AN EVALUATION OF THE HUMAN PATHOGEN TRANSMISSION POTENTIAL OF SELECTED WASTEWATER TREATMENT SYSTEMS, WITH THE DEVELOPMENT OF A RATING SYSTEM FOR PUBLIC USE IN SELECTING A SYSTEM FOR HOME INSTALLATION

by

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ABSTRACT OF DISSERTATION
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Title An Evaluation of the Human Pathogen Transmission Potential of Selected Wastewater Treatment Systems, with the Development of a Rating System for Public Use in Selecting a System for Home Installation

Three noncentralized wastewater treatment systems and three centralized wastewater treatment systems were evaluated for their efficiency in removing indicators of pathogens from domestic sewage. The parameters used in the evaluation were biochemical oxygen demand, total suspended solids, and fecal coliform. The measure of efficiency was based on (a) the discharge effluent concentration of each parameter as the concentration relates to the maximum permissible Environmental Protection Agency limit, and (b) the percentage in reduction of each parameter from the influent value to the effluent value. For the noncentralized wastewater treatment systems, intermittent sand filtration was found to be significantly better ($p < .001$) than either peat moss filtration or constructed-wetland filtration were found to be. For the centralized wastewater treatment systems, the sewage treatment plant operating at Daphne, Alabama, was found to be significantly more effective ($p < .001$) than either the Fairhope, Alabama, plant or the Dauphin Island, Alabama, plant was found to be. In this study, a comparative tool (scoring system) to rank the effectiveness of various systems was developed. The lower the score on this tool is, the more effective the system. The sand filtration treatment scored 1.04, the constructed-wetland treatment scored 3.42, and the peat filtration

treatment scored 3.56. Scores for the three centralized wastewater treatment systems were as follows: 0.53 for the Daphne plant, 0.72 for the Fairhope plant, and 0.69 for the Dauphin Island plant.

DEDICATION

To my sister, Sarah, my son, Jason, and my friend, Julia. Each of them encouraged me to complete the project.

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LIST OF ABBREVIATIONS

ADEM	Alabama Department of Environmental Management
ADPH	Alabama Department of Public Health
BOD	Biochemical oxygen demand
BOD_5	Biochemical oxygen demand of wastewater after 5 days of incubation at 20 °C
COD	Chemical oxygen demand
CWWTS	Centralized Wastewater Treatment System
DWWTS	Decentralized Wastewater Treatment System
FC	fecal coliform
GPD	gallons per day
MSTP	municipal sewage treatment plant
NSF	National Sanitation Foundation
NWWTS	Noncentralized Wastewater Treatment System
Peat3	Peat Filtration Sample Location 3
Peat4	Peat Filtration Sample Location 4
Peat5	Peat Filtration Sample Location 5
Peat6	Peat Filtration Sample Location 6
Sand1	Sand Filtration Sample Location 1
Sand2	Sand Filtration Sample Location 2
SS	suspended solids

STP	Sewage treatment plant
TC	total coliform
TSS	Total suspended solids
USA	University of South Alabama
USEPA	United States Environmental Protection Agency
UV	ultraviolet

CHAPTER 1

INTRODUCTION

History

Human-waste disposal has long been a major concern for civilized populations. The disease burden caused by failure to adhere to strict sanitation can be devastating. The great cultures of the past all developed methods to dispose of human waste in a sanitary manner. The Greek, Roman, and Egyptian civilizations had well developed disposal systems long before Christ walked the earth. Throughout time, successful military leaders have appropriately understood the importance of protecting their troops from disease. In all wars fought before the Gulf War, disease and nonbattle injury accounted for the greatest troop attrition.

Sun Tzu's treatise, *The Art of War* (as cited in Giles, 1910), has long been exalted as the most practical guide for military leaders. For centuries, this masterpiece has been required reading in military academies throughout the world. Sun Tzu has laid out definitive postulates for successful campaigns that include proper sanitation. In Book IX, "The Army on the March," Sun Tzu declares the importance of ensuring that soldiers are well taken care of, with sanitation being one of his principal focal points. Sun Tzu said:

> We come now to the question of encamping the army. These are the useful branches of military knowledge which enabled the Yellow Emperor to vanquish enemies for several sovereigns. If you are careful of your men, camp on hard ground, demand cleanliness, your army will be free from disease of every kind, this will spell victory. Therefore, soldiers must be treated in the first instance with humanity, but kept under control by means of iron discipline. This is a certain road to victory (as cited in Giles, 1910, p 235).

Sir John Pringle, founder of American modern public health (1760s), greatly influenced the Revolutionary Army's success by identifying modes of transmission for disease, thereby preventing the spread of those diseases (Gibson, 1995). Pringle's principal focus was upon human waste and its proper disposal.

Human waste has also long been identified as a transmission vehicle and reservoir for pathogenic organisms that inflict disease on civilian communities. History is filled with notable examples of human suffering caused by diseases transmitted by excreta-contaminated water.[1] Dr. John Snow, credited as being the founder of modern epidemiology, did so through the investigation of a disease transmitted by drinking water contaminated with excreta (Rosenberg, 1962). Snow had already achieved prominence in the mid-19th century as an obstetrician who was among the first to use anesthesia. However, his work in epidemiology is what earned him a lasting place in history (Rosenberg).

During the 1830s and 1840s, when severe cholera epidemics threatened London, Snow had become interested in the cause and transmission of this disease (Snow, 1936). In 1849, he published a brief pamphlet, *On the Mode of Communication of Cholera*, suggesting that cholera is a contagious disease caused by "a poison that reproduces in the human body and is found in the vomitus and stools of cholera patients"(Snow, 1936, p 4). He believed that the main, although not only, means of transmission was water contaminated with this poison. This view differed from a commonly held theory that diseases are transmitted by inhalation of vapors. His pamphlet caused no great stir, and Snow's argument was only one of many hopeful theories proposed during a time when cholera was causing great havoc.

In 1854, Snow (Rosenberg, 1962) was able to prove his theory. During another severe epidemic of cholera in London, Snow painstakingly documented cholera cases and correlated a comparative incidence of cholera among subscribers to the city's two water companies. He showed that cholera occurred much more frequently in customers of one water company, the Southwark and Vauxhall. This company drew its water from the

[1] See the *Epidemiology of Enteric Disease* in this chapter.

lower Thames, where the river had become contaminated with London sewage; however, the other water company obtained water from the far less contaminated upper Thames (Rosenberg).

A dramatic incident during this epidemic has since become legendary. In one particular neighborhood, the intersection of Cambridge Street and Broad Street, the concentration of cholera cases was so great that the number of deaths exceeded 500 in only 10 days (Snow, 1936). Snow concluded that the cause was centered around the Broad Street public water pump. He advised an incredulous but panicked assembly of officials to have the pump handle removed; when this was done, the epidemic was contained. The Broad Street pump handle event has since remained a symbol of practical epidemiology (Snow).

Another famous example of human-waste-associated disease transmission is that of Mary Mallon (Leavitt, 1997). Ms. Mallon became infamously known as Typhoid Mary. She was also one of the most persecuted people in American history and was punished in the name of public health (Leavitt).

In 1907, Ms. Mallon was taken into custody in New York when investigation and tests showed her to be a healthy carrier of *Salmonella typhi* (Leavitt, 1997). Her location and identity had been determined by tracing a large number of typhoid cases to kitchens where she had worked. She was placed in an isolation cottage on North Brother Island, one of the small islands in the East River in New York City, where she remained in custody until her death in 1938. In the name of public health and safety, Mary Mallon was never "tried" in any legal sense; however, she was imprisoned for the remainder of her natural life (Leavitt). To this day, a public health conflict arises when the rights of the individual collide with the public good.

On-site human-waste-disposal systems have been used in the United States since the mid-1800s. Before that time, basic privies were most common in rural areas of the country. At the turn of the century, the mortality rate resulting from waterborne disease was as high as 2,000/100,000 (Mandell, Bennett, & Dolin, 1995). Over the years, technological advances im proved on-site systems from simple outhouses and cesspools to septic tanks to some of the more advanced treatment systems in use today. Early in the 20th century, densely populated areas began to install piping systems to transport sewage to a disposal plant. This method did improve sanitation but mainly because the problem was simply moved away from the city. Over time, municipal sewer systems became the standard of affluence for an American city, and it was thought that true sanitation could only be achieved through centralized systems (B. Stuth, personal communication, December 6, 1997).

During the 1970s and early 1980s, federal interests and funds were directed almost completely toward large municipal wastewater treatment plants. The government promulgation was that, if the country went entirely to municipal treatment, then management over human-waste disposal would be well regulated and controlled. To achieve this end, a policy shift ensued toward using centralized wastewater treatment systems (CWWTSs) rather than noncentralized and/or decentralized systems. As an incentive to local communities, the federal government offered investments in the construction of wastewater facilities focusing primarily on the building of large municipal plants.

In 1972, the Federal Water Pollution Control Act (later called the Clean Water Act) authorized monumental funding toward the development of CWWTSs. Municipalities used funds from the new Construction Grants program to build wastewater treatment systems and centralized sewers under the auspice of meeting national standards for discharged pollutants (U.S. General Accounting Office, 1994). From 1972 to 1990, the federal government spent more than $62 billion in this program for constructing or upgrading municipal (centralized) treatment facilities (Lewis, 1986).

The 1990s have served as a transition period back to the grass-roots realization that noncentralized wastewater treatment may be the better method of management. On-site wastewater treatment is being considered more and more as the system of choice for wastewater treatment and disposal. However, selection of a system is usually not based on the ability of the system to treat wastewater. Most community developers consider all noncentralized wastewater treatment systems (NWWTSs) about equal in their ability to "clean" wastewater. The single most important factor is cost or profitability. Developers usually select the more affordable on-site systems that can be easily installed. If developers had easy-to-understand information concerning the environmental-pollution potential of given systems, perhaps they would give system performance greater consideration in their selection process.

The Problem

To at least some degree, all waters of this planet are contaminated with human pathogens. What has caused this global contamination? The answer is that, over the years, there has been a massive infusion of these pathogenic organisms because of sewage system overflows and nutrients entering surface waters from rain runoff. The existence of more and more people equals the existence of more and more sewage. The population of the world at the turn of this new millennium has been estimated to be in excess of 6 billion people. According to the United States Census Bureau (2000), the United States alone now has a population of nearly 274 million people. All of these people use water daily for a variety of purposes, including drinking, bathing, laundry, and sewerage. All of that water, once used, needs to be made safe and returned to the environment for eventual reuse.

When human civilizations began to develop, evolving communities usually addressed sewage in one of two ways: Either human excreta were considered to have value as a fertilizer for agriculture, or human excreta had no value at all and were considered dangerous. Most cultures did not connect human waste with agricultural productivity. Therefore, most of today's societies developed a standard for sanitation that meant removing human excreta from the dwelling. In the United States, the outhouse was the initial standard latrine. Primarily because of the noxious odors generated within the outhouse, it was usually placed at a distance from the dwelling (hence, the term *out-house*). Later, the watercloset became popular because it afforded the convenience of placing the toilet inside the house while also getting the excreta out of the house. The so-called flush toilet had been available to privileged persons at the height of the Roman age; however, not until 1802 did the first waterworks in the United States become available in Philadelphia. Naturally, because great quantities of water were now being piped into homes for sanitation and other domestic uses, the wastewater had to be piped out again. The first place to which the wastewater was pumped was the basic backyard cesspool.[2] These cesspools regularly overflowed with pathogen-polluted water, which entered surface waters. The immediate result was the spread of waterborne diseases.

By the middle of the 19th century, the diseases spawned by the convenience of the flush toilet gave rise to a demand for the construction of sewers that would carry the sewage not only out of and away from the home but also away from the city. This wastewater transport system, or sewerage, introduced another problem. In cities with sanitary sewers, cholera epidemics abated. However, in the cities downstream from those dumping their sewage into the river, death rates from typhoid and cholera soared. Soon, the standard practice was to "purify" sewage-polluted water from upstream to make drinking water safe instead of treating the sewage where it was produced (Reid, 1991). By the middle of the 20th century, the nutrient burden on recipient waters from human excrement, added to an ever increasing flow of industrial waste, was simply far too toxic to the ecosystem. This problem led to the "treatment" phase of the get-rid-of-it (flush-and-forget) approach to dealing with wastewater.

Centralized collection and treatment of sewage has been the standard in the affluent United States ever since. The reason is not that centralized collection and

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[2] A covered hole or pit for receiving drainage or sewage, as from a house.

treatment is better than noncentralized wastewater disposal is; in actuality, the opposite is true. In fact, the greatest force behind the drive for sewage systems in communities has always industry. Although the bulk of the costs for a sewage-treatment-plant (STP) operation is paid for by homeowners, industrial wastewater is far more polluted. Furthermore, 80% of the total cost of piping and treatment is in the laying of pipes. However, many sanitary (environmental) engineers are now considering a return to noncentralized and decentralized wastewater treatment systems, at least in some situations.

Today, in the United States, approximately 75% of the population lives in communities where wastewater from their homes is carried by sewers, often over long distances, to centralized wastewater treatment plants. Typically, the treated water that comes out of these treatment plants is released to a nearby stream, river, lake, bay, or other body of water. The "treated" wastewater then flows through a natural watershed and drains away to one of the oceans or seas. The remaining 25% of the U.S. population (an estimated 68 million people) lives in areas not served by sewer-collection-and-treatment systems. For the vast majority of these homes, septic tanks collect wastewater from the house for primary treatment (solids removal and solids digestion over time). Generally, secondary wastewater treatment occurs in the soil. Soil microorganisms (including bacteria) work to degrade chemical impurities and consume pathogens. It is generally assumed that, by the time the treated wastewater reaches groundwater, it will be safe to be drawn up through wells and used again. This septic-system on-site disposal method has been employed in rural areas for over a century. In recent years, the move by many people to live outside urban areas has raised the question of whether the standard septic tank with soil dispersal is a treatment system that can adequately protect the public's health.

To ensure that noncentralized wastewater treatment is as effective as possible, an advanced (atypical) secondary treatment process is often included before the discharge of the effluent to the soil dispersal system. These new small-scale treatment systems are especially suited for use in rural or developing areas. In fact, these systems have proven to be so cost effective and treatment capable that government agencies such as the U.S. Environmental Protection Agency (USEPA) now report that the systems are often superior to CWWTSs for these areas. The USEPA goes so far as to recommend that these systems should be considered as permanent solutions to the wastewater treatment needs of most rural and developing areas.

Composition of Sewage

Background

The water people use never goes away. When wastewater receives inadequate treatment, the overall quality of the world's water supply suffers. By degrading overall water quality, humans endanger the public's health. Most wastewater is composed of a very diverse mixture of compounds. Typical wastewater contains biological organisms (both patho genic and nonpathogenic), organic matter, oil, grease, other inorganic material, solids, nutrients, and gases. The major pollutants common to on-site treatment effluent include organic solids, materials with a high BOD, nutrients such as nitrogen and phosphorus, and human pathogens. With typical on-site systems, soil microorganisms perform the secondary treatment process. The ability of soil to remove or inactivate these contaminants depends upon several soil factors (Dow & Loomis, 1996). These soil factors can be divided into three types: physical (the texture and structure of the soil), chemical (the surface area and chemical properties of the soil particles), and biological (the nature of soil microbes that can utilize or degrade incoming pollutants). These same characteristics can be used to categorize the nature of the pollutants. A detailed explanation of how the soil treats (cleans) wastewater is provided in CHAPTER 2, BACKGROUND, *Soil Treatment Processes*.

Chemical

The chemical composition of wastewater is largely dependent upon the location in which the wastewater stream is created. Usually, domestic single-family flows are the least contaminated in toxins but are high in pathogens. In contrast, high-strength wastewater flows, including those from commercial and restaurant wastes, are far more difficult to treat. Other than the water itself, organic constituents are the major component of wastewater. After the organic matter, the principal chemical elements are nitrogen and phosphorus. These substances also become involved in a variety of physical and biological processes. Other common chemical pollutants include heavy metals, chlorides, aluminum, manganese, and oxides of iron. During the primary septic-tank treatment phase of typical on-site treatment, the nitrogen in effluent discharged from the septic tank is chiefly in organic and ammonium nitrogen (NH_4^+-N) forms. During the secondary soil treatment phase, a mineralization process occurs in which the organic nitrogen is transformed into ammonium nitrate. This mineralization process continues throughout the movement of the wastewater through the soil in the absorption field. Once wastewater has moved from the absorption field into the soil beneath, the predominant nitrogen retention reaction becomes the bioconversion of ammonium-N (NH_3) to nitrate-N (NO_3). This chemical transformation reaction is termed biological nitrification. The nitrification process occurs only when aerobic conditions are present. Under wet soil conditions, ammonium-N usually remains in that form and does not undergo nitrification. Under aerobic conditions such as those occurring in an aeration tank or a properly designed and functioning absorption field, biological nitrification is the dominant transformation mechanism. In the nitrification process, NH_4^+-N is readily oxidized to NO_3^--N. With soil as the secondary treatment medium, phosphate anions are capable of being strongly adsorbed to hydrous oxides of iron, aluminum, manganese, and carbonate surfaces on soil particles. Phosphate is also taken up by plant roots and incorporated into microbial cell material, as well as into other organic matter. Phosphate alone is not a toxic compound, but it is the limiting nutrient in freshwater lakes and ponds that is responsible for eutrophication.

Biological

Most of the biological constituents living in wastewater are actually beneficial in that they aid in the breakdown of the chemical and physical contaminants. Without these organisms, much of the wastewater treatment process would not occur. For example, most microorganisms transform inorganic forms of nitrogen (NO_3^--N and NH_4^+-N) into cell tissue. The amount that becomes microbial biomass is relatively small and is not permanently removed. Most of the nitrogen is released back into the environment after microbial die-off. Annelids, amoeba, actinomyces, nematodes, fungi, protozoa, bacteria, rickettsiaceae, and viruses are all common biologic components of wastewater. Numerous species are known to cause disease in humans. These organisms are known as pathogenic organisms and are an important component of environmental pollution from human waste.

Physical

The physical-pollutant makeup of wastewater is temperature, turbidity, and much of the solid material itself. The introduction of solid material is a significant source of contamination. Over the years, levels of nondegradable solid material in wastewater have grown increasingly higher. People now discard tampons, condoms, cigarette butts, drugs, and toilet paper in copious amounts that are flushed into the system.

Distinction Between Classifications of Wastewater Treatment

Over time, traditional wastewater disposal systems have come to be known as either on-site or municipal systems. Today, most professionals in the wastewater treatment field refer to municipal systems as CWWTS and to on-site systems as decentralized wastewater disposal systems (DWWTS). However, there are newly emerging treatment systems that better fit the term *DWWTS* because they actually do decentralize, whereas on-site systems never really were centralized. Therefore, for the purpose of this study, on-site wastewater treatment will be referred to as NWWTS (see Figure 1).

As mentioned, DWWTSs are being developed in increasing numbers. Several excellent examples of decentralized systems have recently been constructed and are fully operational in Mobile County, Alabama. With the bulk of the population growth taking place in the county's western portion, which lacks a wastewater treatment system, the wastewater utility board had a decision to make: Either construct lift stations to pump the sewage over the elevation divide and enlarge the existing main trunk line, or build a new collection system and sewage treatment plant that would discharge into Mississippi's Franklin Creek. A third option was taken; the board decided to use small, decentralized community systems (clusters). Each system is permitted to process 20,000 to 60,000 gallons per day (GPD) but may ultimately be capable of handling 240,000 gallons per day. Each system is designed around packaged recirculating treatment technology and utilizes primary interceptive tanks at each wastewater source (each dwelling). The wastewater flows over the treatment medium several times (80% return) before chlorination and discharge via spray irrigation onto a sod-growing field or via irrigation dispersal. Each system will handle several hundred homes.

