noncompliance Violations Vs Predicted Number of Noncompliance Violations

Based on the predicted values from equation 2, some values were over or under predicted (i.e., outliers) in comparison to the actual number of noncompliance violations, which is not unexpected given the simplicity of the model and the large number of interconnecting factors controlling the performance of wastewater treatment facilities. For example, one of the potential underlying causes for these outliers could be the ability of rural municipalities to hire and retain experienced operators and maintenance staff (Boller, 1997; US EPA, 2022d). All other factors being equal, knowledgeable operators and staff have the expertise to potentially reduce performance issues at a treatment facility (Boller, 1997; Muga and Mihelcic. 2008). However, experienced operators and maintenance staff cannot be represented as a variable since this information is not publicly available. Nonetheless, the r^2 value shows there is a significant association between the frequency of violations in the Black Belt and both the type of treatment and the percent of the municipal service population below poverty.

Based on the regression analysis results, the percent of the municipal population below poverty might have increased performance issues since these municipalities likely have a limited rate and tax base. Therefore, this could cause municipalities in the Black Belt to have issues with funding the costs to properly operate and maintain centralized systems. Additionally, Black Belt facilities with stabilization ponds might have had less performance issues since ponds are a simpler type of treatment in comparison to mechanical treatment plants and aerated lagoons, which typically require more funding and maintenance. In this regression model, it should also be noted that all other technical (e.g., annual flow, annual design flow, age of facility, method of discharge, population, bypasses, and sanitary overflows) and nontechnical variables (e.g., median household income, percent black, percent white, percent eighteen years or older, percent 65 years or older, percent households below $15,000, percent no high school, percent bachelor's degree or higher, and other socio-demographic variables) had no significant effect on the occurrence of predicted violations.

3.4 Conclusions

In this study, it was determined that municipal centralized systems have an important role since municipal wastewater is treated for about half of the Black Belt. Additionally, large facilities in the Black Belt have a major role since these systems serve more of the population (38.9%) in comparison to small sewer systems (12.1%). If Montgomery County was included, centralized sewer systems would have a more important role treating wastewater since most (~87.7) of the County population is served by centralized systems.

When assessing the performance of centralized treatment systems, the rest of the municipal facilities in Alabama performed better than the facilities for small communities in Black Belt. In addition, mechanical treatment plants were respectively the only type of facility that performed worse in the Black Belt in comparison to the remainder of Alabama. Especially with mechanical treatment plants, performance issues might have occurred more frequently due to the financial limitations, inadequate managerial training, and lack of experienced operators and maintenance staff with centralized systems in the Black Belt. Within the Black Belt, stabilization ponds might have performed better than aerated lagoons and mechanical treatment plants since ponds are typically more affordable and easier to maintain for small Black Belt communities.

After examining the relationship between performance, nontechnical characteristics, and technical characteristics for small community treatment facilities in Black Belt, it was determined that the type of treatment facility (e.g., aerated lagoon, mechanical treatment plant, and stabilization pond) and the percent of municipal population below the poverty level were identified as the most significant predictors for noncompliance violations. In the model, all other technical variables (e.g., age of system, flow, annual design flow, discharge type, method of discharge, population, size of system, bypasses, and sanitary overflows) and nontechnical characteristics (e.g., median household income, percent black, percent white, percent 18 years or older, percent 65 years or older, percent households below $15,000, percent no high school, percent bachelor's degree or higher, and other socio-demographic variables) had no significant effect on the occurrence of noncompliance violations.

Chapter Four.

Conclusions and Recommendations

4.1 Conclusions

Black Belt Population on Centralized Sewer Systems

1. Despite the recent focus on decentralized systems, centralized systems treat domestic wastewater from over half of the Black Belt. Large facilities in the Black Belt (population of more than 10,000 or an annual design flowrate ≥ 1 MGD) have a major role since these systems serve more of the population (38.9%) in comparison to small (population of 10,000 and fewer and an annual design flowrate < 1 MGD) sewer systems (12.1%) Additionally, some of these larger facilities accept septage from decentralized systems, such as septic systems. Thus, the overall role of centralized sewer systems in the Black Belt is important. If Montgomery County was considered in this study, centralized sewer systems would be even more important since most (87.7%) of Montgomery County's population is served by centralized sewer systems.

Comparison of Black Belt Noncompliance Occurrences in 2020 and 2021

1. When assessing the performance of centralized treatment systems, the 2020 and 2021 violations for small communities in the Black Belt were significantly higher (probability value < 0.05) than the remainder of all Alabama facilities. This reveals that the rest of the municipal facilities in Alabama perform better than the facilities in the Black Belt. Additionally, violations are significantly higher at Black Belt mechanical treatment plants in comparison to their counterparts in the rest of Alabama. Within the Black Belt, performance issues might have occurred more frequently due to potential underlying causes, such as financial limitations,

inadequate managerial training, and lack of experienced operators and maintenance staff with centralized systems..