Domestic-Sewage-Composition Variance

Domestic Sewage in General

Domestic sewage is that generated from households. Generally, this sewage is far less contaminated with chemical pollutants than industrial wastewater is. Municipal sewage, because the system is centralized, has more chemical pollutants than sewage does that is treated by a noncentralized or decentralized system receiving wastewater primarily from a residence. As previously mentioned, the trend over the past decades has been mostly toward centralized-system development. However, for a short period, funding was readily accessible for innovative noncentralized-system and decentralized-system development.

Decentralized-System Experimentation

During the late 1970s, some state and local governments experimented with different decentralized systems that could accommodate a variety of community conditions while also meeting environmental-protection goals. Subsequently, in the 1980s, the Innovative and Alternative Technology Program and the small-community-set-asides portion of the Construction Grants Program resulted in the construction of numerous small-community innovative technologies. Some of these technologies were hybrid systems, being a combination of both centralized and noncentralized approaches. However, circumstances changed in 1990, when both the federal Construction Grants and Innovative and Alternative Technology programs were completely eliminated. These programs were replaced by the Clean Water State Revolving Fund, which provides communities with low-interest loans, generally for municipal-plant renovations. The characterizations for the variance in influent raw wastewater for a centralized system versus a noncentralized system are significant. Municipal wastewater is generated by numerous source dwellings and businesses. Therefore, less concern is taken by the depositor of the waste. Ownership of the treatment system is not accepted by the individual units attached to the system. Often, anything that is physically capable of fitting through the plumbing gets flushed into the system. In contrast, noncentralized wastewater is generated by source dwellings that claim ownership in the treatment system. People living in the dwelling have a vested interest in the ability of the system to treat the wastewater and have a long service life. Therefore, the initial quality of the wastewater influent is generally much better with a noncentralized system than with a centralized system.

Non-Point-Source Activities

Currently, an estimated 70-80% of all U.S. surface water pollution is generated by non-point-source activities. This non-point-source pollution must be reduced. On-site systems (traditional septic-tank systems) are viewed by some proponents as inefficient wastewater treatment systems when, in fact, many environmental engineers do not recognize on-site systems as being significant contributors to the non-point-source pollution load. However, Environmental Health officials with the Mobile County Health Department estimate the on-site system failure rate within Mobile County to be significant. This evaluation will help to clarify the controversy by comparing some alternative on-site system performances with the performance of some municipal systems.

Sewage Treatment Effluent Quality Measures

Current Standards

The determination of the quality of wastewater effluent is based on several measures. In the United States, only industrial and municipal sewage effluent is regulated by federal, state, and local government agencies. NWWTSs are regulated only by local government agencies, which issue permits for installation and mandate repair when the system fails. There are no treatment standards.

CWWTS Standards

The USEPA has established a permitting system for the discharge of treated sewage effluent from municipal and industrial plants into the surface water environment (USEPA, 1980, 1998). These regulations pertain to the National Pollutant Discharge Elimination System. These specific water quality standards are developed by states in accordance with Protection of Environment, Water Quality Standards 40 CFR § 131 (1996) and Protection of Environment, Secondary Treatment Regulation 40 CFR § 133 (1996). Although these regulations are considered strict, state and local agencies can establish even more stringent standards. However, statutes do not allow a lesser government agency to impose more lenient standards. Table 1 lists parameters routinely monitored and used by the USEPA and most states for discharge permitting.

NWWTS Standards

There are no standards (M. Corry, personal communication, December 3, 2002; C. Shirk, personal communication, December 4, 2002; W. Studyvin, personal communication, December 3, 2002; D. Venhuizen, personal communication, November 3, 1995, and December 2, 2002). Michael Corry is heading the National Onsite Wastewater Recycling Association code effort to standardize NWWTS installation-and-maintenance procedures. However, Corry (personal communication) states that this effort will not set a fixed standard for treatment. Instead, a range of optional standards will be presented to local/state governments, with guidance on selecting a performance standard(s). Multiple standards are to be offered because the risk to health and the environment varies from place to place and because the standards that are adopted should match the risk. "One-size-fits-all" performance standards either over-or underregulate relative to risk across the broad scope of conditions in an area (M. Corry, personal communication).

Specific Parameters

A summary of the more important parameters is as follows.

Alkalinity is a measure of the ability of the wastewater to neutralize an acid. This parameter measures the degree to which this ability is impaired by carbonates, bicarbonates, hydroxides, borates, silicates, and phosphates to neutralize acids. The higher the alkalinity is, the greater the ability of the wastewater to neutralize acids and maintain a constant pH. Alkalinity is measured in milligrams of equivalent calcium carbonate per liter.

Table 1

Parameters Routinely Monitored for Allowable Effluent Discharge

PARAMETER			
Alkalinity (bicarbonate,	Chlorine (free)	Molybdenum	Tannin
carbonate)	Chlorite	Nickel	Temperature
Aluminum	Chloroform	Nitrate	Thallium
Ammonia nitrogen	Chlorophyll A	Nitrite	Thiocyanate
Arsenic	Chromium	Oxygen (dissolved)	Thiosulphate
Benzene, toluene,	Color	Orthophosphate	Total coliforms
ethylbenzene, xylene	Cyanide	Pentachlorophenol	Total dissolved
Biochemical oxygen	Electrical conductivity	pH	solids
demand	*Escherichia coli*	Phenols	Total nitrogen
Boron	Extractable hydrocarbons	Phosphorus	Total Phenols
Bromide	Fecal coliforms	Radiochemistry	Total Phosphorus
Cadmium	Fecal streptococci	Silica, reactive	Total suspended
Carbon Tetrachloride	Fluoride	Silver	solids
Chemical oxygen	Lead	Sulphate	Turbidity
demand	Lignin	Sulphate 3	Zinc
Chlorate	Mercury	Sulphide	
Chloride	Mineral oil and grease	Sulphite	
Chlorine (total)	(Hydrocarbons; gravimetric	Surfactants	
	& infrared)		

Fecal coliform (FC) counts are used as an indicator of the level of biological organisms (pathogens) present. FC organisms are a more definitive subgroup of total coliform (TC) organisms because the former organism come only from the intestines of mammals. Thus, this measure indirectly serves as an indicator of enterobacteria and is expressed as the number of colonies per 100 ml of water in standard cultured media. High colony counts indicate the presence of animal waste (thus, the likely presence of pathogens), which makes the water unsuitable for human recreation and consumption, and for some industrial uses such as the harvesting of filter-feed shellfish, which concentrate bacteria and other pathogenic organisms. Marine FC standards are more strict than freshwater standards are.

Metals and metalloids are elements that are distributed naturally by geologic and biologic processes. Many metals are added through pollution. These metals include antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc. Metals are normally measured by atomic absorption spectroscopy in milligrams per liter or micrograms per liter. Some metals, such as like cadmium and lead are highly toxic, whereas other metals such as iron are simply nuisances.

Nitrogen is measured as total persulfate nitrogen, which includes all organic and inorganic nitrogen; nitrate-nitrite N, which is total oxidized N; ammonia N, which is nitrogen produced by organic breakdown and hydrolysis of urea; and total kjeldahl N, which is ammonia and organic N. The total persulfate N is a more accurate measure than is total kjeldahl N. All nitrogen forms are generally reported in milligrams per liter. Important nitrogenous chemicals in wastewater include dissolved atmospheric molecular nitrogen (N2), organic compounds, ammonia (NH3) and ammonium (NH4+), nitrite (NO2-), and nitrate (NO3-). Nitrate is common in agricultural runoff. Ammonia, nitrate and nitrite are promoters of algal growth.

Nutrients include potassium, calcium, magnesium, sulfur, iron, chlorine, copper, manganese, zinc, molybdenum, boron, cobalt, and sodium. Nitrogen and phosphorus are significant wastewater pollutants because they are limiting factors for beneficial biological growth.

Chemical oxygen demand (COD) is a measure of the amount of oxygen required to oxidize organic matter by aerobic microbial decomposition and chemical means. COD measures the relative potential pollution of organic and inorganic material in the wastewater. COD is faster and more convenient to measure than BOD but does not correlate well with biological-organism concentration in the wastewater.

pH is the negative logarithm of the hydrogen ion concentration (pH = -log $[H^+]$ • H). The pH measure indicates the balance between acids and bases in water. pH affects the wastewater's chemical equilibria, solubility, toxicity of many metals, and availability of trace metals.

Phosphorus is an essential plant nutrient. Phosphorus in wastewater is usually measured as total phosphorus, which includes suspended and organic phosphorus, and orthophosphate. Total phosphorus is reported as milligrams per liter. Phosphorus is an important pollutant in that it can greatly stimulate eutrophication in receiving waters.

Total suspended solids (TSS) are an indicator of organic matter in the wastewater. These solids are insoluble and either float on the surface of or are in suspension in the wastewater. High TSS discharge in treated wastewater effluent is unpleasant (cloudy water) for humans and the environment. High TSS can stress benthic filter feeders and other natural flora and fauna because of reduced light penetration. TSS is sometimes referred to as total nonfilterable residue.

Turbidity is related to the clarity of the water. This parameter measures the light scattered and absorbed rather than being transmitted through the water (caused by suspended solids [SS] such as clay, silt, organic matter, and planktonic organisms). High turbidity reduces photosynthetic activity and also reduces the ability of ultraviolet (UV) radiation to kill pathogens.

BOD[3] is the amount of oxygen required by microorganisms to convert organic material in wastewater into microbial cell mass. Therefore, BOD is a primary indicator of biodegradable organic matter. BOD may be expressed in terms of milligrams per liter (parts per million) or as mass per unit mass (pounds per pound, kilograms per kilogram, etc.). In most wastewater system evaluations, the normal measure of expression is the biochemical oxygen demand (milligrams per liter) of the wastewater after 5 days of

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[3] Sometimes inaccurately termed biological oxygen demand.

incubation at 20°C (BOD_5). This measure is the most definitive test used in assessing wastewater strength.

Human Disease Associated With Sewage Contamination

General

Numerous epidemiological studies have provided evidence for the link between environmental reservoirs and human infection (Adams, Hanna, Mayernik, & Mendez 1994; Alexander, Heaven, Tennant, & Morris, 1992; Beller, Ellis, Lee, Drebot, & Jenkerson 1997; Cameron, Carrington, & Patterson, 1993; Fewtrell, Godfree, Jones, Kay, Salmon, & Wyer 1992; Fleisher, Jones, Kay, Smith, Wyer, & Morano 1993; Mouzin, Mascola, Tormey, & Dassey 1997; Thornton, Fogarty, Hayes, Laffoy, O'Flanagan, Corcoran, Parry, et al., 1995; Vonstille, Stille, Sharer, 1993; Walker, 1992). The field of environmental virology began in the 1940s with the detection of the poliovirus in water contaminated by sewage. Since this discovery, techniques have been developed to detect various environmental enteroviruses, rotaviruses, and caliciviruses in water reservoirs (Metcalf, Melnick, & Estes, 1995). In addition to the multitude of infectious diseases, various chronic diseases with causes such as heavy-metal poisoning also are attributed to sewage contamination of water supplies and recreational water sites. Furthermore, crop irrigation with water contaminated by sewage is another well documented transmission route for disease pathogens. Aquatic food items such as oysters can also transmit disease when harvested from sewage-contaminated waters, especially when consumed raw or undercooked.

The Epidemiology of Enteric Disease

Undeniably, fresh water is the most important natural resource in the world; without fresh water, life itself is not possible. Most but certainly not all diseases transmitted by way of water are enteric. The word *enteric* is derived from the Greek word *enteron*, which means intestine. Enteric disease is transmitted by way of what has long been described as the fecal-oral transmission route; in other words, the pathogen is passed from the fecal material of an infected (source) individual to the oral cavity and digestive tract of another (host) individual.

In the United States, citizens rightly expect the water they drink to be safe and wholesome. A system of standard setting evolved that is perceived as a precise science and meaningful to health. However, because water is the "universal solvent," it will always contain impurities before and after treatment (Bates, 2000). Knowledge of the vast potential for water to become contaminated is necessary to understand the epidemiology associated with waterborne pathogens and their effects.

Water use patterns vary considerably throughout the world, and the variation in water use affects assumptions based on infectivity that are derived from laboratory studies. The fact that an individual ingests water contaminated with a pathogen does not mean the individual will become symptomatic for the disease. Factors influencing infectivity include the individual's immune status, the virility of the pathogen, and the dose level (Pearce, 1999). For example, *Vibrio vulnificus* may have little effect on a healthy individual but may cause fatal septicemia in an individual with impaired liver or immune function. Enterotoxigenic *Escherichia coli*, enteropathogenic *Escherichia coli*, Shigella, *Vibrio cholerae*, and parasitic disease are all scourges in developing countries; however, it is uncertain how many cases are attributed to food, to water, or to person-to-person transmission.

In addition to the ingestion of water as a transmission vehicle, the consumption of food raised in pathogen-contaminated waters also serves as an efficient vector for fecal-oral transmission. The current volume of epidemiological data clearly demonstrates that filter-feeding bivalve shellfish act as very efficient vehicles for the transmission of enteric viruses by the fecal-oral route (Lees, 2000). Also, crops raised by using irrigation water contaminated with untreated wastewater have been implicated in numerous enteric-disease outbreaks. In undeveloped countries, disease outbreaks can occur on an epidemic scale. A vivid illustration of such an occurrence is the 1988 outbreak of Hepatitis A in Shanghai, China, that involved nearly 300,000 cases. Another recent example is the large-scale outbreak of gastroenteritis that occurred in1998 in a Swiss village of 3,500 inhabitants; in this outbreak more than 50% were affected. Examination of the local drinking water revealed the presence of Norwalk-like viruses and enteroviruses (Hafliger, Hubner, & Luthy 2000). Investigation uncovered a defect in the local wastewater treatment system that led to the contamination of the drinking water. Furthermore, Giardia, a well-known enteric parasite affecting humans and a range of domestic and wild mammals, is considered to be a reemerging infection because of its association with outbreaks of diarrhea in childcare centers (Thompson, Hopkins, & Homan 2000).

Newly emerging pathogens have increased the level of concern for most governments of the world. Epidemiological surveillance of waterborne disease has increased in the United States over the recent years (Todd, 1997). Some additional factors that have led to this increased surveillance include the identification of new agents that have caused life-threatening conditions; the increasing number of large outbreaks being reported; the impact of waterborne disease on children, older persons, and immunocompromised persons; and the development of more aquaculture industries (Pell, 1997).

Rates of incidence and/or prevalence for the morbidity and mortality of these enteric diseases are difficult to discern, both at the state level and of the national level. The reason is the massive reporting error. Although reporting most of these diseases to health authorities is required by law, they are seldom reported. The exceptions would be *E. coli* 0157:H7, Hepatitis A, poliovirus, typhoid fever, and cholera; these diseases are rare and fairly easy to accurately diagnose. The bulk of the other enteric diseases are often misdiagnosed, or physicians simply do not make an effort to report them.

The Weeks Bay Experience

The Weeks Bay area of Baldwin County, Alabama, is the location of several of the atypical wastewater treatment sites that contributed data to this study. In 1978, Weeks Bay was closed to commercial harvesting of oysters because of extremely high FC organism counts. Until then, Weeks Bay has been a dominant location for harvesting oysters.

The area of this study is the region of Alabama situated around the Mobile Bay. Mobile Bay is a major watershed catch basin for the southeastern United States (Figure 2).

As such, a tremendous quantity of organic matter eventually makes its way into the receiving waters of the bay. Local contamination of the bay waters also occurs on a continuing basis. Recently, two major episodes of point-source surface water contamination occurred. The first episode occurred in the vicinity of Weeks Bay (Figure 3), early in July, 1999. An estimated 500,000 gallons of untreated sewage were released into the Santa Rosa Sound when a malfunction occurred at one of the municipal sewage treatment plants (MSTPs) in Pensacola, Florida.

Approximately 22 miles of the sound were closed to fishing and swimming for 3 weeks because of high FC counts (the principal indication of human-pathogen contamination). The other recent sewage contamination episode occurred in the Mobile River, which empties into Mobile Bay. An estimated 1,200,000 gallons of raw sewage entered the river after a control panel for a lift station was struck by lightning.

Persistent Organic Pollutants

This study focuses on disease pathogen transmission potential (biologicals) entering the aquatic environment by various atypical NWWTSs. However, biologic organisms are not the only cause of disease. It must be noted that disease transmission associated with exposures to chemicals that have contaminated sediment and biota in lakes and marine waters is also increasing in frequency. For example, persistent organic pollutants represent a significant threat to the environment and the public's health. Contamination of water systems with trihalomethanes, polychlorinated biphenyls, polychlorinated terphenyls, polynuclear aromatic hydrocarbons, and heavy metals (lead, mercury, cadmium, silver, and gold) has increased dramatically over the years.

Disease Magnitude

In 1996, over 2,500 U.S. beaches were closed for at least one day because of some form of pathogen contamination (USEPA, 1998). Most U.S. beaches are not even monitored or are inadequately monitored. Illness can ensue from swimming or playing in contaminated water. Children are more at risk because they tend to accidentally ingest water much more frequently than adults do. Diseases transmittable to humans from sewage-contaminated water include amebiasis, balantidiasis, candidiasis, cholera, coxsackie carditis, cryptosporodosis, cytomegalovirus, echinococcosis, *E. coli* 0157-H7, fasciolopsiasis, fasioliasis, giardiasis, hepatic capillariasis, Hepatitis A, Hepatitis E, herpangina, *Listeria monocytogenes*, Marburg virus, *Mycobacterium paratuberculosis*, paragonimiasis, paratyphoid fever, pleurodynia, poliovirus, rotoviral gastroenteritis, salmonellosis, shigellosis, typhoid fever, *Vibrio vulnificus*, viral gastroenteritis, and yersiniosis. Although other pathogens could be included in the list, these diseases are the most significant. Furthermore, although medicine and public health have advanced tremendously over the past decades, these diseases still pose a major worldwide threat to public health. For example, from 1 January to 31 July 1992, a cholera epidemic was responsible for 548 reported cases among the inhabitants of Riohacha, Colombia. An epidemiological study concluded that the Riohacha cholera cases were transmitted by contaminated municipal drinking water caused by a faulty sewerage system (Cardenas, 1993). Recent studies that examined the pathogenic content of ocean waters receiving treated sewage concluded that all of these waters contain pathogenic organisms (Palmer, 1993; Raghunath, 1993). Of particular note are the facts that *Legionella spp.* are present in all phases of sewage treatment and that population numbers of the species do not significantly decline during the treatment process. Ocean-receiving waters located as far out as 5 miles offshore from the location at which the treated sewage was discharged were found to contain *Legionella spp.* Another recent example is the large outbreak of gastroenteritis that occurred in New South Wales, Australia. This disease outbreak was attributed to sewage contaminating the river used as a source of drinking water. The contamination came from a break in the sewage pipe directly over the underground water tanks (McAnulty, 1993).

Sewage Treatment Effluent Quality Measures Indicative of Potential Pathogen Contamination

Primary Measuring Sticks

In terms of pathogen contamination, wastewater effluent quality is judged by three primary measures. These measures are BOD, TSS, and microbial-indicator-organism levels (TC, FC, *E. coli*, and enterococci).

Many microorganisms (chiefly bacteria) use the carbohydrates and proteins usually found in the suspended solids that elevate BOD_5, however, others employ compounds most organisms cannot use, such as sulfide, ammonia, and hydrocarbons. Therefore, TSS is an indicator of the sewage composition's ability to support the rapid growth of pathogenic organisms. BOD_5 is the measure of the amount of oxygen required by microorganisms for stabilizing organic matter that can be decomposed under aerobic conditions. Most FC species are common, generally harmless forms of bacteria that are normal components of the intestinal system of all mammals. Because humans are included in this class, these organisms serve as classic indicators of contamination with fecal matter and, therefore, of potential human pathogens. FC bacteria levels have been commonly used as an indicator of the presence of pathogenic microbes. Coliform bacteria are not necessarily pathogenic. However, because these bacteria are natural flora common to the human enteric system and are relatively easy to identify in the laboratory, FC serve as an excellent positive indicator of human fecal contamination. The concentrations listed in Table 2 are for typical residential dwellings equipped with standard water-using fixtures and appliances (excluding garbage disposals) and generating approximately 450 GPD. All values are for raw (untreated) residential wastewater.

Table 2

Typical Parameter Influent Concentrations

Parameter80	Concentration (mg/L)
Total suspended solids	200-290
Biochemical oxygen demand, 5 day	200-290
Fecal coliform	10^{8}-10^{10}

Note. Data extracted from *Design manual--Onsite wastewater treatment and disposal systems* (Report No. 125/1-80-012, p 56, 1980, C. Schmidt.

Studies Attempting to Assess Pathogen Potential

Several recently published works have used the parameters of BOD_5, TSS, and FC to assess pathogen pollution. This section contains a synopsis of the reported findings.

Whitby and Palmateer (1993) developed a model for predicting sewage system performance by measuring wastewater disinfection capabilities with different UV irradiation systems. The project measured changes in the quantity of FC bacteria and TSS from influent sample to effluent sample. The study investigated the wavelength dependence of sunlight inactivation with temperature, dissolved oxygen and pH control. Results indicated photoreactivation by a fluorescent lamp in the case of indicator bacteria (heterotrophic bacteria, coliform bacteria, FCs) in raw sewage but not in the case of *E. coli* B and *E. coli* K12 A/lambda(F+). Inactivation of FC (85% reduction) and reduction in total solids (40%) was observed simultaneously during photoreactivation by sunlight. Dose rate at 360-nm wavelength proved to be a useful indicator for assessing the photoreactivation rate and the maximum survival when photoreactivation took place by both fluorescent lamp and sunlight. Whitby and Palmateer concluded that the related World Health Organization microbial guideline (1,000 CFU/100 ml of FCs) was easily met with UV radiation disinfection.

Surampalli (1993) conducted a prospective evaluation of selected wastewater treatment plants by measuring their potential for meeting newly proposed USEPA class B pathogen reduction criteria. The study measured selected actual pathogens and indicator bacterial (FC) reductions in the sludges of wastewater treatment plants. Determinations were based upon several biological measures, including FC and TSS. The effectiveness of different treatment systems in reducing pathogenic density levels was evaluated according to the criteria established by Protection of Environment, Sewage Sludge 40 CFR § 503. The results indicate that anaerobic digestion was superior to aerobic digestion in reducing pathogen density levels under the given field conditions. Composting was far more superior to both anaerobic and aerobic digestion. The study demonstrated that the Class B requirements under the 503 Rule are reasonable and can be achieved by most existing treatment systems, whereas the Class A requirements under the same rule may not be easily achieved by many existing treatment works. Additionally, the log reductions in FC and fecal streptococci appeared to be dependent on volatile suspended solids loading rates.

Ng (1993) examined the relationship between sewage treatment loading factor and the removal of BOD_5, COD, TSS, TC, FC and coliphage during the treatment process. Results indicated that the treatment efficiency of sequencing batch reactors for coliform/coliphage was as high as 99% removal. The test results showed that an average

COD removal of 98.5% was achievable, with BOD removal as high as 99%. Furthermore, predictions of coliform numbers could be made by enumeration of the coliphages. The coliform-coliphage correlation is similar to that for natural water (as proposed by the American Public Health Association's Standard Methods, (Franson 1995)). Ng et al. concluded that an undeniable correlation exists between treatment loading factor and contaminant removal.

Acher (1994) conducted an evaluation of a newly proposed photochemical-disinfection method to be used for treating domestic-wastewater effluent as a potential irrigation water source for edible crops. To measure the effectiveness of the disinfection process, Acher et al. used total and fecal coliform measures taken after disinfection and compared the readings with those measures taken before disinfection. The pilot plant operated at an effluent flow rate of 33 ± 3 m^3/hr (effluent detention time 35 ± 2 min), and the following decreases in microbial counts were observed (log counts): coliforms -3.2 ± 0.3 organisms, fecal coli -3.12 ± 0.2 organism, fecal streptococci -3.9 ± 0.3 organism, and poliovirus -1.9 ± 0.25 organism. The treated effluents did not show regrowth of these microorganisms during 7 days of storage in photoreactors and did not form an impermeable crust when infiltrated into sandy soils.

White (1995) conducted a research project to measure the removal of FC bacteria from septic-tank effluent. The study involved peat-moss biofilters as the post-septic-tank on-site sewage treatment system. One of the intents in this project was to address the contamination of shellfish-growing waters from failing on-site sewage disposal systems into the Gulf of Mexico and associated estuary systems. Results showed reductions in FC densities averaging 93% over a 12-month period and a 98% reduction during the last 3 months of monitoring. Reduction in BOD was 85% over the 12 month sampling period. The conclusion was that improvements observed over 12 months in effluent quality suggest that the peat-moss biofiltration sewage treatment system undergoes a process of acclimation to the ambient environment before reaching maximum efficiency. Furthermore, the use of this system in the coastal region of the Gulf of Mexico could greatly reduce the levels of FC bacteria entering shellfish-growing waters and, therefore, reduce human pathogen contamination.

Tleimat and Tleimat (1996) conducted an analysis of drinking water purity from previously contaminated water stored on U.S. Navy ships. Some vessels rely upon the recovery of gray water and convert it to drinking water by using an evaporation/desalination process. The research used both U.S. Navy and USEPA standards to evaluate the parameters of TSS, FC, and BOD_5. The tests were run at an average temperature of 122 °F in the evaporator. The results show that potable-water recoveries as high as 98.6% are possible. Measured energy consumption by the compressor and rotor (for this small unit) varied from 75 to 90 Wh/gal. Samples of the wastewater, distilled water, and blowdown were collected for analysis. The results of the analysis of the distilled-water samples indicate that TSS, FC, and BOD were below the detection limits of the instruments used in the analysis. The COD varied from below 10 milligrams per liter (detection limit) to 30 milligrams per liter.

Jowett (1997) conducted an evaluation that measured the pathogen removal potential of a newly proposed free-draining aerobic biofilter. The intended market for the new filter was treating domestic septic-tank effluent before its discharge into the environment. The principal measures used in the evaluation to declare the system effective were >95% BOD_5 reduction, >95% TSS reduction, and >99.5% reduction in total and fecal coliform counts. This field trial demonstrated that the system removes 97.8% of BOD, 95.1% of TSS, and 99.5% of FC bacteria with 12-16 °C wastewater loaded at 49 cm/day(-1). Laboratory column experiments demonstrated that removal of FC averages >99.99% at 80 cm/day(-1) loading, and >99.99% at 10 cm/day(-1) after a 10-14 day acclimatization period. Ammonium is thoroughly oxidized to NO3-, with typically <2.5 mg/L(-1) NH4+-N in the effluent. Overall treatment improves with forced air flow compared with natural convection. Cold influent and plugging by freezing are the main causes of poor treatment. Conclusions indicated this treatment system would find general application in renovating polluted water, including water for domestic consumption in developing regions of the world. Jowett also indicated preliminary work had begun on correlating these data to virus removal.

Olsson (1997) published an evaluation of the pathogen reduction potential for sequencing batch reactors. These reactors are used in the treatment of wastewater by certain municipal treatment plants. Their purpose is to increase the capacity of a particular aeration lagoon. To be deemed effective, a reactor had to achieve at least a 99% reduction in BOD_5, a >65% reduction in TSS, and a >97% reduction in FCs. The results showed very good removal rates of 99% for BOD, 88% for COD, and 65% for TSS. Aeration requirements were found to be 1.5 L/min and 0.5 L/min for two 4-L reactors in series. The Coefficients A and B for the determination of oxygen requirements were established at 0.68 g O_2/g BOD and 0.32 day(-1), respectively. Dissolved oxygen levels of 1-3 mg/L were maintained at a design mean cell residence time of 20 days. Coliforms were reduced from 3,500 MPN/100 ml in the influent to 80 MPN/100 ml in the effluent. Confirmed coliforms were identified as *Bacillus spp.* and *Micrococcus spp.* Salmonella and FCs were not detected in either the influent or the effluent wastewater.

Vera (1997, 1998) conducted studies to measure the risk associated with using treated wastewater effluent to irrigate crops for human consumption. Vera et al. (1997) estimated the potential for pathogen transmission associated with the reuse of the secondary treated wastewater (after microfiltration) for the irrigation of banana and tomato crops. Pathogen indicator criteria used to approximate risk included the laboratory measurement of FC, TSS, and BOD. Vera et al.'s 1997 study was devoted to preliminary results obtained with cross-flow filtering through a 0.14-μm inorganic composite membrane (i.e., Carbosep M14), which, indeed, was a total barrier for suspended solids, TC, FC and fecal streptococci. The removals of turbidity and total COD were also significant at about 93% and 60%, respectively. There was no rejection of the soluble fraction of a size lower than 0.01 µm. A 45% abatement of phosphorus was also obtained. Therefore, the microfiltered water was perfectly adapted to irrigation. Vera et al.'s 1998 study involved the same data obtained for the earlier study but addressed microfiltration's ability to meet required standards. Results indicated suspended solids, TC, FC, and fecal streptococci were 100% removed by the microfiltration process. There was no rejection of the soluble fraction of a size lower than 0.01 µm. A 45% abatement of phosphorus was also obtained. Vera et al. (1998) concluded that the microfiltered water could meet all required standards for irrigation water.

Ponugoti (1997) conducted a study to measure the effects of different biosolids treatment systems on pathogen and pathogen indicator reduction. The different systems were evaluated according to the criteria established by the USEPA (40 CFR Part 503 Rule). The results indicate that anaerobic digestion was superior to aerobic digestion in reducing pathogen density levels under the given field conditions. Composting was far more superior to both anaerobic and aerobic digestion. The study demonstrated that the Class B requirements under the 503 Rule are reasonable and can be achieved by most existing treatment systems, whereas the Class A requirements under the same rule may not be easily achieved by many existing treatment works. Additionally, the log reductions in FC and fecal streptococci appeared to be dependent on volatile suspended solids loading rates.

Tanner (1998) conducted a demonstration project to show the relationships between pollutant mass loading and the removal of pathogen indicators. The research involved various pilot-scale constructed wetlands that were used as secondary treatment for atypical wastewater treatment systems. The parameters of BOD_5, TSS, FC counts, and total nitrogen were used. Results basically followed seasonal patterns in influent-wastewater strength. Mean annual mass removals of 58% to 78% of TSS, 73% to 91% of BOD, and 93% to 99.6% of FC were recorded, with removal efficiencies inversely related to loadings. Mass removal rates were monotonically related to loading rates and could be modeled using a simple plug-flow, first-order approach accounting for removal down to nonzero background concentrations. Comparisons with treatment performance recorded for the wetlands soon after commissioning showed relatively constant relationships between mass loading and removal of BOD and FC. In contrast, TSS and total nitrogen removal declined significantly over the same period. Reduced TSS removal efficiency appeared to result from clogging of the gravel substratum by refractory organic solids, and reduced total nitrogen removal appeared to be caused by saturation of substratum sorption capacity and filling of plant storage pools. To improve nitrogen removal predictions for wetlands treating ammonium-rich wastewaters, the use of a combined carbonaceous and nitrogenous BOD term was proposed that addresses the oxygen dependence of microbial nitrification.

Gearheart (1999) conducted a study to assess the capability of a constructed wetland treatment system and a UV radiation disinfection unit to meet Title 22 California Reuse Standards for public use irrigation. The study examined FC, BOD, and TSS reductions in domestic wastewater after treatment through atypical sewage treatment processes. The process involved a constructed open-water wetland, a slow sand filter, and a portable UV disinfection unit. This one-year pilot project utilized oxidation pond effluent as the influent to the test system effectiveness in removing key pathogen constituents (BOD, TSS, FC, and nitrate nitrogen); th results, along with the cost of the system is compared with the results and costs of other water reuse treatment systems. Gearheart Concluded that free surface constructed wetlands have demonstrated high efficiency and reliability in removing pathogen indicators. The performance data for the proposed pond/wetland/UV system has been incorporated into a decision support model, Water and Wastewater Treatment Technologies Appropriate for Reuse.

Al-Muzaini (1999) evaluated the pollution contribution from a major sewage outlet located close to Shuwaikh Harbor that discharges raw and treated wastewater from the Al-Ardhiya sewage treatment plant, as well as raw sewage from a pumping station.

Samples were collected from 11 fixed stations at high tide and 6 stations at low tide to examine water quality parameters of NO3, NO2, NH3, SO4, S2, PO4, BOD, COD, TSS heavy metals (Pd, V, Cd, Ni, Mn, Cr, Cu), and FC. The results of the physical and chemical analyses for both high and low-tide samples, along with microbiological analyses, indicate that the Shuwaikh marine area is polluted. The pollution is high near the discharge point and decreases with distance. The data revealed a lower level of chemical pollutants and fecal counts at high tide than at low tide. This disparity was concluded to be attributable to the dilution effect caused by incoming seawater at high tide. Although tidal movement helps reduce pollution in the area, it was recommended that biological wastewater treatment be initiated to remove most of the organic matter before discharge.

Khan (1999) conducted a study of the Kabul river and its tributaries to assess the pollution extent caused the levels of organic matter and FC. Thirty-eight water samples were collected and analyzed over a one-year period. Each sample was analyzed for total organic strength measured as COD and degradable organics measured as BOD. For a reason that is not explained in the report, river water samples from different locations were also analyzed bacteriologically for FCs. All of the wastewater samples and river water at a few locations were found to be high in COD, BOD, and FC rendering the river water unfit for irrigation and human consumption Khan concluded that the effluents from Khazana Sugar Mills, Colony Sarhad Textile Mills, Amarjee Paper and Paper Board Mills, and from different tanneries are the main sources of organic pollution in the Kabul river.

Kayyali and Jamrah (1999) evaluated the effect of centralized wastewater treatment plant effluent in terms of pathogen pollution. The research premise was that "wastewater reuse for irrigation increases the prevalence of health infections". The study covered a 4-year period and evaluated data from plants operated by the government of Jordan ($n = 16$) and others operated by the private sector ($n = 5$). Samples were collected from the effluents of these plants and were analyzed for their content of BOD, COD, TSS, FC, and selected parasites (protozoa and helminthes). The results of the study indicated all plants met treatment standards. Furthermore, Kayyali and Jamrah also concluded on the basis of BOD, COD, FC, and TSS that the effluents of the treatment plants included in the study can be reused for irrigation purposes ranging from unrestricted irrigation to irrigation for animal feed.

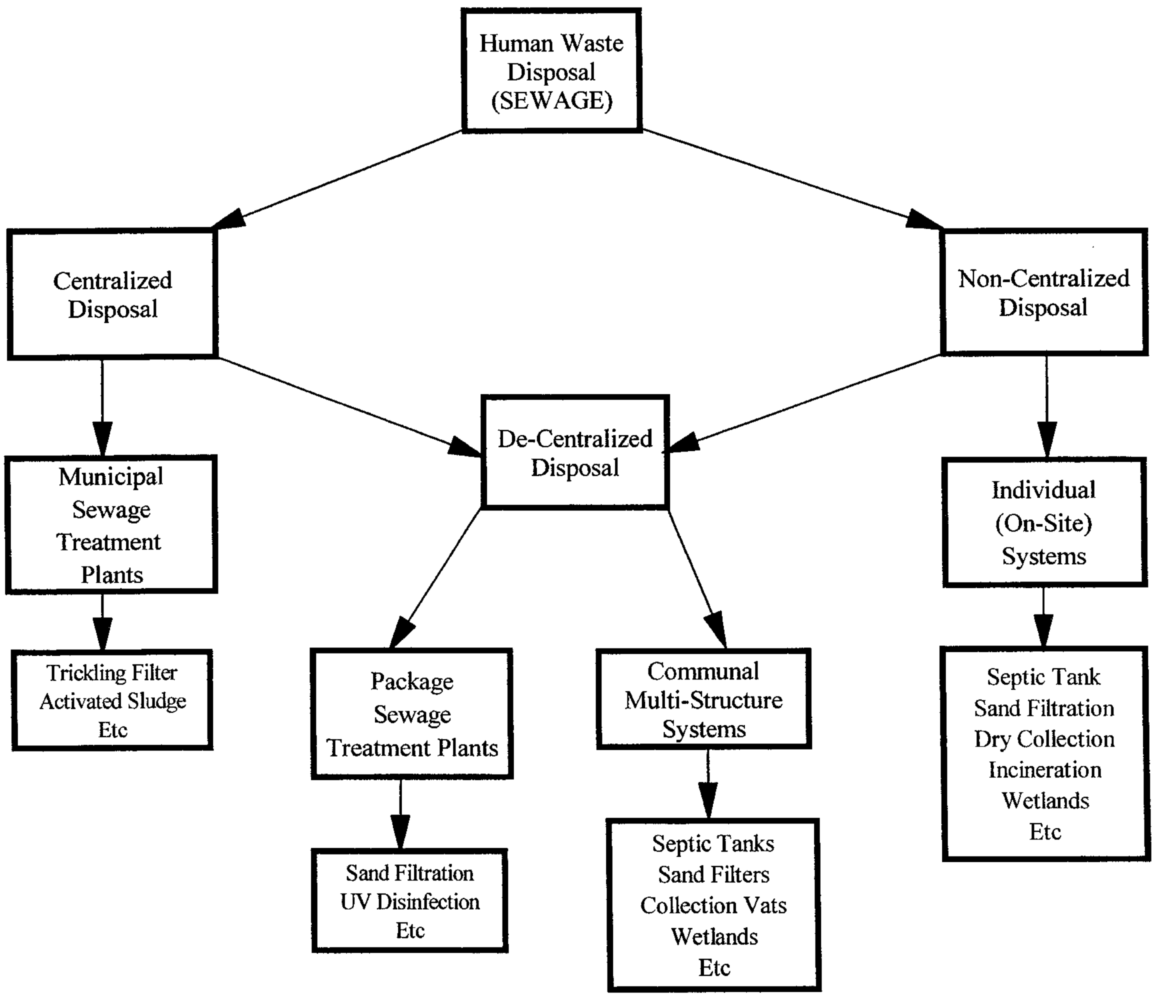

Figure 1. Classification of wastewater treatment systems. UV = ultraviolet.