2. Within the Black Belt, the violations for aerated lagoons and mechanical treatment plants are significantly higher than stabilization ponds in the Black Belt. This reveals that the stabilization ponds might have performed better than the other types of treatment facilities since ponds are not as complex and do not generally require as much maintenance and funding.

Regression Analysis of Violations, Nontechnical Characteristics, and Technical Characteristics of Black Belt Facilities

1. In this section, the relationship between municipal sewer system performance, social characteristics, and technical characteristics was analyzed for small communities in the Black Belt. It was determined that the type of treatment system and the percent of municipal population below the poverty level were identified as significant predictors for noncompliance violations. In the model, all other variables (e.g., median household income, race, education, household income, type of discharge, bypasses/sanitary sewer overflows, annual design capacity, method of discharge, size of system, population, and average annual flow) were not significant predictors.
2. When using the significant predictors, it was notable that there were a few facilities that were not predicted accurately (i.e., facilities that were outliers) for noncompliance violations. These observations, for example, could be potentially due to experienced staff not being represented as predictive variable. In a predictive model, the outcome of having this variable cannot be predicted since experienced professionals at a municipality cannot be determined.

4.2 Recommendations for Future Work

1. Considering the population in the Black Belt is constantly changing, the population size from the NPDES permits may not be most accurate since not all permits were not recently renewed prior to 2021. In future work, population estimates should be directly requested from the individual facilities since this would ensure a more recent estimate.

2. Ideally, a national average of violations including all treatment facilities should be used when assessing the performance of Black Belt facilities. This comparison would determine if Black Belt facilities performed better or worse than all the other facilities for the rest of the U.S. A national average would also be useful to make other comparisons for centralized sewer systems in similar small and rural communities throughout the U.S. However, this information is not easily obtainable without assistance from the U.S. EPA.
3. In the future, the number of noncompliance violations should incorporate a longer timeframe rather than a two-year period. The drawback of a recent two-year dataset is that the performance of centralized systems in previous years is not known. However, a more extensive range of data, such as five years, would be beneficial since this information could be used to determine if the Alabama Black Belt has ongoing performance issues.
4. Noncompliance violations will fluctuate in the upcoming years since effluent permit limits, wastewater treatment technologies, and sewer service areas change with respect to time. Thus, the relationship between performance, nontechnical characteristics, and technical characteristics should be analyzed over a long-time frame.

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Appendices

Appendix A. Black Belt Population on Centralized Sewer Systems

Table A.1: Small Black Belt Centralized Wastewater Systems (annual design flowrate of < 1 MGD and population of ≤10,000)

County	Facility Name(s)	Permittee	Sewer System Area(s)	Population
Bullock	Midway Land Application	Town of Midway	Midway	499
Greene	City of Eutaw Lagoon	City of Eutaw	Eutaw and Boligee	3,475
Hale	Akron Lagoon	Town of Akron	Akron	365
Hale	Moundville Lagoon	City of Moundville	Moundville	2,450
Lowndes	Fort Deposit WWTF	Fort Deposit Water Works & Sewer Board	Fort Deposit	1,300
Lowndes	Hayneville HCR Lagoon	Town Of Hayneville	Hayneville	700
Macon	Notasulga WWTF	Town of Notasulga	Notasulga	475
Macon	Shorter WWTF	Town of Shorter	Shorter	300
Marengo	City of Linden HCR Lagoon	Utilities Board of The City of Linden	Linden	1,898
Perry	Marion WWTP	City Of Marion	Marion	3,275
Perry	Uniontown WWTP	The Waterworks and Sewer Board of the City of Uniontown	Uniontown	1,520
Russell	Hurtsboro HCR Lagoon	The Water and Sewer Board of the Town of Hurtsboro	Hurtsboro	335
Sumter	Cuba WWTP	Town Of Cuba	Cuba	600
Sumter	Livingston Lagoon	City of Livingston	Livingston	1,650
Sumter	York Lagoon	City of York	York	1,250
Wilcox	Camden North WWTP	City of Camden	Camden	4,500
Wilcox	City of Camden South WWTP			
Wilcox	Pine Hill Lagoon	Town of Pine Hill	Pine Hill	660

Abbreviations: HCR-Hydrograph Controlled Release, WWT- Wastewater Treatment, WWTF- Wastewater Treatment Facility, WWTP- Wastewater Treatment Plant

Table A.2: Large Black Belt Centralized Wastewater Systems (annual design flowrate of ≥ 1 MGD or population of >10,000)

COUNTY	FACILITY NAME(s)	Permittee	Sewer System Area(s)	Population
Bullock	Union Springs WWTPs and Land Application	City of Union Springs Utilities Board	Union Springs	4,800
Dallas	Valley Creek WWTP	Selma Water Works & Sewer Board	Selma	19,000
Hale	Greensboro Lagoon	Utilities Board of the City of Greensboro	Greensboro	3,300
Macon	Tuskegee North WPCP	Utilities Board of the City of Tuskegee	Tuskegee	10,000
Marengo	Demopolis WWTP	The Water Works and Sewer Board of the City of Demopolis	Demopolis	7,700
Russel	Phenix City WWTP	Phenix City Department of Public Utilities	Phenix City	36,000

Abbreviations: WWTP- Wastewater Treatment Plant, WPCP- Water Pollution Control Plant

Appendix B. Comparison of Black Belt Noncompliance Occurrences in 2020 and 2021

Table B.1: 2020 and 2021 Noncompliance Violations for Centralized Facilities that serve Small Communities in the Alabama Black Belt Study Area

Black Belt Facilities					
County	**Facility Name**	**Size of Facility**	**Type of Facility**	**NC**	**NC %**
Bullock	Midway Land Application	Small	Aerated Lagoon	4	50
Greene	City of Eutaw Lagoon	Small	Stabilization Pond	1	12.5
Hale	Moundville Lagoon	Small	Aerated Lagoon	3	37.5
Hale	Akron Lagoon	Small	Aerated Lagoon	2	25
Lowndes	Fort Deposit WWTF	Small	Aerated Lagoon	3	37.5
Lowndes	Hayneville HCR Lagoon	Small	Aerated Lagoon	8	100
Macon	Shorter WWTF	Small	Stabilization Pond	1	12.5
Macon	Notasulga WWTF	Small	Stabilization Pond	2	25
Marengo	City of Linden HCR Lagoon	Small	Stabilization Pond	1	12.5
Perry	Uniontown WWTP	Small	Aerated Lagoon	7	87.5
Perry	Marion WWTP	Small	Mechanical Treatment Plant	8	100
Russell	Hurtsboro HCR Lagoon	Small	Stabilization Pond	0	0
Sumter	Livingston Lagoon	Small	Aerated Lagoon	6	75
Sumter	York Lagoon	Small	Aerated Lagoon	0	0
Sumter	Cuba WWTP	Small	Mechanical Treatment Plant	3	37.5
Wilcox	Pine Hill Lagoon	Small	Aerated Lagoon	5	62.5
Dallas	Dallas County WWTP	Large	Mechanical Treatment Plant	3	37.5
Hale	Greensboro Lagoon	Large	Aerated Lagoon	5	62.5
Macon	Tuskegee North WPCP	Large	Mechanical Treatment Plant	8	100
Marengo	Demopolis WWTP	Large	Mechanical Treatment Plant	1	12.5

Abbreviations: HCR-Hydrogrpah Controlled Release, WWTF- Wastewater Treatment Facility, WWTP- Wastewater Treatment Plant, WPCP- Water Pollution Control Plant, NC- Noncompliance Violations

Table B.2: 2020 and 2021 Noncompliance Violations for Centralized Facilities that serve Small Communities within the Control Area

Lower Alabama Facilities					
County	**Facility Name**	**Size of Facility**	**Type of Facility**	**NC**	**NC %**
Barbour	Clio Lagoon	Small	Aerated Lagoon	7	87.5
Choctaw	North Choctaw WWTP	Small	Aerated Lagoon	3	37.5
Choctaw	Pennington WWTF	Small	Aerated Lagoon	1	12.5
Clarke	Jackson Lagoon	Small	Aerated Lagoon	1	12.5
Coffee	New Brockton WWTP	Small	Aerated Lagoon	4	50
Crenshaw	Luverne WWTP	Small	Aerated Lagoon	3	37.5
Crenshaw	Rutledge Wastewater Lagoon	Small	Aerated Lagoon	4	50
Escambia	Flomaton Lagoon	Small	Aerated Lagoon	1	12.5
Henry	Jimmy Carr WWTP	Small	Aerated Lagoon	5	62.5
Houston	Cottonwood Lagoon	Small	Aerated Lagoon	0	0
Baldwin	Robertsdale WWTP	Small	Mechanical Treatment Plant	1	12.5
Baldwin	Town of Loxley WWTP	Small	Mechanical Treatment Plant	1	12.5
Barbour	Clayton WWTF	Small	Mechanical Treatment Plant	4	50
Butler	Georgiana WWTP	Small	Mechanical Treatment Plant	3	37.5
Choctaw	Gilbertown WRRF	Small	Mechanical Treatment Plant	4	50
Clarke	James Creek WWTP	Small	Mechanical Treatment Plant	1	12.5
Covington	Lockhart/Florala WWTP	Small	Mechanical Treatment Plant	4	50
Escambia	East Brewton WWTP	Small	Mechanical Treatment Plant	1	12.5
Geneva	Geneva WWTP	Small	Mechanical Treatment Plant	2	25
Henry	Abbeville South Lagoon	Small	Mechanical Treatment Plant	1	12.5
Houston	Ashford WWTP	Small	Mechanical Treatment Plant	3	37.5
Mobile	Citronelle WWTP	Small	Mechanical Treatment Plant	1	12.5
Mobile	Dauphin Island WWTP	Small	Mechanical Treatment Plant	0	0
Mobile	North Mobile County WWTP	Small	Mechanical Treatment Plant	6	75
Mobile	Satsuma WWTF	Small	Mechanical Treatment Plant	2	25
Pike	Brundidge WWTP	Small	Mechanical Treatment Plant	8	100
Washington	Chatom WWTF	Small	Mechanical Treatment Plant	0	0
Barbour	Louisville WWTP	Small	Stabilization Pond	8	100
Choctaw	Butler HCR Lagoon	Small	Stabilization Pond	3	37.5
Coffee	Elba Lagoon	Small	Stabilization Pond	3	37.5
Crenshaw	Brantley Lagoon	Small	Stabilization Pond	3	37.5
Crenshaw	Dozier Lagoon	Small	Stabilization Pond	3	37.5
Dale	Ariton Lagoon	Small	Stabilization Pond	4	50
Geneva	Hartford Lagoon	Small	Stabilization Pond	2	25
Geneva	Samson Lagoon	Small	Stabilization Pond	7	87.5
Geneva	Slocomb Lagoon	Small	Stabilization Pond	0	0
Houston	Town of Gordon WWTP	Small	Stabilization Pond	0	0
Washington	Millry Lagoon	Small	Stabilization Pond	2	25
Clarke	Thomasville HCR Lagoon & Sprayfield	Large	Aerated Lagoon	2	25
Conecuh	Evergreen Lagoon	Large	Aerated Lagoon	7	87.5
Mobile	Chickasaw Lagoon	Large	Aerated Lagoon	6	75
Butler	Greenville WWTP	Large	Mechanical Treatment Plant	4	50
Mobile	Bayou La Batre WWTF	Large	Mechanical Treatment Plant	3	37.5
Monroe	Monroeville Double Branch WWTP	Large	Mechanical Treatment Plant	1	12.5
Escambia	Atmore WWTP	Large	Mechanical Treatment Plant	3	37.5