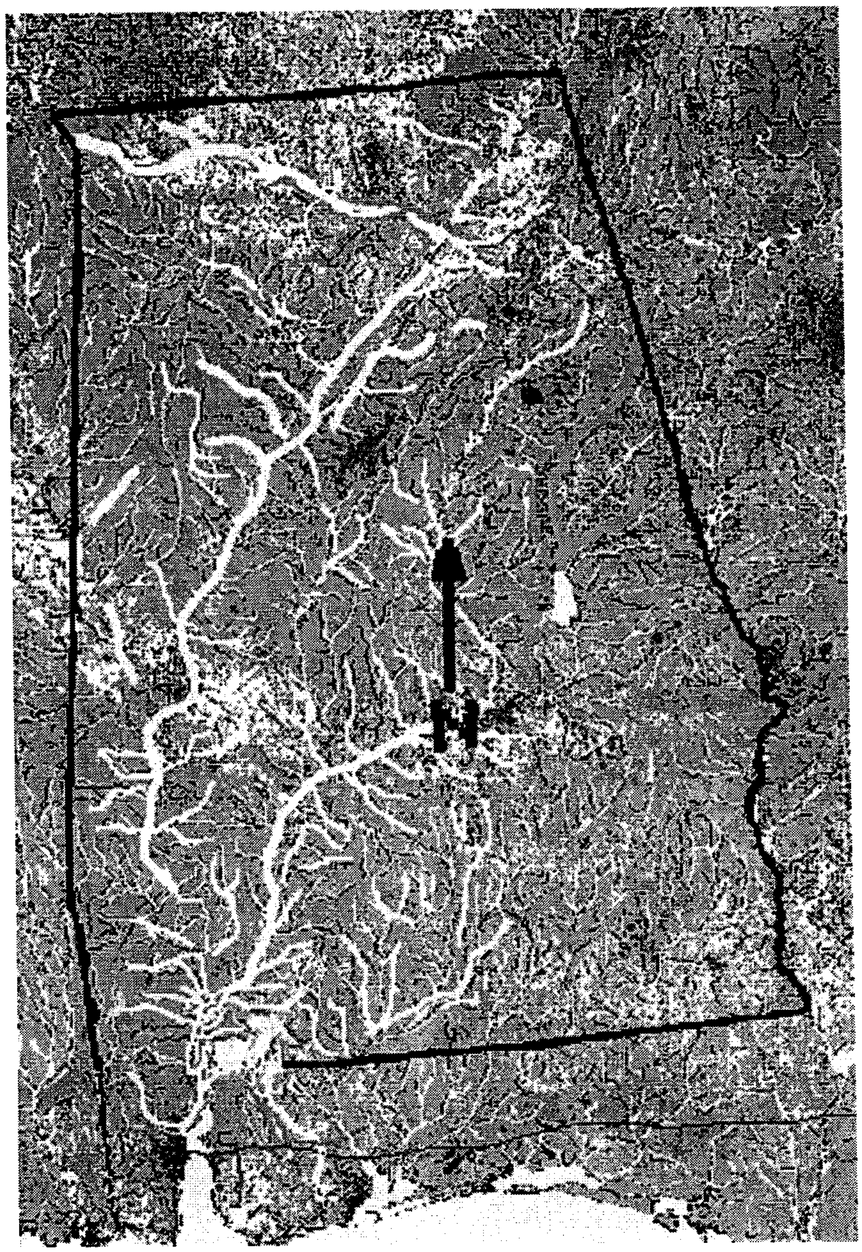

Figure 2. Mobile Bay watershed catch basin.

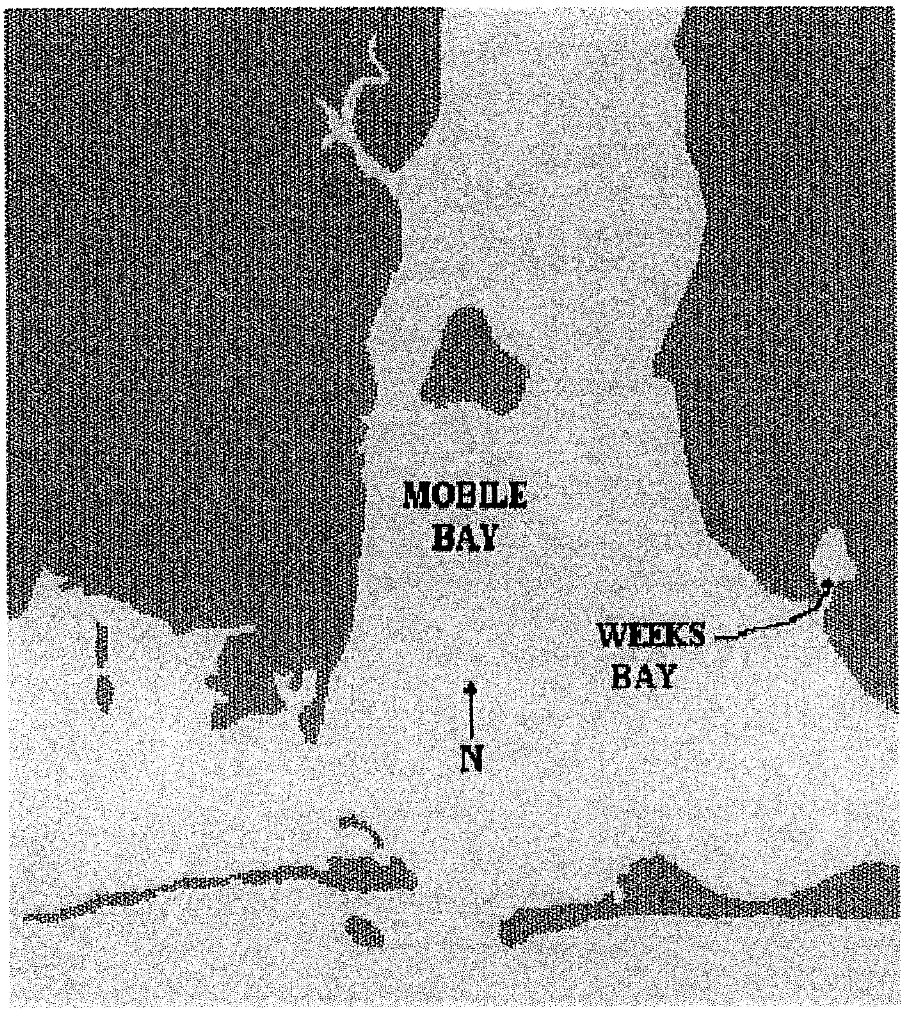

Figure 3. Weeks Bay, Alabama.

CHAPTER 2

BACKGROUND

Noncentralized Wastewater Treatment and Disposal

General

A properly installed and maintained system for treating and disposing of human and other household wastewater should reduce the impact of the system on groundwater and surface water supplies (USEPA, 1980). State and many local authorities enact codes specifying the manner in which noncentralized wastewater systems must be designed, installed, and maintained. In Alabama, the Department of Health regulates private sewage systems independently from municipal systems, which are regulated federally and by the Alabama Department of Environmental Management (ADEM). On-site system regulations include installation approval specifications, as well as minimum separation distances the wastewater system must be from a private well or other water sources. Decentralized-system regulation has yet to be fully addressed by most states. In Alabama, if the final effluent is discharged subsurface, the Alabama Department of Public Health (ADPH) has permitting jurisdiction. However, ADPH has yet to establish rules for the new alternative technologies. If the proposed decentralized system is intended to discharge final effluent to the surface (streams, bays, spray irrigation, etc.), then ADEM has permitting jurisdiction. ADEM applies the same centralized municipal system performance based standards, regardless of the alternative technology.

With most NWWTSs, primary and secondary treatment processes are all that occur. Therefore, it is important that wastewater treatment actually begin at the source. Beginning treatment at the source accomplishes the following objectives: (a) Gross solid generation within the household is kept to an absolute minimum, (b) overall water usage is less, and (c)excessive use of harsh chemicals is kept to a minimum. Certain chemicals have a toxic effect on beneficial microbes. Therefore, owners of noncentralized systems must keep chemical contamination to a minimum. During primary treatment, the septic-tank provides both a quiescent zone where solids settle out of suspension and a site for anaerobic digestion. Some systems even take advantage of aerobic treatment. The digestion process within the septic-tank is actually quite efficient, reaching maximum efficiency during the warmer portion of the year. The solids-separating ability in a septic-tank is maximized in the colder periods because less gas generation and less particulate resuspension occur with colder temperatures. Basically, there are two broad categories for these systems: Conventional and atypical.

Conventional

The conventional NWWTS consists of the septic-tank (Figure 4) and the disposal trench, which uses only the ambient soil for secondary treatment. It is essential that the septic-tank be water tight to ensure proper operation of any system employing the tank as the first step of the treatment process.

Periodic inspection and pumping of septic-tanks on an as-needed basis help assure that the digestion process is maximized and that life cycle costs to the homeowner are kept to a minimum. Effluent filters placed on the outlets of tanks are simple yet effective devices for retaining solids within the digestion step and safeguarding absorption fields. Pollutants common to septic-tank effluent include: TSS, material requiring high BOD, nutrients such as nitrogen and phosphorus, and human pathogens. The ability of soil to remove or inactivate these contaminants depends upon several soil factors (Dow, 1996). These factors include soil texture and structure, the amount of soil particle surface area and particle chemical properties, and the presence of soil microbes that utilize or degrade incoming pollutants. When geological and hydrological conditionsare optimum, these simple systems work quite well in reducing the pollution burden to the environment. However, very few regions have optimum geological and hydrological conditions.

Bacteria in the septic-tank wastewater are facultative anaerobes or obligate anaerobes. Facultative bacteria have the capability of living either in the presence or in the absent of oxygen, whereas obligate anaerobes require no oxygen at all. These single-celled organisms grow and, when they have attained a certain size, divide and become two organisms. If the food supply is adequate, these two single celled organisms then grow and divide again like the original cell. Every time a cell splits (approximately every 20-30 min) a new generation occurs. This stage is known as the exponential or logarithmic growth phase. At the exponential growth rate, the largest number of cells are produced in the shortest period. These bacteria and their enzyme systems are responsible for many different chemical reactions that produce the degradation (digestion) of organic matter. Basically, these colonies of bacteria are literally factories for the production of enzymes. The enzymes that are manufactured by the bacteria will be appropriate to the substrate in which the enzyme will be working; in other words, the bacteria automatically produce the right enzyme for the biological reduction of any waste material (Wagner et al., 2002). Important genera of these bacteria include *Achromobacter, Aeromonas, Alcaligenes, Arthrobacter, Bacillus, Bacteroides, Citrobacter, Citromonas, Clostridium, Desulfotomaculum, Edwardsiella, Enterobacter, Erwinia, Escherichia, Flavobacterium, Fusobacterium, Hafnia, Klebsiella, Micrococcus, Morganella, Nitrobacter, Nitrosomonas, Oscillospira, Photobacterium, Planococcus, Plesiomonas, Proteus, Providencia, Pseudomonas, Salmonella, Serratia, Shigella, Sporolactobacillus, Sporosarcina, Staphylococcus, Stomatococcus, Veillonella, Vibrio, Yersinia,* and *Zoogloea* (Atlas, 1987; Jenkins, 1993). Many of the organisms from these genera become part of the biomat formed in the percolation zone and combine with the natural fauna of the soil for further biodigestion.

Atypical

As previously mentioned, most NWWTSs are conventional, which means that the existing soil does the work of secondary treatment. Therefore, soils are a key factor in wastewater treatment, and soil types can vary extensively from region to region. For example, at one extreme, soils that limit water movement (clays) are problematic in that surfacing of the wastewater will occur. At the other extreme, soils that do not limit water movement (sands) are problematic in that retention time is not sufficient to allow adequate treatment. The microbiological processes in soil are sensitive to environmental conditions such as temperature, oxygen levels, and moisture status. For example, cold temperatures reduce biological efficiency and treatment performance, low oxygen levels reduce the efficiency and types of aerobic treatment processes, and high moisture is favorable for the survival of anaerobic septic microbes and inhibits the growth of naturally occurring (and beneficial) soil microbes. Therefore, numerous atypical advanced treatment NWWTSs have been developed that do not depend entirely upon ambient soil for secondary treatment. These systems use a variety of aerobic biological mechanisms (suspended growth or artificial growth) for secondary treatment. These alternative advanced treatment systems have several advantages over both centralized systems and conventional noncentralized systems (H. Ball, personal communication, January 11, 1998). In general, these alternative systems are less expensive per capita to install and maintain. Centralized wastewater sewerage systems require a huge financial investment that can often exceed the financial capability of the community (T. Bounds, personal communication March 6, 1998). Advanced systems normally reduce water usage, save energy, save materials, and are often environmentally safer and more reliable in ecologically sensitive areas (e.g., groundwater protection and protection of offshore shellfish beds or where construction of other wastewater collection systems may disrupt the ecosystem). Advanced wastewater disposal systems do not discharge chlorinated effluent. By contrast, most centralized municipal wastewater treatment facilities do discharge chlorinated effluent. The chlorine is used to disinfect the effluent (tertiary treatment). Although dechlorination occurs, regulations require a minimum chlorine residual of 1.0 ppm in the discharged treated effluent. Several centralized municipal systems have made a transition to other tertiary treatment methods such as ozone and UV light (Langlais, 1992; Oppenheimer, 1997; Rakness, 1993). However, chlorination remains the predominant tertiary treatment method used by centralized wastewater treatment systems. Chlorination is not an issue with most alternative wastewater disposal systems. Furthermore, previous site-limiting factors such as high groundwater tables, impervious soils, or shallow bedrock no longer preclude the installation of many of these innovative atypical systems. These many factors have ignited great interest from engineers, community leaders, and community developers in selecting atypical noncentralized systems as the choice for domestic-wastewater disposal.

Soil Treatment Processes

The soil performs the lion's share of the cleaning process in on-site wastewater treatment (K. White, personal communication, November 20, 2000). Although some chemical processes (primarily cation exchange) occur, most of the soil treatment process involves biological action. Various biological processes reduce the amount of carbon, nitrogen, phosphorus, solids, and pathogens that enter groundwater. BOD is an excellent indicator of the biodegradable pollutant in the wastewater.

Environmental engineers use the U.S. Department of Agriculture soil grouping description system. This system consists of four soil groups, Which are displayed in Table 3.

Most of Alabama has what is termed prairie soil, which is a tight clay-like soil that falls into Soil Group IV. However, in a large portion of Baldwin County, the soil is loam sand to sandy loam, Soil Groups I and II, respectively. In southern Baldwin County, the soil is too sandy to allow sufficient retention time. Furthermore, in that part of the

Table 3

U. S. Department of Agriculture Soil Classification System

Soil Group	USDA Description	Percolation
I	Sand, gravel, loam sand	Very Good
II	Sandy loam, loam, sandy clay loam	Good
III	Silty loam, clay loam, silty clay loam	Moderate
IV	Sandy clay, silty clay, clay	Poor

Note. Data extracted from *Soil taxonomy - a basic system of soil classification for making and interpreting soil surveys*, p 13, 1999.

county, the water table is 2 ft or less from the surface. This situation is termed *hydric*, which means the soil is water soaked most of the time. The U.S. Army Corps of Engineers often designated land of this type as wetland.

Excessive nitrate-nitrogen (NO3) released into groundwater can be a significant health hazard to persons receiving drinking water from a well. A phenomenon known as blue-baby syndrome (methemoglobinemia) can occur in babies less than 6 weeks of age because they lack an enzyme and cannot tolerate additional NO3. The use of nitrate-contaminated drinking water to prepare infant formula is a well-known risk factor for infant methemoglobinemia (Avery, 1999; Centers for Disease Control, 1997; Downs, Cifuentes-Garcia, & Suffet, 1999; Gelberg, Church, Casey, London, Roerig, Boyd, et al., 1999; Gupta, Gupta, Seth, Gupta, & Bassin, 2000; Knobeloch, Salna, Hogan, Postle, & Anderson, 2000; Saito, Takeichi, Osawa, Yukawa, & Huang, 2000). Affected infants develop a peculiar blue-gray skin color and may become irritable or lethargic, depending on the severity of their condition. The condition can progress rapidly to cause coma and death if not recognized and treated appropriately. Because of this danger to infants, the national drinking water standard for NO3 is $\leq$ 10 mg/L.

The method by which soil treats wastewater is the formation of a biomat. Carbon materials present in wastewater allow more organism growth. The primary organism group responsible for treatment is aerobic and facultative bacteria; however, higher life forms such as protozoans, rotifers, algae, nematodes, annelids, insects, and insect larvae also contribute to the biomat matrix. The principal bacteria genera important in the soil treatment process include *Aeromononas, Bacillus, Alcalingenes, Flavobacteria, Micrococcus,* and *Pseudomonas*. The ability of a soil to support a larger biomat is dependent on total surface area and the ability of fluid to pass through the soil. Although soil high in clay content may have tremendous surface area, the soil is so tightly compacted that the wastewater cannot pass through the soil. In contrast, a high-gravel-content soil will allow the wastewater to pass through it too quickly; as a result retention time is not sufficient for treatment to occur. It is estimated that 50% of all Alabama on-site systems fail (W. Studyvin, personal communication, November 21, 2000). These failures are attributed to the excessive formation of biomass, which results in the inability of the wastewater to flow downward; consequently, the wastewater pools on the surface.

Additionally, once the treated wastewater enters the ground water further bio-digestion continues. A ground water movement study was conducted in Jefferson county Alabama in 1994 using various computer modeling modules. The study found ground water moves as slowly as one foot per day (Unpublished Study, Jablecki, 1994).

The organisms that actually perform the cleaning process like to be attached to something. Therefore, for effective wastewater treatment by soil, a high volume of surface area available for microbial attachment is preferable. However, if the soil particles are too small (clay), then even if tremendous surface area exists, there is not enough room to allow the wastewater to percolate (flow) through the soil.

Systems Evaluated

Sand Filtration

Sand filtration (Figure 5) is essentially old technology yet remains very effective (Montiel, 1988). This system has great application in most regions of the country

(Dymond,1981; Mitchell, 1986; Perley, 1985; Scherer & Mitchell, 1982; Venhuizen, 1994).

Intermittent sand filtration consists of the typical anaerobic septic-tank as primary wastewater treatment and an intermittent[4] sand filter as secondary treatment. Because of the small-grained porous nature of the sand, the tremendous surface area allows aerobic decomposition of the organic waste material (D. Mitchell, personal communication, April 1997). Under a government-funded demonstration project, numerous homesites were provided with these systems in housing divisions near Mobile Bay and the Gulf of Mexico. The ADPH selected the homesites. These intermittent sand filters were designed and constructed on the basis of criteria developed by Orenco Systems and consist basically of a polyvinyl-lined area of approximately 60 vertical centimeters of sand upon which a distribution manifold rests (Figure 6).

Dosing is accomplished electronically via float switches, with the effluent collected in a collection manifold and pumped to an approved absorption field. White (1995) evaluated several sand filtration systems in southern Alabama and reported excellent performance; the mean BOD_5 output was 10 mg/L (90% reduction), and the mean FC concentration was 1,400 colonies per 100 ml (>99% reduction). Cagle (1993) evaluated sand filtration methodology in a western portion of the United States and found a reduction in effluent concentration of >95% for BOD_5, >90% for TSS, and >95% for FCs. Other studies (Anderson, 1985; Ball, 1995; Nichols, 1997) have yielded similar findings. Sand filtration is also applicable to very large treatment systems (D. Sievers, personal communication, December 1997). A 1992 study evaluated a large wastewater treatment plant at Ben Sergao, Morocco, that used an infiltration-percolation method (A. Bennani, et al. 1992). This plant treated 40,000 M^3 of highly concentrated raw effluent per day. Bennani, et al. found FC concentrations to be reduced by >98%.

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[4] Intermittent refers to the periodic dosing of the filter.

Constructed-Wetlands

Constructed-wetland sewage treatment systems (Figure 7) also offer excellent potential for small and large decentralized sites, as well as for individual home applications. As with sand filters, these systems have also been built for large-scale treatment. Constructed-wetland systems also consist of the typical anaerobic septic-tank as primary wastewater treatment. However, with this system, secondary treatment follows with two relatively large constructed-marsh areas (wetlands) that use aquatic plant and animal life to decompose the organic waste material.

A point of note with this system is that bacterial decomposition is mostly anaerobic because the aquatic environment is primarily in oxygen deficit. However, there is some aerobic decomposition occurring around the root proximal to each plant. Under the same government-funded demonstration project used for the sand filtration systems, numerous homesites were provided with these constructed-wetland systems in housing divisions near Weeks Bay, Mobile Bay, and the Gulf of Mexico. Again, the ADPH selected the homesites to be provided with these systems. These constructed-wetland systems (Figure 8) were of the subsurface horizontal-flow type and were designed and built on the basis of criteria established by the Tennessee Valley Authority.

These systems consist of two individual basins, with the initial receiving basin being polyvinyl lined and filled with approximately 30 vertical centimeters of medium-to-large stone. The second basin is also filled with approximately 30 vertical centimeters of medium-to-large stone but is not lined. Each basin readily supports aquatic plant growth. Four of these systems were routinely sampled for both influent and effluent wastewater by students and faculty of the University of South Alabama (USA) School of Civil Engineering. Page et al. (1997) evaluated an innovative two-phased wastewater treatment facility to determine if the system could meet new, stricter USEPA discharge requirements. The second phase of the system was a constructed-wetland. Page et al. concluded the system was likely to meet the new standards. Badkoubi, et al (1998) evaluated the performance of a pilot-scale subsurface constructed-wetland treatment plant in Iran; reported reductions in effluent concentrations were 90 ± 3% for BOD_5, 89 ± 4% for TSS, and >99% for FCs. Obviously, these systems are best suited for warmer regions of the country. White (1995) evaluated several constructed-wetland systems in southern Alabama and reported excellent performance; the mean BOD_5 output was 22 mg/L (82% reduction) and the mean FC concentration was 12,600 colonies per 100 ml (93% reduction). Tanner, et al (1998) evaluated five pilot-scale constructed-wetlands in their 4th and 5th years of operation; reported reductions in effluent concentrations were 91% for BOD_5, 78% for TSS, and >93% for FCs. Other studies (Hammer & Knight, 1994; Mandi, 1993) yielded similar findings. The performance of these systems is considerably based upon the design of the system. The technology probably exists today to design a system that can achieve up to 99.9% FC reduction. However, achieving this level of performance would certainly be cost prohibitive. Most environmental engineers design systems that are affordable to a family in the middle-income range. Generally, engineers use available technology to achieve optimum system performance within prevailing cost constraints.

Peat Media Filtration

Peat media filtration (Figure 9) is a relatively new technology in the United States. The best peat-moss for these atypical devices comes from Ireland. The concept is similar to that of sand filtration, and involves a superquantified surface area for microbial digestion. These systems are well suited for all geographical regions of the country.

Peat Media Filtration (PMF) also consists of the typical anaerobic septic tank as primary wastewater treatment; a peat filtration bed constitutes secondary treatment. As with the intermittent-sand-filtration system, the tremendous surface area of the peat media allows extensive aerobic bacteria growth for rapid digestion of the organic waste material. Under the same government-funded demonstration project used for the sand filtration and constructed-wetland systems, numerous homesites were provided with these peat media filtration systems in housing divisions near Weeks Bay, Mobile Bay, and the Gulf of Mexico. Again, the ADPH selected the homesites to be provided with these systems. These peat biofilters (Figure 10) are PURAFLO® modular systems manufactured in Ireland by Bord na Mona and are installed according to manufactures specifications.

Each module contains approximately 60 vertical centimeters of peat. The modules rest on a gravel base of approximately 20 centimeters in height. Dosing from the septic-tank was accomplished electronically via float switches to a distribution manifold atop the peat membrane. The wastewater is allowed to percolate through the media and is retained for up to 48 hr. Four of these systems were routinely sampled for both influent and effluent wastewater by students and faculty of the USA School of Civil Engineering. White (1995) evaluated several peat filtration systems in southern Alabama and reported excellent performance; the mean BOD_5 output was 18 mg/L (87% reduction), and the mean FC concentration was 5,000 colonies per 100 ml (98% reduction). Riznyk, et al (1993) evaluated the effectiveness of two pilot peat leach fields in treating wastewater in Alaska, and found the quality of the effluent from the peat filter (on the basis parameters including BOD_5, TSS, and FC) to be similar to that of wastewater undergoing tertiary treatment from a centralized wastewater plant. Coleman and Gaudet (1994) assessed the effectiveness of peat filter columns in the treatment of septic-tank effluent, and reported efficiency similar to that of constructed-wetland systems and sand filtration systems; the reduction in effluent concentration was >75% for BOD_5 and >95% for FC.

The Void in Public Information on Treatment Performance

There has been a growing concern lately about septic-tank performance and the potential for pathogen contamination of ground and surface waters (Brooks, 1980). A reasonable amount of information on the performance of alternative wastewater technology has been published (Clark, 1989; Perley, 1985; Scherer, 1982; Swanson, 1987; Teske, 1979; USEPA, 1980; Venhuizen, 1996). Many of the published works address the problems of on-site and small-scale wastewater management (Perley, 1985; Scherer, 1982; Teske, 1979); however, these works offer little assessment of the ability of an alternative (atypical) wastewater technology to reduce the pathogen transmission potential of given systems. Nonetheless, use of such systems has expanded; these systems are becoming more and more well suited to rural communities, small clusters of homes, individual residences, and business establishments. Many of the systems can achieve advanced levels of secondary or even tertiary treatment. Additionally, most of these systems can operate consistently well with minimal attention (Venhuizen, 1994).

The aim of most evaluation studies conducted thus far centers on measuring nitrification. To date, only a limited number of studies concerned with microorganism release have been published. However, information on microorganism release would help determine the potential for pathogen contamination of the environment. Studies quantifying pathogen contamination could encourage increased used of on-site disposal and allow on-site systems to be used on very restrictive sites without compromising public health or environmental values. The pathogen content of wastewater influent and effluent has rarely been directly measured. Instead, indicator organisms are measured as a surrogate. The historical standard indicator organism is coliform bacteria, which are present not only in human feces but also in other mammal feces and in some environmental reservoirs (Bahlaoui, 1998; Buisson, 1998; Dugba, 1997; Han, 1997; Liang, 1998; Oppenheimer, 1997; Peterson, 1994; Rose, 1996; Sanchez, 1998; Skousen, 1998). The standard reporting value is the number of colonies grown per 100 ml of filtered water. One hundred ml of sample water are filtered under pressure through a millipore filter membrane and allowed to incubate under optimum growing conditions. The rawest measure is the TC colony, count followed by the FC colony count. Recently, an even more refined measure, the specific *E. coli* count, has been studied. The current edition of

Standard Methods for the Examination of Water and Wastewater offers promise for this even more definitive parameter to quantify potential pathogen contamination as the new environmental standard; Method 9221F (Proposed) will be used for quantifying the *E. coli* organism. However, as of this writing, the method has not yet been approved.

Also, the use of atypical wastewater treatment augmentation can minimize the adverse effect known as hydraulic mounding (Figure 11). The standard septic-tank soil absorption system trenches for the tile field are sized on the basis of soil type and anticipated loading rates (Tanner, et al.1998). Although the use of an applied secondary treatment such as that employed with atypical wastewater treatment will not reduce the groundwater hydraulic-mounding effect, at least the wastewater at that juncture is cleaner than if it had simply been discharged from a septic-tank. A major benefit of these atypical systems is that they discharge a cleaner effluent to the environment. Although sparse, work has been published on the ability of different soil types to clean wastewater.

In general, coarse loose soils do better at removing bacteria, protozoa, and helminth's; however, tightly compacted clay-like soils do better at removing viruses (Skousen, Sencindiver, Owens, & Hoover, 1998). Recently, controversy has arisen about the validity of what is called the 6/50 rule. In many states, to install a septic-tank system; the bottom of the soil absorption trench must be at least 6 in. above the maximum annual height of the groundwater table and be at least 50 ft. from the nearest drinking water source. Nearly all states have a variation of this rule that ranges from 6/50 to 36/200. Alabama uses 18/100 (W. Studyvin, personal communication, April 24, 2000). The problem centers around the phenomenon of groundwater hydraulic mounding. This mounding phenomenon can occur directly below the septic-tank tile field absorption trenches and in effect "pulls" the groundwater closer to the wastewater. Groundwater mounding is affected by two principal factors: (a) saturated hydraulic conductivity and (b) aquifer thickness.

From the published evaluations of the performance of certain atypical NWWTSs, we know many of these systems can perform exceptionally well with very little maintenance. For example, sand filtration systems have been shown to demonstrate up to a 96% BOD_5 removal efficiency and 98% FC reduction efficiency (Furman, 1955; Mitchell, 1987).

This research project is a comparative evaluation of atypical advanced NWWTSs against CWWTSs and a standard on-site septic system. Furthermore, a simple rating tool for quantitatively ranking the disease pathogen contamination risk of these systems has also been developed. This rating tool could easily be adapted to rate other NWWTSs and can be calculated by using readily available National Sanitation Foundation (NSF) published data. The NSF publishes evaluation reports concerning wastewater treatment systems in three standard formats: Standard 40, Standard 41, and Criteria C-9. All of these report formats use as indicator organism data either TC or FC counts, as well as TSS and BOD. Evaluation data are available for both influent and effluent sampling.

Currently, the information available to the general public on NWWTS performance is of little value to the nonscientific consumer of these products. The data are too complex for the average person to understand. Furthermore, the claim that centralized wastewater disposal is superior to either NWWTS or DWWTS has never been well substantiated. Scientific evidence to support the claim that CWWTSs pollute the environment less than NWWTSs do is scarce. Therefore, this research project also compared the pollution potential of selected NWWTSs to that of selected CWWTSs under similar environmental conditions in both time and space.

A simple rating system would be beneficial to housing-community developers, city managers, and home owners selecting a NWWTS that will maximize efficiency, and pollute the environment as little as possible. Despite hundreds of years of operating history and more than 2 decades of extensive and progressive development, NWWTSs are not well understood in terms of disease transmission potential. The lack of knowledge about these advanced design concepts is a barrier to establishing these concepts as a new standard for on-site/small-scale wastewater management. A consumer guide rating similar to that used for energy efficiency ratings on refrigeration equipment will go far in breaking that knowledge barrier.

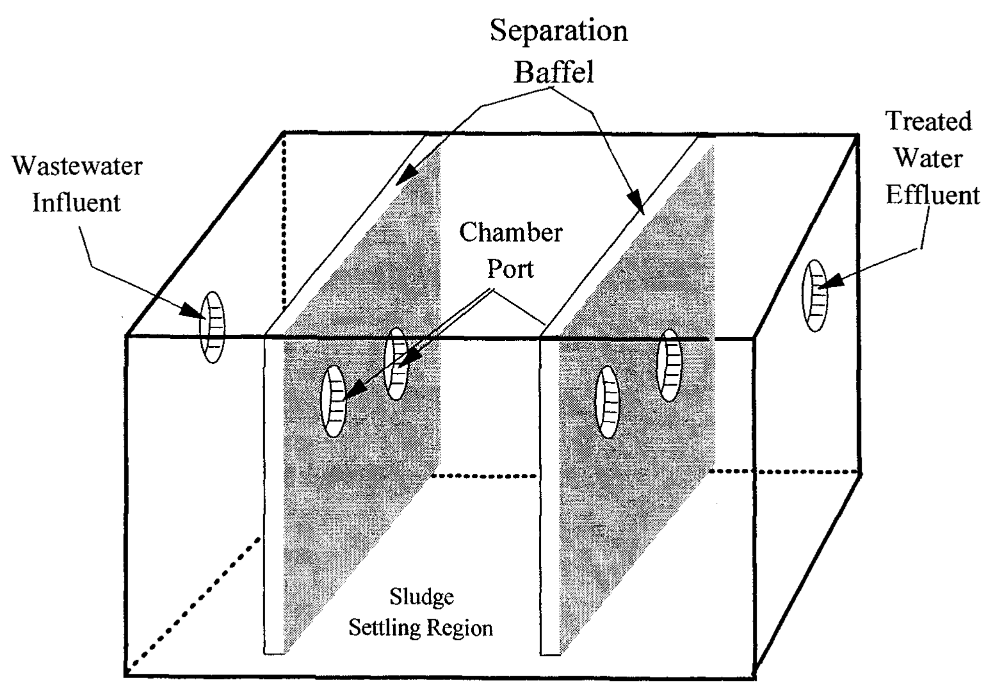

Figure 4. Typical three-chamber septic tank

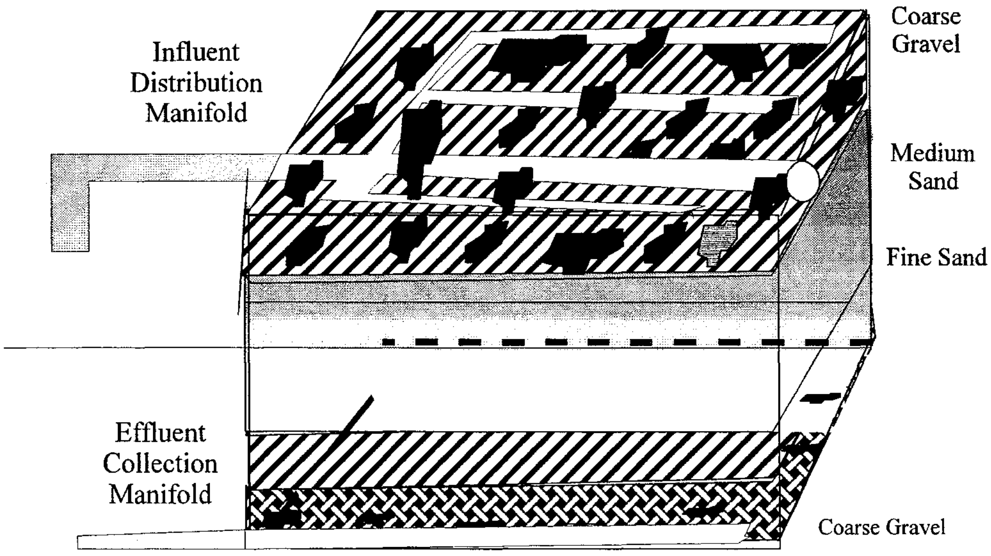

Figure 5. Sand filtration.

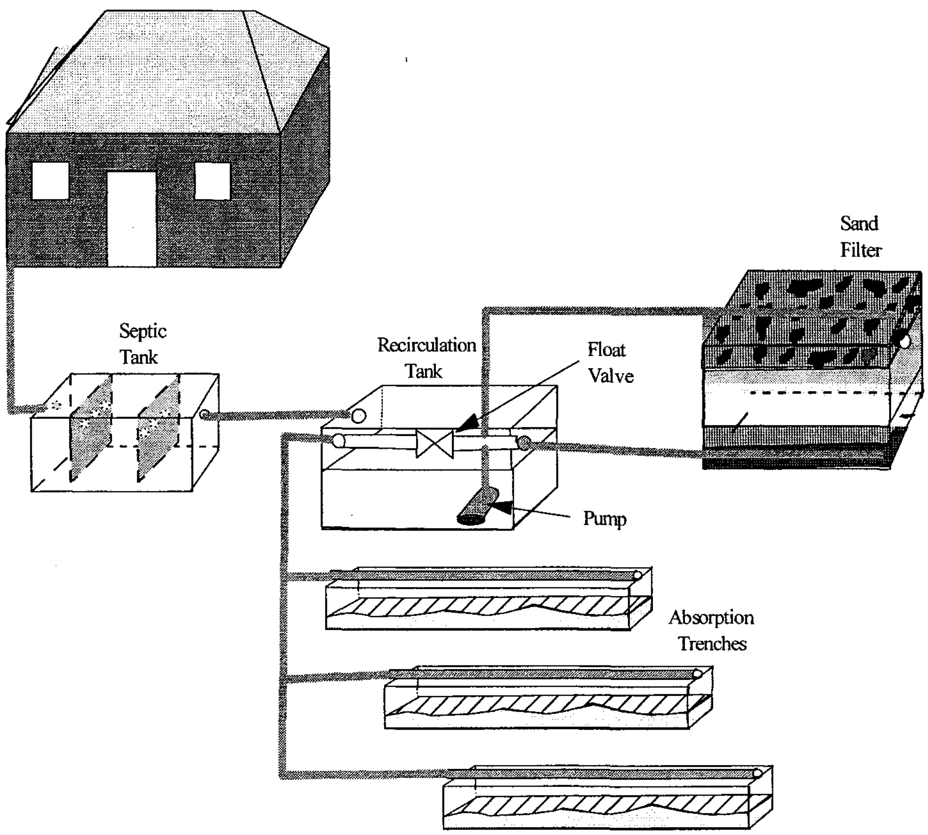

Figure 6. Intermittent sand filtration.

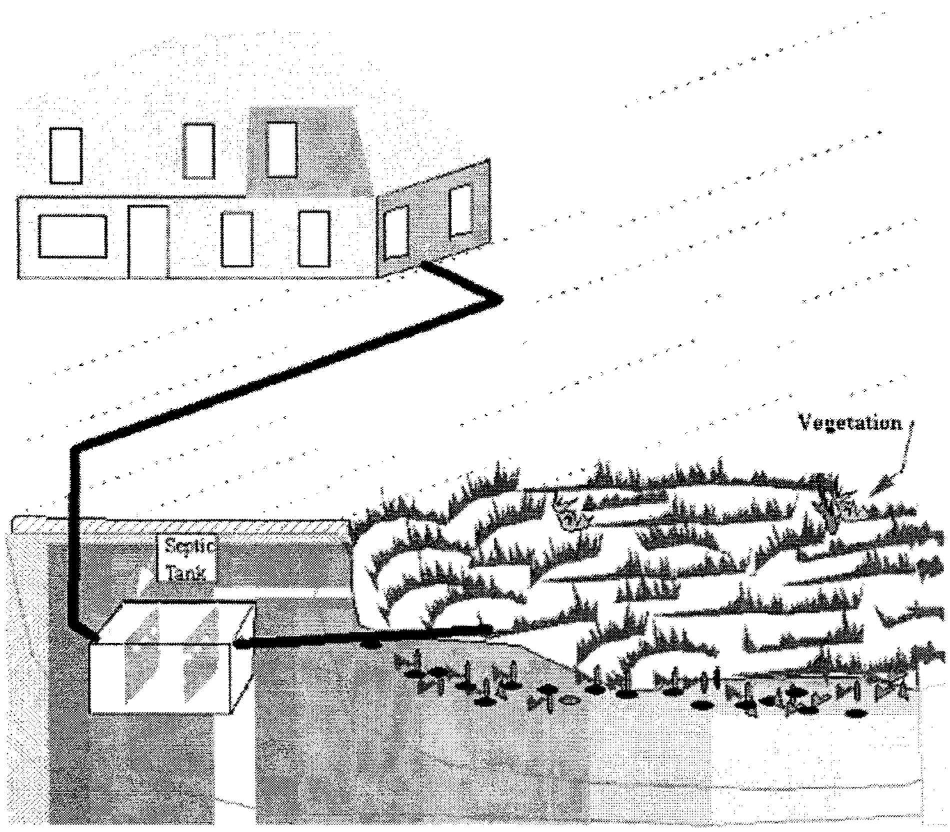

Figure 7. Generic constructed-wetland application.

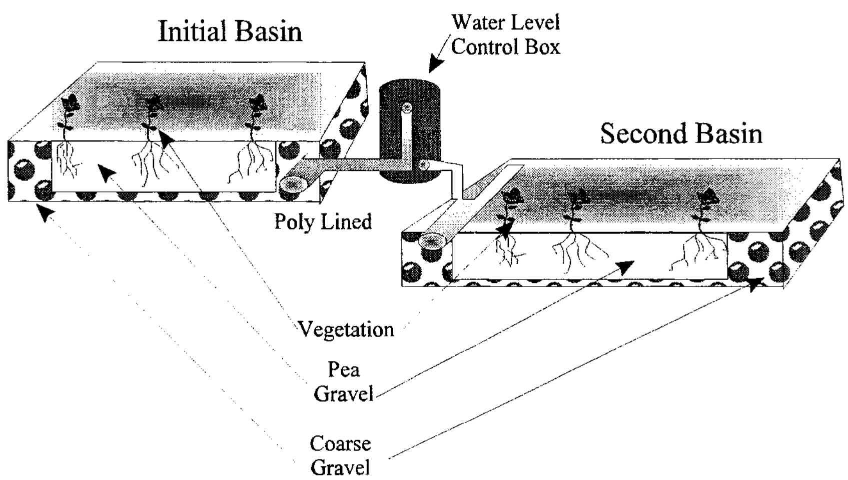

Figure 8. Constructed-wetland treatment system. Poly = Polyvinyl.