Abbreviation: HCR-Hydrograph Controlled Release, WWT- Wastewater Treatment, WWTF- Wastewater Treatment Facility, WWTP- Wastewater Treatment Plant, and WRRF- Water Resource Recovery Facility

Table B.3: 2020 and 2021 Noncompliance Violations for Centralized Facilities that serve All Communities in Alabama Excluding the Black Belt

State of Alabama Facilities Excluding the Black Belt								
Facility Name	**Type of Facility**	**NC**	**NC %**		**Facility Name**	**Type of Facility**	**NC**	**NC %**
Autaugaville WWTP	Mechanical Treatment Plant	3	37.5		Stevenson Wastewater Treatment Lagoon	Aerated Lagoon	7	87.5
Prattville Autauga Creek Clean Water Facility	Mechanical Treatment Plant	1	12.5		Woodville WWTP	Mechanical Treatment Plant	6	75
City Of Orange Beach WWTF	Mechanical Treatment Plant	2	25		Cahaba River WWTP	Mechanical Treatment Plant	0	0
Daphne WRF	Mechanical Treatment Plant	2	25		Five Mile Creek WRF	Mechanical Treatment Plant	1	12.5
Fairhope WWTP	Mechanical Treatment Plant	0	0		Leeds WWTP	Mechanical Treatment Plant	0	0
Foley WWTP	Mechanical Treatment Plant	0	0		Prudes Creek WRF	Mechanical Treatment Plant	2	25
Gulf Shores WRF	Mechanical Treatment Plant	1	12.5		Trussvillle WWTP	Mechanical Treatment Plant	0	0
Robertsdale WWTP	Mechanical Treatment Plant	2	25		Turkey Creek WRF	Mechanical Treatment Plant	1	12.5
Town Of Loxley WWTP	Mechanical Treatment Plant	1	12.5		Valley Creek WWTP	Mechanical Treatment Plant	0	0
Clayton WWTF	Mechanical Treatment Plant	4	50		Village Creek WRF	Mechanical Treatment Plant	3	37.5
Clio Lagoon	Aerated Lagoon	7	87.5		Warrior WRF	Mechanical Treatment Plant	0	0
Eufaula WWTP	Stabilization Pond	2	25		City Of Sulligent WWTP	Mechanical Treatment Plant	5	62.5
Louisville WWTP	Stabilization Pond	8	100		Millport Lagoon	Aerated Lagoon	7	87.5
Centreville-Brent WWTP	Aerated Lagoon	2	25		Vernon Wastewater Lagoon	Stabilization Pond	8	100
West Blocton WWTP	Mechanical Treatment Plant	4	50		Cypress Creek WWTP	Mechanical Treatment Plant	0	0
Blountsville HCR Lagoon	Aerated Lagoon	0	0		Lexington Lagoon And Sprayfield	Aerated Lagoon	7	87.5
Cleveland WWTP	Mechanical Treatment Plant	5	62.5		Town Of Anderson WWTP	Mechanical Treatment Plant	1	12.5
Oneonta WWTP	Mechanical Treatment Plant	2	25		Moulton WWTP	Mechanical Treatment Plant	1	12.5
Snead WWTP	Mechanical Treatment Plant	0	0		Town Creek WWTP	Mechanical Treatment Plant	0	0
West Blount Lagoon	Stabilization Pond	1	12.5		Town Of Courtland HCR Lagoon	Stabilization Pond	1	12.5
Georgiana WWTP	Mechanical Treatment Plant	3	37.5		H.C. Morgan WPCF	Mechanical Treatment Plant	3	37.5
Greenville	Mechanical	4	50		Opelika Eastside	Mechanical	2	25