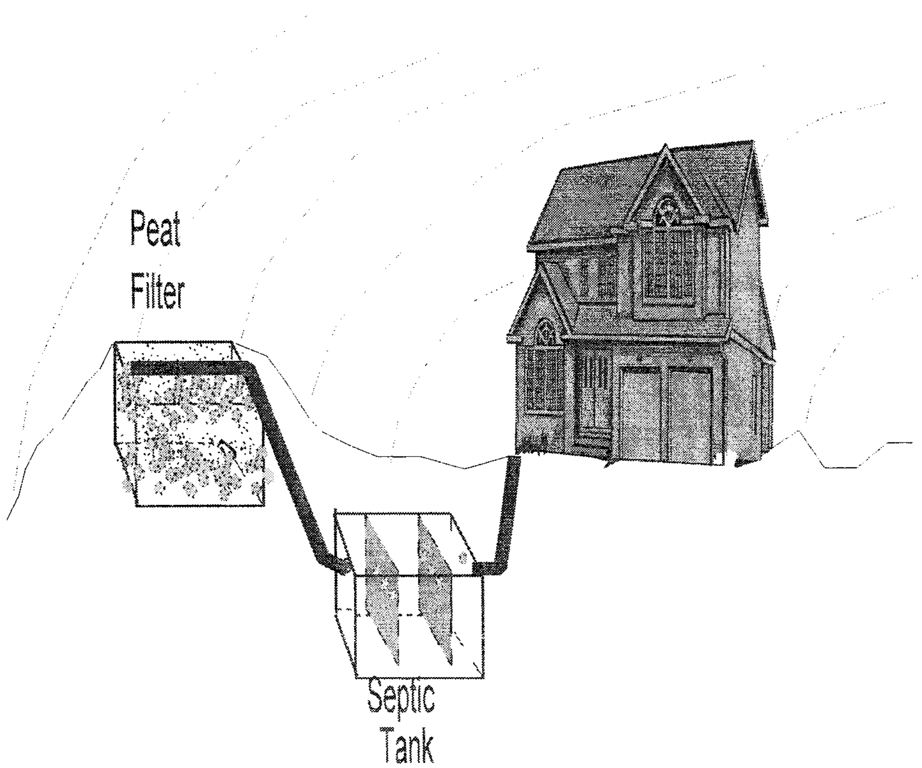

Figure 9. Generic schematic depiction of peat filtration.

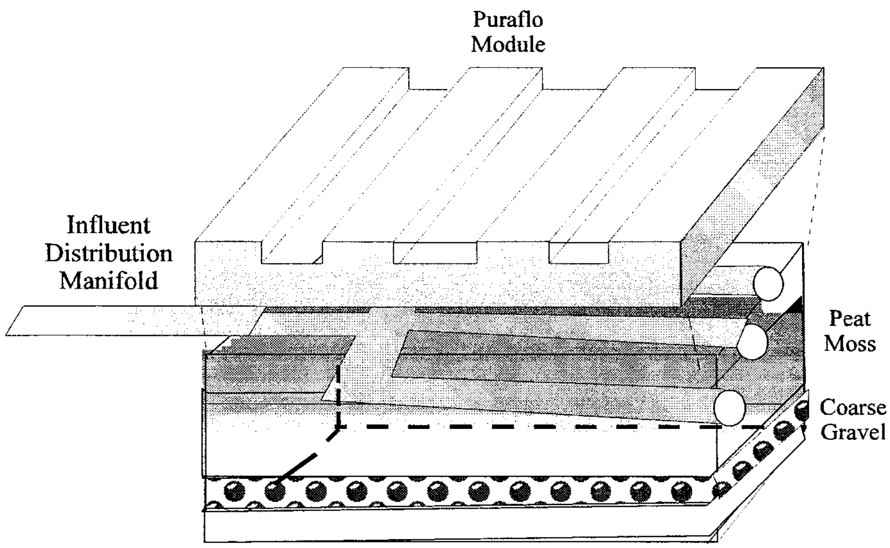

Figure 10. Peat biofiltration system.

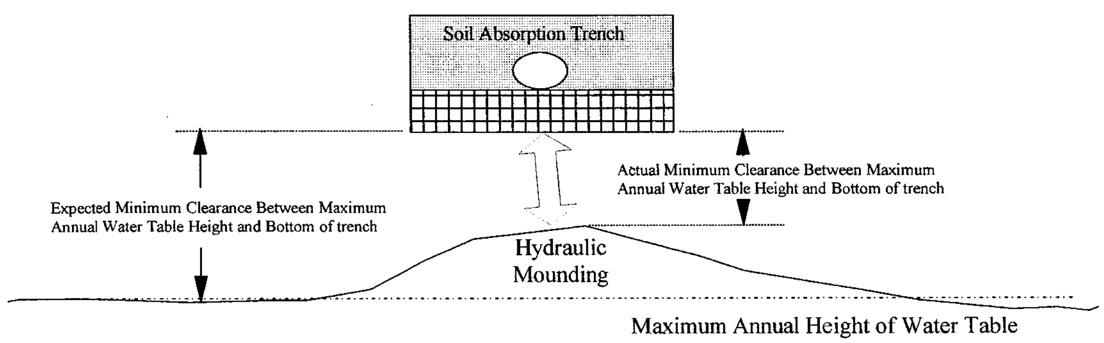

Figure 11. Hydraulic mounding effect.

CHAPTER 3

RESEARCH OBJECTIVES

Performance of Alternative Treatment Technology

General

Two questions were to be answered. First, do alternative (atypical) wastewater treatment systems perform as well as municipal wastewater treatment systems do in reducing organic contaminants (Question 1)? Second, is one atypical methodology statistically superior to others in reducing organic contaminates (Question 2)? The research hypotheses are as follows for Question 1:

H_0: There is no statistically significant difference between the treatment performance of alternative (atypical) wastewater treatment systems and the treatment performance of municipal wastewater treatment systems from within the same geographic region.

H_1: A statistically significant difference exists.

The research hypotheses are as follows for Question 2:

H_0: There is no statistically significant difference among the treatment performances of alternative (atypical) wastewater treatment systems from within the same geographic region.

H_1: A statistically significant difference exists.

Application of the Data to a Scoring System

Rationale

Each parameter (FC, BOD_5, and TSS) was scored and ranked. Additionally, each parameter was characterized both by the mean value of the effluent discharged from the system and by the percentage of reduction within the system from influent to effluent. The scoring system was designed so that the higher the score, the less efficient the system is in reducing potential pathogens. In other words, the higher the score, the greater the risk of polluting the environment is.

A scoring system was used to apply a structured evaluation process which ranked the various atypical noncentralized/decentralized wastewater treatment systems on the basis of their potential to contaminate water supplies with human pathogens. This evaluation tool was based on the analytic hierarchy process (Saaty, 1980). The analytic hierarchy process is a decision-making method for prioritization of alternatives when multiple criteria are considered (Weingarten, 1997). The method has been widely applied in a variety of decision-making environments in the business, safety, and healthcare fields (Dolan, 1995; Kassirer & Sonnenberg, 1991; Sonnenberg & Beck, 1993; Sonnenberg & Pauker,1987). The selection of a DWWTS/NWWTS is based on the evaluation of several factors. Some of these factors are performance based, and others (e.g., costs and maintenance), are not so based. At this time, there are no generally accepted guidelines for the average public consumer to use when selecting a wastewater treatment system that are based on easy-to-understand performance criteria. Instead, the public consumer usually bases his or her selection upon a combination of professional advice, cost considerations, and luck. Qualitative and quantitative data are rarely presented to the consumer.

The scoring-system approach has been used modestly over the past few years in the field of occupational health and safety as a technique to organize risk components (Carter & Bard, 1986; Dawson & Henderson, 1987; Hayes, 1998). The approach has exciting potential in the field of environmental-health-risk evaluation. The purpose of using this approach in this study is to apply a structured evaluation process to the development of a performance-based score that is simple to understand for the general public.

The basis for this scoring system is the analytic hierarchy process. With this approach, performance measures are typically prioritized according to their importance in achieving the overall goal (Burdorf & Swuste, 1999). Because the goal here is to identify wastewater treatment systems that perform better than others do in reducing pathogen contamination to the environment, those measures that best indicate organic matter presence will receive the highest priority in the score calculation (e.g., strong averaging). The results of all of these measurements form the basis of a scoring system that can be used to evaluate wastewater treatment systems (Weingarten, 1997).

Selection of the criteria used in this evaluation was based on the fact that, almost without exception, the environmental-engineering standard measures for organic constituents in wastewater are BOD, TSS, and some measure of microbiological indicator organisms. The most common indicator organism reported is FC. Nearly all wastewater studies and evaluations use measurements of these parameters for comparisons. Each of these parameters will provide two criteria measures: the mean effluent value compared with the regulatory maximum acceptable value (Parameter sub M $\{X_M\}$) and the percentage of reduction of the parameter by the wastewater treatment system from influent to effluent (Parameter Percent sub R $\{X\%_R\}$).

The resultant number of each of these criteria measures forms the basis of the scoring system that can be used as a decision tool by developers, consumers, and city planners for the selection of an atypical NWWTS. As applied to the risk of pathogen contamination to the environment, the standardized analytic hierarchy process consists of the following elements:

1. Goal: selection of an atypical noncentralized/decentralized wastewater treatment system that presents the least risk of contaminating the environment with pathogenic organisms.

2. Selection criteria: parameter measures (BOD, TSS, and FC) for organic constituents in wastewater viewed in terms of final effluent concentration and percentage of cleanup.

3. Ratings: the scores obtained by the calculations associated with each criterion.

CHAPTER 4

METHODS

System Performance Parameters

Raw Data

Noncentralized Wastewater Systems

The data used for the study had been collected by the USA Department of Civil Engineering and involved selected atypical NWWTSs secondary treatment processes. These data were from sites of a demonstration project of atypical on-site wastewater treatment systems in Mobile and Baldwin counties. These projects consist of three[5] constructed-wetland sites, four peat filtration sites, and two sand filtration sites.

Field collection techniques. The peat filtration sampling sites are located in an area west of Weeks Bay near the southern extreme of Baldwin County, Alabama. The sampling sites for the constructed-wetland treatment systems are primarily located in an area north of Weeks Bay. Figure 12 depicts these sampling sites.

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[5] Data were in fact collected for four constructed-wetland sites. However, one of the sites was not representative because usage of the septic system was sporadic and infrequent (single-person usage). The other three sites were representative because each was used by a three- to four-person family on a daily basis.

The sand filtration systems are primarily located in the southern extreme of Mobile County, which is on the western edge of Mobile Bay. Figure 13 shows the sampling sites for these systems.

Each of the three wetland treatment systems, four peat filtration treatment systems, and two sand filtration systems was sampled monthly from December 1995 to September 1998. Sampling for each specific site began approximately 3 months after the completion of system construction and continued for at least 12 months. Two samples (influent and effluent) were collected from each treatment system on each sampling date.

For each treatment system, the influent sample was essentially collected just after th infulent left the septic tank (primary treatment). For the wetland sites, a U-shaped plastic sampling port was attached to the inlet header; the septic-tank pump was manually initiated and allowed to run for 10-15 s before collecting the sample in a sterile, 1-L amber glass bottle. For each treatment system, the effluent sample was essentially collected just after the effluent left the atypical augmentation to the treatment system (secondary treatment) before being discharged into the soil for final treatment. Samples were immediately cooled in an ice container and transported to the USA Environmental Engineering Laboratory, located on USA's main campus.

Laboratory analysis procedures. Sample analyses for these NWWTSs were performed according to the 18th edition of *Standard Methods for the Examination of Water and Wastewater* (Franson, 1992). Numerous parameters were assayed, including BOD, TSS, and FC (membrane filtration technique). Specific methods used for each analysis are described in Table 4.

Table 4

Wastewater Analysis, Parameter and Method

Parameter analyzed	Method used
Biochemical oxygen demand, 5 day	Standard 5-day incubation, method 5210B. Dissolved oxygen difference day 1 verses day 5.
Total suspended solids	Standard dried residue recovery, method 2540D.
Fecal coliform	Standard membrane filter technique, Method 9221E. Colonies grown after incubation per 100 ml of water filtered.

Note. Data extracted from *Standard Methods for the examination of water and wastewater* (18th ed.), p 94; 543 - 550; 937 - 939. 1992, M. Franson.

Accepted effluent values. Because the treated effluent from these atypical wastewater disposal systems receives additional treatment while percolating through the soil, acceptable initial effluent values are much higher than if the effluent were discharged directly into surface waters. To date, there are no performance standards (federal, state, county, or industry) for minimum acceptable effluent discharge for any NWWTS (J. Crosby, 1998). In this study, the USEPA standard for maximum allowable discharge to surface water is used (BOD 30mg/L, TSS 30 mg/L, FC 200 colonies/100 ml).

Statistical analysis. Atypical NWWTS performance was evaluated and contrasted on the basis of the parameters of FC, BOD_5, and TSS. Independent parameter analysis of raw untransformed data was also performed. Comparisons were made for each wastewater treatment system on the basis of BOD, TSS, and FC reduction. Additionally, comparisons were made for each wastewater treatment system on the basis of the range and mean of each parameter measured at the final effluent discharge to the environment (environmental burden). This statistical analysis was conducted via SPSS® software to an alpha level of 0.05. The distribution of the data was tested by the Kolmogorov-Smirnov test (Daniel, 1995.). The data were found not to be normally distributed (see the RESULTS Chapter). Therefore, nonparametric analysis was performed by using the Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and the Kruskal-Wallis Test.

Centralized Wastewater Systems

BOD_5, TSS, and FC[6] data were obtained for three local area STPs located in close proximity to the NWWTS sites (Figures 12 and 13). Two centralized municipal STPs that do not chlorinate effluent are located in Baldwin County in proximity to the Peat filtration and constructed-wetland sampling sites. One of these plants is the Fairhope, Alabama, plant (AL0020842); the other is the Daphne, Alabama, plant (AL0027561). The Dauphin Island municipal STP (AL0050547), located in Mobile County, also does not discharge chlorinated effluent and is located in close proximity to the sand filtration sampling sites. These municipal STPs are further described as follows:

The Daphne STP was upgraded to an activated-sludge treatment system in 1997 (see Figure 12 for location). In conjunction with this upgrade, tertiary treatment (disinfection) was changed from chlorination to UV radiation. Therefore, monthly mean FC

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[6] FC is only reported for those plants that do not chlorinate as a disinfection measure. STPs that employ chlorination only need report the residual chlorine value of the effluent. STPs that do not chlorinate effluent must report effluent FC concentration but not influent FC concentration.

concentration reporting for the discharged effluent is required to be submitted to ADEM. The Daphne plant has its own environmental laboratory that analyzes required parameters and submits the results to ADEM. ADEM conducts one annual unannounced quality control visit. Treated effluent is discharged into the Blakley River and flows less than one mile before entering Mobile Bay. The average daily flow of the effluent discharged is 1.618 million GPD. Sample collection dates were matched to those of the NWWTS sampling period ($n = 34$).

The Fairhope STP was originally built in the early 1970s as a trickling filter plant that used chlorination as tertiary treatment (see Figure 12 for location). An upgrade project for the entire plant was completed in 1998. The upgrade included technology transformation to activated-sludge secondary treatment and UV radiation tertiary treatment. Again, monthly mean FC concentration reporting for the discharged effluent was required to be submitted to ADEM. The Fairhope plant also has its own environmental laboratory that analyzed the required parameters and submits the results to ADEM. ADEM also conducts one annual unannounced quality control visit. Treated effluent is discharged directly into Mobile Bay via a pipe that extends approximately 0.5 mile from the recreation beach. The average daily flow for the effluent discharge is 1.577 million GPD. Sample collection dates were matched to those of the NWWTS sampling period ($n = 34$).

The Dauphin Island STP was originally built in the early 1960s as a trickling filter plant that used chlorination as tertiary treatment; the plant was upgraded to larger capacity in 1985 (see Figure 13 for location), and the plant continues to use trickling filter technology, with chlorination/dechlorination as tertiary treatment. Although a plant disinfecting with chlorine is required to submit Cl^- residual instead of FC counts, ADEM requires this plant to also submit monthly mean FC counts because the treated effluent is discharged directly into recreational waters on the sound side of the island. Renovation plans have been approved for the construction of a predesigned package plant addition to the system. The package plant addition will be activated-sludge technology and will enable the plant to go from a current effluent output of 0.49 million GPD to an effluent output of 1.0 million GPD. The plant manager is exploring both UV radiation and ozone as possibilities for tertiary treatment. Sample collection dates were again matched to those of the NWWTS sampling period ($n = 30$).

The CWWTS raw data were tested for normality by the Kolmogorov-Smirnov method. The distribution was found not to be normal (see the RESULTS Chapter).

Field collection techniques. Each of the three comparison CWWTSs had samples collected during the same period in which the samples were collected from the atypical wastewater treatment systems. The samples were collected in accordance with the methodology described in *Standard Methods for the Examination of Water and Wastewater* (Franson, 1992). Two samples (influent and effluent) were collected from each treatment system. These samples were one-liter "grab" samples stored in a cubitainer™ for transportation to the laboratory.

Laboratory analysis procedures. Sample analysis for the municipal STPs was also performed in accordance with the 18th edition of *Standard Methods for the Examination of Water and Wastewater* (Franson, 1992). As with the NWWTSs, numerous parameters were assayed, including BOD, TSS, and FC (membrane filtration technique). Specific methods used for these analysis are the same as previously described in Table 4.

Comment on FC influent. Samples were not analyzed for influent FC at municipal STPs. The recognized standard for residential municipal influent FC concentration is 1.5e6 colonies per 100 ml. To confirm this Figure, influent raw sewage was analyzed by the Daphne plant laboratory technician using the 19th edition of *Standard Methods for the Examination of Water and Wastewater*, (Franson, 1995); serial dilutions were made until less than 60 colonies per plate were counted. The resultant Figure was 1.46e6 colonies per 100 ml.

Accepted effluent values. Under federal mandates established by the National Pollution Discharge Elimination System, centralized wastewater treatment plants must submit regular reports concerning laboratory testing of influent and effluent wastewater samples. In Alabama, ADEM is the repository for these reports. Acceptable effluent discharge values must be <30 mg/L for BOD, <30 mg/L for TSS, and <200 colonies/100 ml for FC (Table 5).

Statistical analysis. The same independent parameter analysis and tests of inference were performed as explained previously.

Table 5

Acceptable Effluent Concentrations

Parameter	Value
Biochemical oxygen Demand, 5 day	30 mg/l
Total suspended solids	30 mg/l
Fecal coliform	200 colonies/100ml

Rank Score Performance Measuring Tool

A scoring tool was developed to rank the overall performance efficiency of each system for easy comparison. This tool is discussed in detail in chapter 6.

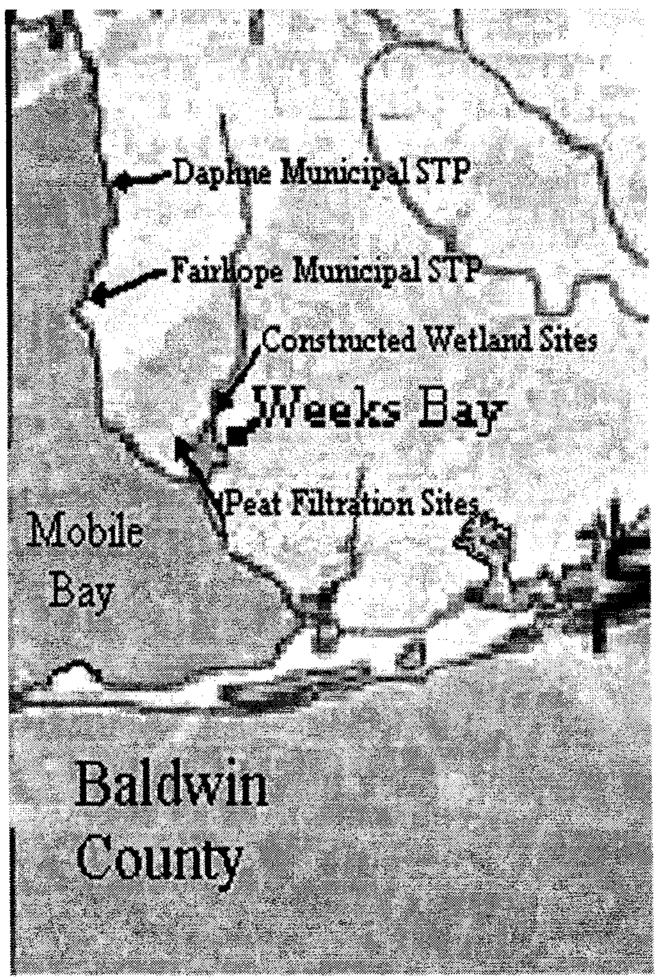

Figure 12. Baldwin County sampling site locations. STP = sewage treatment plant.

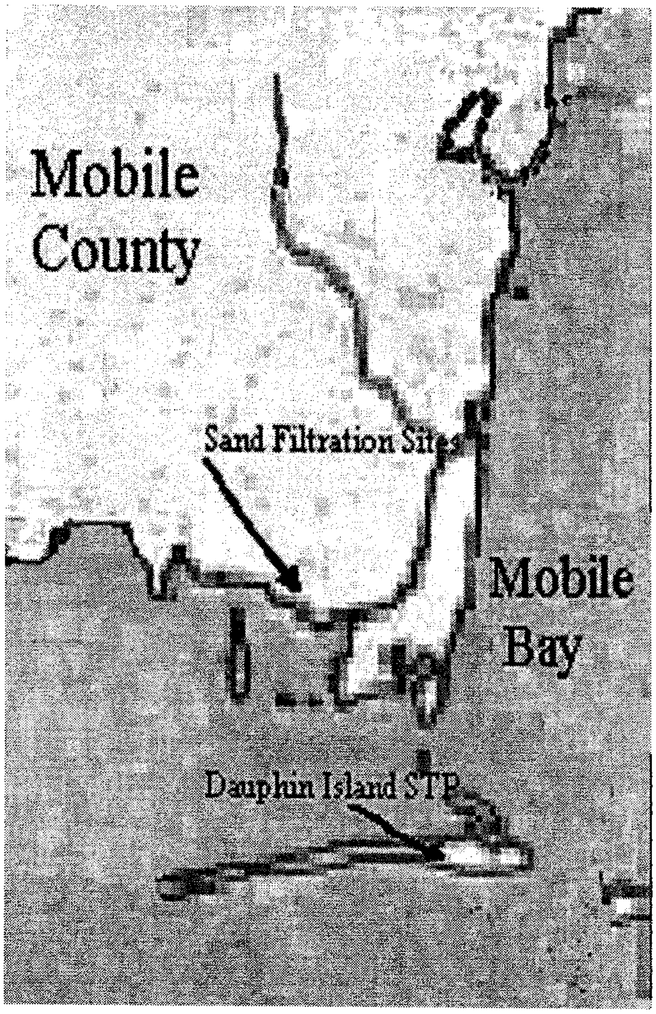

Figure 13. Mobile County sampling site locations.
STP = sewage treatment plant.

CHAPTER 5

RESULTS

Descriptive Statistics

By Type of Treatment System (Table 6)

Combining all sample data by type of treatment system reveals that the overall treatment efficiency of the centralized systems is superior to that of the noncentralized systems. However, this finding is at least partially erroneous and will be explained in detail in chapter 6.

By Subtype of Treatment System

Noncentralized Wastewater Systems (Table 7)

Analysis of the three NWWTS subtypes reveals that the overall FC treatment efficiency of the sand filtration systems is superior to that of either the peat filtration systems or the constructed-wetland systems. Furthermore, the overall BOD treatment efficiency of the sand filtration systems is also superior to that of either the peat filtration systems or the constructed-wetland systems. In terms of TSS treatment, all three NWWTS subtypes perform at essentially the same level.

Sand filtration. BOD influent median was 169 mg/L, mean was 175 mg/l, and range was 18-390 mg/L. BOD effluent median was 2 mg/L, mean was 4 mg/L, and range

Table 6

Wastewater Treatment Performance by Type of System

Parameter	BOD Influent (mg/L)	BOD Effluent (mg/L)	BOD Efficiency (mg/L)	TSS Influent (mg/L)	TSS Effluent (mg/L)	TSS Efficiency (mg/L)	FC Influent (col/100 ml)	FC Effluent (col/100 ml)	FC Efficiency (col/100 ml)
Centralized wastewater treatment systems (*n* = 98)									
Mean	169.7	10.3	0.9294	172.6	13.8	0.9091	1.5e+06	98.2	0.9999
Median	175.0	9.0	0.9409	172.0	13.0	0.9247	1.5e+06	42.5	1.0000
Std. Dev.	63.7	6.7	0.0742	60.0	9.3	0.1080	0.0	1.9e+02	0.0001
Minimum	45.0	1.0	0.3778	71.0	1.2	0.0357	1.5e+06	1.0	0.9992
Maximum	335.0	29.0	0.9932	295.0	58.0	0.9926	1.5e+06	1.1e+03	1.0000
%ile > Std[a]		0.0			3.1			8.2	
Noncentralized wastewater treatment systems (*n* = 127)									
Mean	127.3	14.4	0.8481	77.3	14.9	0.7599	1.6e+06	3.0e+04	0.9344
Median	108.9	11.0	0.8930	60.0	11.0	0.8033	4.4e+05	3.7e+03	0.9819
Std. Dev.	76.6	14.9	0.1442	121.7	14.2	0.1950	3.6e+06	8.3e+04	0.1350
Minimum	4.5	0.2	0.2405	8.0	0.0	0.1429	3.0e+03	0.0	0.1071
Maximum	390.0	103.8	0.9994	1,382.0	101.0	1.0000	2.7e+07	7.3e+05	1.0000
%ile > Std[a]		8.7			11.0			89.0	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = colonies; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Standard = 30 mg/L, TSS Standard = 30 mg/L, FC Standard = 200 colonies/100 ml.

Table 7

Wastewater Treatment Performance by Subtype of Noncentralized Wastewater Treatment System

	BOD			TSS			FC		
Parameter	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (col/100 ml)	Effluent (col/100 ml)	Efficiency (col/100 ml)
Sand filtration (*n* = 14)									
Mean	175.4	3.8	0.9725	171.1	25.5	0.7057	4.1e+06	1.1e+03	0.9991
Median	168.8	1.9	0.9876	69.5	25.5	0.7168	1.4e+06	3.2e+02	0.9998
Std. Dev.	88.7	4.8	0.0337	349.9	13.6	0.1988	6.1e+06	1.7e+03	0.0016
Minimum	18.0	0.2	0.8778	44.0	1.0	0.1429	2.2e+05	0.0	0.9944
Maximum	390.0	16.5	0.9994	1.3e+03	48.0	0.9787	2.1e+07	5.6e+03	1.0000
%ile > Std[a]		0.0			28.6			57.1	
Peat filtration (*n* = 67)									
Mean	132.1	11.7	0.8782	74.3	15.1	0.7679	1.1e+06	4.1e+04	0.9372
Median	105.0	7.0	0.9256	66.0	11.0	0.8421	4.5e+05	5.4e+03	0.9750
Std. Dev.	80.4	13.8	0.1348	37.7	15.3	0.2000	1.6e+06	1.1e+05	0.1233
Minimum	12.6	0.8	0.2405	10.0	0.0	0.1818	2.9e+04	100.0	0.2772
Maximum	381.0	103.8	0.9962	170.0	101.0	1.0000	7.9e+06	7.3e+05	0.9999
%ile > Std[a]		4.5			10.4			97.0	
Constructed-wetland filtration (*n* = 46)									
Mean	105.5	21.6	0.7665	53.0	11.4	0.7646	1.5e+06	2.2e+04	0.9107
Median	94.4	18.0	0.7918	49.5	8.0	0.8016	2.5e+05	4.5e+03	0.9710
Std. Dev.	58.8	15.5	0.1351	26.0	10.9	0.1882	4.4e+06	5.3e+04	0.1638
Minimum	4.5	1.5	0.2987	8.0	0.0	0.3077	3.0e+03	50.0	0.1071
Maximum	261.0	78.0	0.9674	143.0	4.0	1.0000	2.7e+07	3.2e+05	1.0000
%ile > Std[a]		17.4			6.5			95.7	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = colonies; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Standard = 30 mg/L, TSS Standard = 30 mg/L, FC Standard = 200 colonies/100 ml.

was 0.2-17 mg/L. TSS influent median was 70 mg/L, mean was 241 mg/L, and range was 44-1.38e^3 mg/L. TSS effluent median was 26 mg/L, mean was 26 mg/L, and range was 1-48 mg/L. FC influent median was 1.4e^6 colonies/100 ml, mean was 4.1e^6 col/100 ml, and range was 2.2e^5-2.1e^7 col/100 ml. FC effluent median was 315 col/100 ml, mean was 1.08e^3 col/100 ml, and range was 0-5.6e^3 colonies/100 ml.

Peat filtration. BOD influent median was 105 mg/L, mean was 132 mg/L, and range was 12.6-381 mg/L. BOD effluent median was 6.3 mg/L, mean was 11.3 mg/L, and range was 1-104 mg/L. TSS influent median was 66 mg/L, mean was 74 mg/L, and range was 10- 70 mg/L. TSS effluent median was 11 mg/L, mean was 15 mg/L, and range was 0-101 mg/L. FC influent median was 4.5e^5 colonies/100 ml, mean was 1.1e^6 colonies/100 ml, and range was 2.9e^4-7.9e^6 colonies/100 ml. FC effluent median was 5,400 colonies/100 ml, mean was 4.1e^5 colonies/100 ml, and range was 100-7.3e^5 colonies/100 ml.

Constructed-wetland. BOD influent median was 93 mg/L, mean was 95 mg/L, and range was 4.5-261 mg/L. BOD effluent median was 17 mg/L, mean was 19 mg/L, and range was 1.5-78 mg/L. TSS influent median was 49 mg/L, mean was 49 mg/L, and range was 8-143 mg/L. TSS effluent median was 8 mg/L, mean was 12 mg/L, and range was 0-54 mg/L. FC influent median was 2.0e^6 colonies/100 ml, mean was 1.4e^6 colonies/100 ml, and range was 3.0e^3-2.7e^7 colonies/100 ml. FC effluent median was 2.5e^3 colonies/100 ml, mean was 1.9e^4 colonies/100 ml, and range was 50-3.2e^5 colonies/100 ml.

Centralized Wastewater Systems (Table 8)

Analysis of the three CWWTS subtypes reveals that the overall FC treatment efficiency is essentially the same. However, the quality of the treated effluent for the Daphne STP is superior to that of either the Fairhope STP or the Dauphin Island STP. Furthermore, the overall TSS treatment efficiency of the Daphne STP was found to be superior to that of either the Fairhope STP or the Dauphin Island STP. Also, the TSS quality of the treated effluent for the Daphne STP is superior to that of either the Fairhope STP or the Dauphin Island STP. In terms of BOD treatment, the results are similar to those of the TSS treatment.

Daphne plant. BOD influent median was 177 mg/L, mean was 175 mg/L, and range was 133-233 mg/L. BOD effluent median was 4 mg/L, mean was 4 mg/L, and range was 1-8 mg/L. TSS influent median was 162 mg/L, mean was 165 mg/L, and range was 117-288 mg/L. TSS effluent median was 4 mg/L, mean was 6 mg/L, and range was 1-19 mg/L. FC influent median was $1.5e^6$ colonies/100 ml, mean was $1.5e^6$ colonies/100 ml, and range was $2.0e^5$-$2.4e^7$ colonies/100 ml. FC effluent median was 8 colonies/100 ml, mean was 10 colonies/100 ml, and range was 2-74 colonies/100 ml.

Dauphin Island plant. BOD influent median was 82 mg/L, mean was 93 mg/L, and range was 45-162 mg/L. BOD effluent median was 10 mg/L, mean was 11 mg/L, and range was 5-29 mg/L. TSS influent median was 92 mg/L, mean was 115 mg/L, and range was 71-227 mg/L. TSS effluent median was 15 mg/L, mean was 16 mg/L, and range was 6-58 mg/L. FC influent median was $1.5e^6$ colonies/100 ml, mean was $1.5e^6$ colonies/100

Table 8

Wastewater Treatment Performance by Subtype of Centralized Wastewater Treatment System

	BOD			TSS			FC		
Parameter	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (col/100 ml)	Effluent (col/100 ml)	Efficiency (col/100 ml)
Daphne sewage treatment plant (*n* = 34)									
Mean	176.5	4.1	0.9769	165.2	5.5	0.9669	1.5e+06	10.4	1.0000
Median	175.0	3.9	0.9794	162.0	4.4	0.9741	1.5e+06	8.0	1.0000
Std. Dev.	23.0	1.9	0.0110	34.4	4.3	0.0247	0.0	12.3	0.0000
Minimum	134.0	1.0	0.9535	117.0	1.2	0.8833	1.5e+06	2.0	0.9999
Maximum	233.0	8.0	0.9932	288.0	18.9	0.9926	1.5e+06	74.0	1.0000
%ile > Std[a]		0.0			0.0			0.0	
Dauphin Island sewage treatment plant (*n* = 30)									
Mean	93.0	11.8	0.8669	114.8	15.7	0.8620	1.5e+06	1.6e+02	0.9999
Median	82.5	10.0	0.9043	92.0	14.8	0.8796	1.5e+06	53.5	1.0000
Std. Dev.	29.7	7.2	0.1052	44.6	10.0	0.0692	0.0	2.7e+02	0.0002
Minimum	45.0	4.5	0.3778	71.0	6.0	0.6588	1.5e+06	1.0	0.9992
Maximum	162.0	29.0	0.9458	227.0	58.0	0.9339	1.5e+06	1.1e+03	1.0000
%ile > Std[a]		0.0			6.7			20.0	
Fairhope sewage treatment plant (*n* = 34)									
Mean	230.4	15.2	0.9371	231.0	20.5	0.8928	1.5e+06	1.3e+02	0.9999
Median	224.0	16.0	0.9366	229.0	21.0	0.9202	1.5e+06	84.0	1.0000
Std. Dev.	37.8	4.1	0.0204	32.5	5.4	0.1541	0.0	170.1	0.0001
Minimum	171.0	6.0	0.8947	178.0	12.0	0.0357	1.5e+06	25.0	0.9993
Maximum	335.0	22.0	0.9718	295.0	32.0	0.9583	1.5e+06	1.0e+03	1.0000
%ile > Std[a]		0.0			2.9			8.5	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = colonies; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Standard = 30 mg/L, TSS Standard = 30 mg/L, FC Standard = 200 colonies/100 ml.

ml, and range was $2.0e^5$-$2.4e^7$ colonies/100 ml. FC effluent median was 53 colonies/100 ml, mean was 164 colonies/100 ml, and range was 1 - 1100 colonies/100 ml.

Fairhope plant. BOD influent median was 224 mg/L, mean was 230 mg/L, and range was 171-335 mg/L. BOD effluent median was 15 mg/L, mean was 14 mg/L, and range was 6-22 mg/L. TSS influent median was 229 mg/L, mean was 226 mg/L, and range was 28-295 mg/L. TSS effluent median was 19 mg/L, mean was 19 mg/L, and range was 11-32 mg/L. FC influent median was $1.5e^6$ colonies/100 ml, mean was $1.5e^6$ colonies/100 ml, and range was $2.0e^5$-$2.4e^7$ colonies/100 ml. FC effluent median was 60 colonies/100 ml, mean was 115 colonies/100 ml, and range was 7-1000 colonies/100 ml.

By Location Within Subtype of System

Noncentralized Wastewater Systems

Sand Filtration (Table 9). Sand Filtration location1 (Sand 1) demonstrated slightly superior BOD and TSS removal efficiency when compared with Sand Filtration location 2 (Sand 2); FC removal efficiency was essentially the same for both locations. In terms of the quality of the treated effluent, both locations performed at essentially the same level for BOD and TSS; however, FC quality of the Sand 2 location effluent was found to be inferior to that of the Sand 1 effluent.

Peat (Table 10). Peat Filtration Location 5 (Peat 5) was superior in BOD removal efficiency when compared with the other three sample locations. All four sample locations achieved-good quality effluent in terms of BOD. Peat 5 was also superior in

Table 9

Wastewater Treatment Performance for Sand Filtration Locations

	BOD			TSS			FC		
Parameter	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (mg/L)	Effluent (mg/L)	Efficiency (mg/L)	Influent (col/100 ml)	Effluent (col/100 ml)	Efficiency (col/100 ml)
Sand location1 (*n* = 7)									
Mean	222.2	2.4	0.9876	272.7	27.3	0.7659	5.6e+06	1.1e+03	0.9987
Median	210.0	2.3	0.9877	99.0	28.0	0.7153	1.0e+06	180.0	0.9999
Std. Dev.	84.1	1.8	0.0113	490.0	13.3	0.1493	8.0e+06	1.4e+03	0.0021
Minimum	135.0	0.2	0.9644	47.0	1.0	0.6232	2.8e+05	0.0	0.9944
Maximum	390.0	4.8	0.9994	1.3e+03	42.0	0.9787	2.1e+07	3.4e+03	1.0000
%ile > Std[a]		0.0			0.0			37.5	
Sand location2 (*n* = 7)									
Mean	128.6	5.2	0.9574	69.6	23.7	0.6455	2.7e+06	1.1e+03	0.9996
Median	135.0	1.6	0.9633	59.0	17.0	0.7183	1.7e+06	3.2e+02	0.9998
Std. Dev.	69.6	6.4	0.0424	32.9	14.8	0.2343	3.6e+06	2.0e+03	0.0005
Minimum	18.0	0.4	0.8778	44.0	8.0	0.1429	2.2e+05	30.0	0.9986
Maximum	207.0	16.5	0.9968	142.0	48.0	0.8182	1.1e+07	5.6e+03	0.9999
%ile > Std[a]		0.0			0.0			37.5	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = colonies; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Standard = 30 mg/L, TSS Standard = 30 mg/L, FC Standard = 200 colonies/100 ml.