WWTP	Treatment Plant				WWTP	Treatment Plant		
Anniston Choccolocco Creek WWTP	Mechanical Treatment Plant	1	12.5		Opelika Westside WWTP	Mechanical Treatment Plant	1	12.5
Jacksonville WWTP	Mechanical Treatment Plant	0	0		Ardmore WWTP	Mechanical Treatment Plant	3	37.5
Piedmont Lagoon	Aerated Lagoon	7	87.5		Athens WWTP	Mechanical Treatment Plant	1	12.5
East Alabama Lower Valley WWTP	Mechanical Treatment Plant	2	25		Elkmont Rural Village WWTP	Mechanical Treatment Plant	2	25
Lafayette Mill Creek WWTP	Mechanical Treatment Plant	0	0		Aldridge Creek WWTP	Mechanical Treatment Plant	2	25
Lanett WWTP	Mechanical Treatment Plant	3	37.5		Chase Area WWTP	Mechanical Treatment Plant	1	12.5
Cedar Bluff WWTP	Aerated Lagoon	4	50		Gurley WWTP	Mechanical Treatment Plant	6	75
Centre Lagoon	Aerated Lagoon	0	0		Huntsville Western Area WWTP	Mechanical Treatment Plant	1	12.5
Cherokee County WWTP	Mechanical Treatment Plant	5	62.5		Madison WWTP	Mechanical Treatment Plant	1	12.5
Maplesville WWTP	Mechanical Treatment Plant	3	37.5		New Hope WWTP	Aerated Lagoon	0	0
Thorsby HCR Lagoon	Stabilization Pond	4	50		Owens Cross Roads WWTP	Mechanical Treatment Plant	1	12.5
Walnut Creek WWTP	Mechanical Treatment Plant	0	0		Spring Branch WWTP	Mechanical Treatment Plant	1	12.5
Butler HCR Lagoon	Stabilization Pond	2	25		Brilliant WWTP	Mechanical Treatment Plant	7	87.5
Gilbertown WRRF	Mechanical Treatment Plant	4	50		Guin Lagoon	Stabilization Pond	3	37.5
North Choctaw WWTP	Aerated Lagoon	3	37.5		Hackleburg WWTP	Mechanical Treatment Plant	2	25
Pennington WWTF	Aerated Lagoon	2	25		Hamilton WWTP	Mechanical Treatment Plant	1	12.5
Jackson Lagoon	Aerated Lagoon	1	12.5		Winfield WWTP	Aerated Lagoon	1	12.5
James Creek WWTP	Mechanical Treatment Plant	1	12.5		Boaz Slab Creek WWTP	Mechanical Treatment Plant	7	87.5
Thomasville HCR Lagoon & Sprayfield	Aerated Lagoon	2	25		Eastlake WWTP	Mechanical Treatment Plant	3	37.5
Ashland WWTP	Mechanical Treatment Plant	1	12.5		Gilliam Creek WWTP	Mechanical Treatment Plant	4	50
Lineville Lagoon	Aerated Lagoon	3	37.5		Mub WWTP	Mechanical Treatment Plant	1	12.5
Heflin Lagoon	Aerated Lagoon	5	62.5		Bayou La Batre WWTF	Mechanical Treatment Plant	3	37.5
Elba Lagoon	Stabilization Pond	4	50		Carlos Morris WWTP	Mechanical Treatment Plant	4	50
Enterprise College Street WWTP	Mechanical Treatment Plant	4	50		Chickasaw Lagoon	Aerated Lagoon	6	75
Enterprise	Mechanical	1	12.5		Citronelle WWTP	Mechanical	1	12.5

Northeast WWTP	Treatment Plant					Treatment Plant		
New Brockton WWTP	Aerated Lagoon	5	62.5		Clifton C. Williams WWTP	Mechanical Treatment Plant	4	50
Cherokee Lagoon	Stabilization Pond	4	50		Dauphin Island WWTP	Mechanical Treatment Plant	0	0
Leighton WWTP	Mechanical Treatment Plant	2	25		North Mobile County WWTP	Mechanical Treatment Plant	7	87.5
Littleville WWTP	Mechanical Treatment Plant	5	62.5		Saraland WWTP	Mechanical Treatment Plant	4	50
Muscle Shoals WWTP	Mechanical Treatment Plant	1	12.5		Satsuma WWTF	Mechanical Treatment Plant	2	25
Sheffield WWTP	Mechanical Treatment Plant	1	12.5		Wright Smith Jr. WWTP	Mechanical Treatment Plant	0	0
Tuscumbia WWTP	Mechanical Treatment Plant	3	37.5		Monroeville Double Branch WWTP	Mechanical Treatment Plant	1	12.5
Evergreen Lagoon	Aerated Lagoon	8	100		Catoma Creek WWTP	Mechanical Treatment Plant	0	0
Goodwater Lagoon	Mechanical Treatment Plant	7	87.5		Econchate WWTP	Mechanical Treatment Plant	1	12.5
Rockford WWTP	Mechanical Treatment Plant	6	75		Milley's Creek WPCP	Mechanical Treatment Plant	0	0
Andalusia Riverside WWTP	Mechanical Treatment Plant	0	0		Towassa WWTP	Mechanical Treatment Plant	1	12.5
Lockhart/Florala WWTP	Mechanical Treatment Plant	5	62.5		Decatur Utilities WWTP	Mechanical Treatment Plant	0	0
Brantley Lagoon	Stabilization Pond	3	37.5		Falkville HCR Lagoon	Stabilization Pond	5	62.5
Dozier Lagoon	Stabilization Pond	2	25		Hartselle Utilities WWTP	Mechanical Treatment Plant	2	25
Luverne WWTP	Aerated Lagoon	3	37.5		Priceville Lagoon	Stabilization Pond	7	87.5
Rutledge Wastewater Lagoon	Aerated Lagoon	3	37.5		Aliceville West Lagoon	Aerated Lagoon	4	50
Cullman WWTP	Mechanical Treatment Plant	2	25		Carrollton Lagoon	Aerated Lagoon	6	75
Garden City Wastewater Lagoon	Aerated Lagoon	8	100		Gordo WWTP	Mechanical Treatment Plant	5	62.5
Hanceville WWTP	Mechanical Treatment Plant	0	0		Reform WWTP	Mechanical Treatment Plant	7	87.5
Riley Maze Creek WWTP	Mechanical Treatment Plant	5	62.5		Brundidge WWTP	Mechanical Treatment Plant	7	87.5
West Point WWTP	Mechanical Treatment Plant	0	0		Troy Walnut Creek WWTP	Mechanical Treatment Plant	2	25
Ariton Lagoon	Stabilization Pond	4	50		Roanoke WWTF	Mechanical Treatment Plant	6	75
Ozark Southside WWTF	Mechanical Treatment Plant	1	12.5		Wadley Lagoon	Aerated Lagoon	0	0
Collinsville Lagoon	Aerated Lagoon	0	0		Wedowee Lagoon	Aerated Lagoon	8	100
Fort Payne	Mechanical	4	50		Alabaster WWTP	Mechanical	3	37.5

WWTP	Treatment Plant					Treatment Plant		
Rainsville Wastewater Treatment Plant	Mechanical Treatment Plant	1	12.5		Columbiana WWTP	Mechanical Treatment Plant	3	37.5
Eclectic Lagoon And Sprayfield	Aerated Lagoon and Mechanical	1	12.5		Helena WWTP	Mechanical Treatment Plant	4	50
Millbrook WWTP	Mechanical Treatment Plant	0	0		Montevallo WWTP	Mechanical Treatment Plant	0	0
Prattville Pine Creek Clean Water Facility	Mechanical Treatment Plant	0	0		Pelham WWTP	Mechanical Treatment Plant	1	12.5
Tallassee Sewer Stabilization Pond	Aerated Lagoon	4	50		Wilsonville WWTP	Mechanical Treatment Plant	2	25
Wilako WWTF	Mechanical Treatment Plant	1	12.5		Ashville Lagoon	Stabilization Pond	3	37.5
Atmore WWTP	Mechanical Treatment Plant	3	37.5		Dye Creek WWTP	Mechanical Treatment Plant	0	0
East Brewton WWTP	Mechanical Treatment Plant	1	12.5		Margaret WWTP	Mechanical Treatment Plant	1	12.5
Flomaton Lagoon	Aerated Lagoon	0	0		Springville Lagoon	Aerated Lagoon	4	50
Altoona Lagoon	Mechanical Treatment Plant	0	0		St. Clair Correctional Facility WWTP	Mechanical Treatment Plant	0	0
Attalla Wastewater Treatment Lagoon	Aerated Lagoon	6	75		Steele Lagoon	Stabilization Pond	5	62.5
Gadsden East River WWTP	Mechanical Treatment Plant	2	25		The David Treadwell WRF	Mechanical Treatment Plant	4	50
Gadsden West River WWTP	Mechanical Treatment Plant	3	37.5		J Earl Ham WWTP	Mechanical Treatment Plant	3	37.5
Glencoe Lagoon	Mechanical Treatment Plant	0	0		Lincoln WWTP	Mechanical Treatment Plant	0	0
Rainbow City WWTP	Mechanical Treatment Plant	0	0		Oxford Tull C. Allen WWTP	Mechanical Treatment Plant	0	0
Southside Waste Stabilization Ponds	Stabilization Pond	3	37.5		Sycamore WWTP	Mechanical Treatment Plant	2	25
Fayette WWTP	Mechanical Treatment Plant	1	12.5		Talladega Main WWTP	Mechanical Treatment Plant	5	62.5
Town Of Berry WWTF	Stabilization Pond	1	12.5		Camp Hill Lagoon	Aerated Lagoon	6	75
Phil Campbell WWTP	Mechanical Treatment Plant	3	37.5		Dadeville WWTP	Mechanical Treatment Plant	0	0
Radford "Joe" Murray WWTP	Mechanical Treatment Plant	0	0		Sugar Creek Advanced WWTP	Mechanical Treatment Plant	0	0
Red Bay Wastewater Treatment Lagoon	Stabilization Pond	0	0		Hilliard N. Fletcher WWTP	Mechanical Treatment Plant	4	50
Geneva WWTP	Mechanical Treatment Plant	2	25		Northport WWTP	Mechanical Treatment Plant	5	62.5

Hartford Lagoon	Stabilization Pond	2	25		Vance WWTP	Aerated Lagoon	1	12.5
Samson Lagoon	Stabilization Pond	7	87.5		Carbon Hill WWTP	Mechanical Treatment Plant	0	0
Slocomb Lagoon	Stabilization Pond	0	0		Cordova WWTP	Mechanical Treatment Plant	5	62.5
Abbeville South Lagoon	Mechanical Treatment Plant	2	25		East Walker County WWTP	Mechanical Treatment Plant	5	62.5
Jimmy Carr WWTP	Aerated Lagoon	5	62.5		Oakman HCR Lagoon	Aerated Lagoon	1	12.5
Ashford WWTP	Mechanical Treatment Plant	4	50		Parrish HCR Lagoon	Aerated Lagoon	5	62.5
Cottonwood WWTF	Aerated Lagoon	0	0		Sumiton Lagoon	Aerated Lagoon	5	62.5
Dothan Little Choctawhatchee WWTP	Mechanical Treatment Plant	1	12.5		Town Creek WWTP	Mechanical Treatment Plant	2	25
Dothan New Cypress Creek WWTP	Mechanical Treatment Plant	1	12.5		Chatom WWTF	Mechanical Treatment Plant	0	0
Dothan Omussee Creek WWTP	Mechanical Treatment Plant	2	25		Millry Lagoon	Stabilization Pond	2	25
Town Of Gordon WWTP	Stabilization Pond	0	0		Addison Lagoon & Sprayfield	Aerated Lagoon	0	0
Bridgeport Sewage Lagoon	Mechanical Treatment Plant	6	75		Double Springs WWTP	Mechanical Treatment Plant	1	12.5
Hollywood WWTP	Mechanical Treatment Plant	5	62.5		Haleyville South WWTP	Mechanical Treatment Plant	1	12.5
Scottsboro Southside WWTP	Mechanical Treatment Plant	1	12.5					

Note: The facilities are listed alphabetically based on the County.
Abbreviation: HCR-Hydrograph Controlled Release, WWT- Wastewater Treatment, WWTF- Wastewater Treatment Facility, WWTP- Wastewater Treatment Plant, WRF-Water Reclamation Facility, WRRF- Water Resource Recovery Facility, WPCF- Water Pollution Control Facility, WPCP- Water Pollution Control Plant

Table B.4: Number of Centralized Facilities in the Black Belt Study Area, Control Area, and the Baseline Area of Alabama

Study Area	**Number of Centralized Facilities**			
	Aerated Lagoon	**Mechanical Treatment**	**Stabilization Pond**	**Overall**
Black Belt	10	4	5	19
Small Black Belt Facilities	9	2	5	16
Large Black Belt Facilities	1	2	NA	3
Control Area	13	21	11	45
Control Area Small Facilities	10	17	11	38
Control Area Large Facilities	3	4	NA	7
State of Alabama Excluding the Black Belt	41	150	25	215

Note: One facility, the Eclectic Lagoon and Sprayfield, within the State of Alabama excluding the Black Belt is considered to have aerated lagoons and mechanical treatment. Therefore, it was counted as both types of treatment processes, but as a singular facility for the overall number of facilities.
Abbreviation: NA-Not Applicable

Appendix C. Regression Analysis of Violations, Nontechnical Characteristics, and Technical Characteristics of Black Belt Facilities

Table C.1: Poisson Regression Models

Model	Deviance Adjusted R-Sqr[1]	AICc[2]	Variable(s)	Variable Type	Wald Test P value[3]	VIF[4]	Sign (+/-)
1	NA[5]	NA[5]	Percent Hawaiian Islander	Continuous	NA[5]	NA[5]	NA[5]
2	0.00%	100.21	Percent 18 Years or Older	Continuous	0.993	1	-
3	0.00%	100.21	Percent 17 Years or Under	Continuous	0.993	1	+
4	0.00%	100.2	Method of Discharge	Categorical	0.925	Varies[6]	Varies[6]
5	0.00%	100.04	Percent No Highschool	Continuous	0.688	1	-
6	0.00%	100.01	Percent Asian	Continuous	0.648	1	+
7	0.00%	99.96	Percent American Indian	Continuous	0.637	1	-
8	0.00%	99.94	Percent Highschool or General Education Diploma	Continuous	0.605	1	+
9	0.00%	99.44	Percent Two or More Races	Continuous	0.404	1	-
10	0.00%	99.47	Percent Households above $75,000	Continuous	0.393	1	-
11	0.00%	99.32	Percent Hispanic or Latino	Continuous	0.358	1	-
12	0.00%	99.31	Percent Some Other Race	Continuous	0.315	1	+
13	0.21%	99.11	Size of System	Categorical	0.28	Varies[6]	Varies[6]
14	0.82%	98.85	Percent Highschool with No Diploma	Continuous	0.245	1	+
15	0.95%	98.79	Percent Bachelor's Degree or Higher	Continuous	0.225	1	+
17	1.13%	98.71	Annual Design Flow	Continuous	0.205	1	+
16	1.20%	98.68	Percent Households between $15,000 and $75,000	Continuous	0.217	1	-
19	2.08%	98.30	Annual Average Flow	Continuous	0.146	1	+
20	2.08%	98.3	Percent Average Flow at Capacity	Continuous	0.146	1	+
21	2.79%	97.98	Population	Continuous	0.118	1	+
18	2.91%	97.93	Percent 65 Years or Older	Continous	0.147	1	-
22	4.98%	97.03	Percent Black	Continuous	0.086	1	+
23	5.33%	96.88	Percent White	Continuous	0.08	1	-
26	5.71%	96.71	Bypass/Overflow due to Heavy Rain	Continuous	0.038	1	+
24	6.54%	96.34	Percent Some College	Continuous	0.05	1	-
25	7.67%	95.85	Age	Continuous	0.04	1	-
27	8.63%	95.43	Percent Households below $15,000	Continuous	0.031	1	+
28	9.31%	95.13	Percent Associate Degree	Continuous	0.029	1	-
29	10.16%	94.76	Bypass/Overflow due to Equipment Failure	Continuous	0.01	1	+

30	15.28%	92.52	Percent Below Poverty	Continuous	0.003	1	+
31	15.57%	92.39	MHI	Continuous	0.008	1	-
32	15.94%	92.23	Unemployment Rate	Continuous	0.004	1	+
33	32.94%	86.65	Type of Treatment	Categorical	0.004	Varies[6]	Varies[6]
34	35.20%	87.92	Type of Treatment	Categorical	0.006	Varies[6]	Varies[6]
			Bypass/Overflow due to Heavy Rain	Continuous	0.131	1.06	+
35	36.05%	87.54	Type of Treatment	Categorical	0.007	Varies[6]	Varies[6]
			Age	Continuous	0.128	1.02	-
36	37.18%	87.05	Type of Treatment	Categorical	0.008	Varies[6]	Varies[6]
			Percent Associate Degree	Continuous	0.099	1.01	-
37	37.63%	86.85	Type of Treatment	Categorical	0.005	Varies[6]	Varies[6]
			Percent Households below $15,000	Continuous	0.085	1.28	+
38	37.76%	87.23	Type of Treatment	Categorical	0.009	Varies[6]	Varies[6]
			Bypass/Overflow due to Equipment Failure	Continuous	0.08	1.03	+
39	39.82%	85.89	Type of Treatment	Categorical	0.012	Varies[6]	Varies[6]
			Unemployment Rate	Continuous	0.042	1.03	+
40	40.49%	85.6	Type of Treatment	Categorical	0.006	Varies[6]	Varies[6]
			MHI	Continuous	0.053	1.34	-
41	41.08%	85.34	Type of Treatment	Categorical	0.006	Varies[6]	Varies[6]
			Percent Below Poverty	Continuous	0.029	1.31	+
42	42.70%	87.39	Type of Treatment	Categorical	0.011	Varies[6]	Varies[6]
			Percent Below Poverty	Continuous	0.129	1.56	+
			Unemployment Rate	Continuous	0.193	1.25	+

Note: Model 41 has the best passing variables out of the 42 models that were analyzed.

[1]Deviance Adjusted R-Sqr is a measure of goodness of fit to determine if adding a new term improves the model

[2] AICc (Akaike's Information Criterion with Correction for small sample size) indicates less bias in the model

[3]Wald Test P Value (probability value) indicates the variables that are statistically significant

[4]VIF (Variance Inflation Factor) is a measure of collinearity, and a value of 1 indicates no redundant information

[5]NA-Not Applicable

[6]Varies indicates the VIF or sign is different for each category within the variable