Table 10

Wastewater Treatment Performance for Peat Filtration Locations

Parameter	BOD Influent (mg/L)	BOD Effluent (mg/L)	BOD Efficiency (mg/L)	TSS Influent (mg/L)	TSS Effluent (mg/L)	TSS Efficiency (mg/L)	FC Influent (col/100 ml)	FC Effluent (col/100 ml)	FC Efficiency (col/100 ml)
Peat filtration location 3 (*n* = 17)									
Mean	62.42	10.80	78.25	52.76	13.88	76.05	1.2E+06	8.1E+04	91.04
Median	57.30	9.57	85.06	50.00	7.00	80.00	7.8E+05	5.8E+03	99.20
Std. Dev.	27.35	8.03	19.49	26.77	23.30	22.40	1.1E+06	1.8E+05	19.85
Minimum	12.60	1.35	24.05	10.00	0.00	22.31	2.2E+05	1.0E+02	27.72
Maximum	104.40	36.00	97.67	130.00	101.00	100.00	4.7E+06	7.3E+05	99.98
%ile > Std[a]		0.00			0.00			96.60	
Peat filtration location 4 (*n* = 17)									
Mean	97.58	10.80	89.11	59.29	17.12	68.40	1.1E+06	1.5E+04	96.22
Median	97.50	6.96	92.56	60.00	12.00	79.25	3.9E+05	4.6E+03	99.21
Std. Dev.	21.55	8.35	7.66	17.59	13.21	22.87	1.9E+06	1.9E+04	4.64
Minimum	54.00	1.80	70.46	10.00	2.00	18.18	1.1E+05	3.0E+02	86.30
Maximum	132.60	28.80	98.54	81.00	54.00	96.36	7.9E+06	5.6E+04	99.99
%ile > Std[a]		0.00			0.00			95.70	
Peat filtration location 5 (*n* = 17)									
Mean	230.01	14.27	93.10	117.06	14.82	85.99	1.5E+05	1.4E+04	91.05
Median	228.00	5.40	97.16	127.00	13.00	88.24	1.1E+05	4.4E+03	95.24
Std. Dev.	68.85	24.01	11.84	39.82	10.41	12.74	9.5E+04	2.9E+04	12.90
Minimum	100.50	3.15	50.14	43.00	3.00	44.19	2.9E+04	1.5E+03	50.00
Maximum	381.00	103.80	98.94	170.00	34.00	97.66	3.5E+05	1.2E+05	99.11
%ile > Std[a]		0.00			0.00			95.50	
Peat filtration location 6 (*n* = 16)									
Mean	138.94	10.91	91.02	67.81	14.38	76.71	2.1E+06	5.5E+04	96.72
Median	144.90	8.93	91.83	72.50	10.50	81.20	6.7E+05	1.0E+04	97.31
Std. Dev.	65.78	8.13	5.79	24.21	11.80	17.80	2.2E+06	9.3E+04	3.88
Minimum	34.80	0.78	77.71	17.00	2.00	37.50	5.6E+04	3.0E+02	86.25
Maximum	282.00	31.68	99.62	94.00	40.00	97.06	6.3E+06	3.4E+05	99.98
%ile > Std[a]		0.00			0.00			98.00	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = coliforms; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Std = 30 mg/L, TSS Std = 30 mg/L, FC Std = 200 colonies/100 ml.

TSS removal efficiency when compared with the other three sample locations. Again, all four sample locations achieved good-quality effluent in terms of TSS content. Peat Filtration Location 4 (Peat 4) and Peat Filtration Location6 (Peat 6) were superior to location Peat Filtration Location 3 (Pea when compared with t 3) and Peat 5 in terms of FC removal. However, the quality of the effluent was poor at all four locations, with high FC content remaining.

Constructed-wetland (Table 11). Constructed-wetland location Leiser was superior in BOD removal efficiency when compared with the other two sample locations. All three sample locations achieved good-quality effluent in terms of BOD. Constructed-wetland location Leiser was also superior in TSS removal efficiency when compared with the other two sample locations, with all three sample locations achieving good-quality effluent in terms of TSS content. Constructed-wetland location Clark was superior to locations Leiser and Zywick in terms of FC removal. However, the quality of the effluent was poor at all three locations, with high FC content remaining.

Centralized Wastewater Systems

A single location was sampled at each site.

Tests of Inference

Tests for Normality (Tables 12 and 13)

The Kolmogorov-Smirnov statistic with a Lilliefors significance level for testing normality strongly rejects the hypothesis for normality for all six groups.

Table 11

Wastewater Treatment Performance for Constructed-Wetland Locations

Parameter	BOD Influent (mg/L)	BOD Effluent (mg/L)	BOD Efficiency (mg/L)	TSS Influent (mg/L)	TSS Effluent (mg/L)	TSS Efficiency (mg/L)	FC Influent (col/100 ml)	FC Effluent (col/100 ml)	FC Efficiency (col/100 ml)
Clark wetland location (*n* = 14)									
Mean	112.83	21.92	76.89	54.86	11.50	78.30	8.6E+05	1.2E+04	94.20
Median	99.00	18.15	77.65	48.50	5.50	80.91	2.2E+05	5.4E+03	98.03
Std. Dev.	67.99	12.64	10.85	35.35	14.20	19.60	1.5E+06	1.6E+04	9.04
Minimum	28.35	5.97	59.22	11.00	1.00	30.77	3.0E+03	5.0E+01	66.67
Maximum	251.40	55.50	94.77	143.00	54.00	97.83	5.4E+06	5.8E+04	99.97
%ile > Std[a]		0.00			0.00			96.30	
Leiser wetland location (*n* = 16)									
Mean	105.52	17.67	80.07	61.69	10.56	82.53	1.7E+06	3.2E+04	91.48
Median	108.75	15.75	87.11	62.50	7.50	87.43	4.5E+05	5.0E+03	96.08
Std. Dev.	46.45	14.69	17.17	20.65	9.66	13.68	3.5E+06	7.9E+04	13.75
Minimum	4.50	1.50	29.87	17.00	0.00	52.31	2.1E+04	5.0E+01	53.62
Maximum	187.00	54.70	96.74	90.00	31.00	100.00	1.2E+07	3.2E+05	100.00
%ile > Std[a]		0.00			0.00			96.00	
Zywick wetland location (*n* = 16)									
Mean	99.06	25.14	73.01	42.69	12.19	68.79	2.0E+06	2.2E+04	87.93
Median	71.50	20.90	75.43	47.50	9.00	73.44	1.4E+05	4.5E+03	97.10
Std. Dev.	64.07	18.39	11.14	18.07	9.22	20.90	6.6E+06	4.0E+04	22.90
Minimum	24.00	4.80	50.00	8.00	0.00	33.33	7.0E+03	3.0E+02	10.71
Maximum	261.00	78.00	93.95	79.00	32.00	100.00	2.7E+07	1.5E+05	99.97
%ile > Std[a]		0.00			0.00			95.60	

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; col = colonies; Std. Dev. = standard deviation; %ile > Std = percentile greater than standard.

[a]BOD Std = 30 mg/L, TSS Std = 30 mg/L, FC Std = 200 colonies/100 ml.

Table 12

Test for Normality of Influent Noncentralized Wastewater Treatment System Samples

Parameter	Kolmogorov-Smirnov statistic[a]	*df*	*p Value*
BOD	0.104	127	0.002
TSS	0.292	127	<0.001
FC	0.333	127	<0.001

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform.

[a] Lilliefors significance correction.

Table 13

Test for Normality of Influent Centralized Wastewater Treatment System Samples

Parameter	Kolmogorov-Smirnov* statistic[a]	*df*	*p Value*
BOD	1.362	98	<0.001
TSS	0.906	98	<0.001
FC	3.099	98	<0.001

Note. BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform.
[a] Lilliefors significance correction.

Between Types of Systems

BOD (Table 14 and Figure 14)

The null hypothesis (H_0) is $\mu_{CWWTS} = \mu_{NWWTS}$, with $\alpha = 0.05$. When Z is used as the test statistic ($n > 30$) H_0 is rejected. For overall BOD removal, the centralized systems perform at a statistically significantly better efficiency level (CWWTS $\mu = 92.94\%$, NWWTS $\mu = 84.81\%$). There is considerable variance in the BOD sample results with the data from both system types, but the degree of variance is larger among the NWWTS data.

TSS (Table 15 and Figure 15)

When the same null hypothesis, α, and z test statistic are used, H_0 is again rejected. For overall TSS removal, the centralized systems perform at a statistically significantly better efficiency level (CWWTS $\mu = 90.91\%$, NWWTS $\mu = 75.99\%$). Again, there is considerable variance in the TSS sample results with the data from both system types, however, the degree of variance is larger among the NWWTS data.

Table 14

Efficiency of Removal of Biochemical Oxygen Demand (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Centralized wastewater treatment systems	98	13,265.0	11,074.0	484.1469	135.3571
Noncentralized wastewater treatment systems	127	12,160.0	14,351.0	484.1469	95.7480

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	13,265.00	Chi-Square	20.4800
Normal approximation		*df*	1
Z[a]	4.5245	*pr* > Chi-Square	$p < .0001$
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > Z|	$p < .0001$		
t Approximation			
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > |Z|	$p < .0001$		

[a] Z includes a 0.5 continuity correction.

FC (Table 16 and Figure 16)

Again, when the same null hypothesis, α, and *z* test statistic are used that were used with the BOD analysis, H_0 is also rejected for FC. For overall FC removal, the centralized systems perform at a statistically significantly better efficiency level (CWWTS μ = 99.99%, NWWTS μ = 93.44%). There is almost no variance among the CWWTS data; again however, considerable variance is found among with the data from the NWWTS samples.

Table 15

Efficiency of Removal of Total Suspended Solids (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Centralized wastewater treatment systems	98	14,574.0	11,074.0	484.1465	148.7143
Noncentralized wastewater treatment systems	127	10,851.0	14,351.0	484.1465	85.4409

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	14,574.00	Chi-Square	52.2616
Normal approximation		*df*	1
Z[a]	7.2282	*pr* > Chi-Square	$p < .0001$
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > Z|	$p < .0001$		
t Approximation			
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > |Z|	$p < .0001$		

[a] Z includes a 0.5 continuity correction.

Among Subtypes of Systems

BOD (Table 17 and Figure 17)

The variance in the BOD sample data is greatest with the Dauphin Island samples, the peat filtration samples, and the constructed-wetland samples. The sand filtration samples exhibited moderate variance, whereas the Daphne and Fairhope samples had very little variance. The constructed-wetland system performed least efficiently ($\mu = 76.65\%$). The Daphne plant and sand filtration systems performed most efficiently ($\mu = 97.69\%$ and $\mu = 97.25\%$, respectively). The variance in the BOD sample data is greatest

Table 16

Efficiency of Removal of Fecal Coliforms (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Centralized wastewater treatment systems	98	16,793.0.0	11,074.0	484.1071	171.3571
Noncentralized wastewater treatment systems	127	8,632.0	14,351.0	484.1071	67.9685

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	16,793.00	Chi-Square	139.5588
Normal approximation		*df*	1
Z[a]	11.8125	*pr* > Chi-Square	$p < .0001$
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > Z|	$p < .0001$		
t Approximation			
One-sided *pr* > Z	$p < .0001$		
Two-sided *pr* > |Z|	$p < .0001$		

[a] Z includes a 0.5 continuity correction.

with the Dauphin Island samples, the peat filtration samples, and the constructed-wetland samples. The sand filtration samples exhibited moderate variance, whereas the Daphne and Fairhope samples had very little variance. The constructed-wetland system performed least efficiently (μ = 76.65%). The Daphne plant and sand filtration systems performed most efficiently (μ = 97.69% and μ = 97.25%, respectively).

Table 17

Efficiency of Removal of Biochemical Oxygen Demand by Subtypes of Centralized Wastewater Treatment Systems and Noncentralized Wastewater Treatment Systems

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2721.00	1683.0	133.9834	80.0294
Dauphin Island	30	592.50	1485.0	129.7289	19.7500
Fairhope	34	1537.50	1683.0	133.9834	45.2206
Sand	14	1521.50	896.0	129.9016	108.6786
Peat	67	4838.50	4288.0	207.0734	72.2164
Wetland	46	1768.00	2944.0	199.3575	38.4348

Kruskal-Wallace Test (NWWTSs)		Kruskal-Wallace Test (CWWTSs)	
Chi-Square	46.1628	Chi-Square	72.8084
df	2	*df*	2
Pr > Chi-Square	$p < .0001$	Pr > Chi-Square	$p < .0001$

TSS (Table 18 and Figure 18)

The variance in the TSS sample data is greatest with the sand filtration samples, followed by the constructed-wetland, peat filtration, and Fairhope plant samples. The Dauphin Island plant samples exhibited moderate variance, whereas the Daphne plant samples had very little variance. The sand filtration system performed least efficiently (μ = 70.59%). The peat filtration and constructed-wetland systems performed at essentially the same efficiency (μ = 76.79% and μ = 76.46%, respectively). The Daphne plant removed TSS most efficiently (μ = 96.69%).

FC (Table 19 and Figure 19)

The variance in the FC sample data is greatest with the constructed-wetland followed by the peat filtration sample data. However, FC removal efficiency is rather good

Table 18

Efficiency of Removal of Total Suspended Solids by Subtypes of Centralized Wastewater Treatment Systems and Noncentralized Wastewater Treatment Systems

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2,653.00	1,683.00	133.9842	78.0294
Dauphin Island	30	673.00	1,485.00	129.7297	22.4333
Fairhope	34	1,525.00	1,683.00	133.9842	44.8529
Sand	14	696.00	896.00	129.9000	49.7143
Peat	67	4,455.50	4,288.00	207.0709	66.5000
Wetland	46	2,976.50	2,944.00	199.3552	64.7065
Kruskal-Wallace Test (NWWTSs)			Kruskal-Wallace Test (CWWTSs)		
Chi-Square		2.4353	Chi-Square		62.3210
df		2	*df*		2
Pr > Chi-Square		p 0.2959	Pr > Chi-Square		$p < .0001$

Table 19

Efficiency of Removal of Fecal Coliforms by Subtypes of Centralized Wastewater Treatment Systems and Noncentralized Wastewater Treatment Systems

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2,638.50	1683.0	133.8676	77.6029
Dauphin Island	30	1,157.50	1485.0	129.6167	75.6533
Fairhope	34	1,055.00	1683.0	133.8676	76.2094
Sand	14	1,588.00	896.0	129.8932	113.4286
Peat	67	4,015.50	4288.0	207.0600	59.9328
Wetland	46	2,524.50	2944.0	199.3447	54.8804
Kruskal-Wallace Test (NWWTSs)			Kruskal-Wallace Test (CWWTSs)		
Chi-Square		28.8958	Chi-Square		52.0729
df		2	*df*		2
Pr > Chi-Square		$p < .0001$	Pr > Chi-Square		p 0.5211

(μ = 91.07% and μ = 93.72%, respectively). There was almost no variance among the FC sample data from the other four treatment systems. The Daphne plant, Dauphin Island plant, Fairhope plant, and sand filtration systems all had exceptionally efficient FC removal (μ = >99%).

Among Noncentralized Wastewater Systems

BOD (Table 20 and Figure 20)

In this analysis, the null hypothesis (H_0) is $\mu_{Sand} = \mu_{Peat} = \mu_{Wetland}$, with $\alpha = 0.05$. When chi-square is used as the test statistic, H_0 is rejected. For overall BOD removal, the sand filtration systems perform at a statistically significantly better efficiency level (sand μ = 97.25%, peat μ = 87.82%, wetland μ = 76.65%).

Table 20

Efficiency of Removal of Biochemical Oxygen Demand by Subtypes of Noncentralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Sand	14	1,521.50	896.0	129.9016	108.6786
Peat	67	4,838.50	4,288.0	207.0734	72.2164
Wetland	46	1,768.00	2,944.0	199.3575	38.4348
		Kruskal-Wallace Test			
		Chi-Square	46.1628		
		df	2		
		Pr > Chi-Square	$p < .0001$		

TSS (Table 21 and Figure 21)

When the same null hypothesis and α are used that were used with the previous BOD analysis, H_0 cannot be rejected. Therefore, for overall TSS removal, there is no statistically significant difference in the ability of these three systems to remove TSS during treatment. Mean TSS efficiency is essentially the same (sand μ = 70.59%, peat μ = 76.79%, wetland μ = 76.46%).

Table 21

Efficiency of Removal of Total Suspended Solids by Subtypes of Noncentralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Sand	14	696.00	896.0	129.9000	49.7143
Peat	67	4,455.50	4,288.0	207.0709	66.5000
Wetland	46	2,976.50	2,944.0	199.3552	64.7065
		Kruskal-Wallace Test			
		Chi-Square	2.4353		
		df	2		
		Pr > Chi-Square	p 0.2959		

FC (Table 22 and Figure 22)

Once again when the same null hypothesis and α are used that were used with the BOD analysis, H_0 is also rejected for FC. For overall FC removal, the sand filtration systems perform at a statistically significantly better efficiency level (sand μ = 99.91%, peat μ = 93.72%, wetland μ = 91.07%).

Table 22

Efficiency of Removal of Fecal Coliforms by Subtypes of Noncentralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Sand	14	1,588.00	896.0	129.8932	113.4286
Peat	67	4,015.50	4,288.0	207.0600	59.9328
Wetland	46	2,524.50	2,944.0	199.3447	54.8804
		Kruskal-Wallace Test			
		Chi-Square	28.8958		
		df	2		
		Pr > Chi-Square	$p < .0001$		

Among Centralized Wastewater Systems

BOD (Table 23 and Figure 23)

This analysis is the same analysis that was performed on the NWWTS, data, with the null hypothesis (H_0) being $\mu_{\text{Daphne}} = \mu_{\text{Dauphin Isl}} = \mu_{\text{Fairhope}}$ and with $\alpha = 0.05$. When the chi-square is used as the test statistic, H_0 is rejected. For overall BOD removal, the Daphne treatment plant performs at a statistically significantly better efficiency level (Daphne $\mu = 97.69\%$, Dauphin Island, and $\mu = 86.69\%$, Fairhope $\mu = 93.71\%$).

TSS (Table 24 and Figure 24)

When the same null hypothesis and α are used that were used with the previous BOD analysis, the Chi-Square p value is very strong evidence for rejecting H_0 again. For overall TSS removal, the Daphne treatment plant performs at a statistically significantly better efficiency level (Daphne $\mu = 96.69\%$, Dauphin Island, and $\mu = 86.20\%$, and Fairhope $\mu = 89.28\%$).

Table 23

Efficiency of Removal of Biochemical Oxygen Demand by Subtypes of Centralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2,721.00	1,683.00	133.9834	80.0294
Dauphin Island	30	592.50	1,485.00	129.7289	19.7500
Fairhope	34	1,537.50	1,683.00	133.9834	45.2206
		Kruskal-Wallace Test			
		Chi-Square	72.8084		
		df	2		
		Pr > Chi-Square	$p < .0001$		

Table 24

Efficiency of Removal of Total Suspended Solids by Subtypes of Centralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2,653.00	1,683.00	133.9842	78.0294
Dauphin Island	30	673.00	1,485.00	129.7297	22.4333
Fairhope	34	1,525.00	1,683.00	133.9842	44.8529
		Kruskal-Wallace Test			
		Chi-Square	62.3210		
		df	2		
		Pr > Chi-Square	$p < .0001$		

FC (Table 25 and Figure 25)

Again when the same null hypothesis and α are used that were used with the BOD analysis, H_0 cannot be rejected for FC. Therefore, for overall FC removal, there is no statistically significant difference in the ability of these three systems to remove FC

Table 25

Efficiency of Removal of Fecal Coliform by Subtypes of Centralized Wastewater Treatment Systems (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Daphne	34	2,638.50	1,683.00	133.8676	77.6029
Dauphin Island	30	1,157.50	1,485.00	129.6167	75.6533
Fairhope	34	1,055.00	1,683.00	133.8676	76.2094
		Kruskal-Wallace Test			
		Chi-Square	52.0729		
		df	2		
		Pr > Chi-Square	p 0.5211		

bacteria during treatment (mean FC Daphne $\mu = 99.99\%$, Dauphin Island, $\mu = 99.91\%$, and Fairhope $\mu = 99.95\%$).

Between Sand Locations

BOD (Table 26 and Figure 26)

In this analysis the null hypothesis (H_0) is $\mu_{Sand1} = \mu_{Sand2}$, with $\alpha = 0.05$. When the t approximation is used as the test statistic ($n < 30$) H_0 cannot be rejected. Therefore, for overall BOD removal, there is no statistically significant difference in the ability of these two sand system locations to remove BOD during treatment (mean BOD: Sand 1 $\mu = 98.76\%$, Sand 2 $\mu = 95.74\%$). There is considerable variance in the BOD sample results with the data from both system types, but the degree of variance is far larger among the Sand 2 sample data. Therefore, although μ_{Sand1} and μ_{Sand2} are different, there is far too much variance to reject H_0.

Table 26

Efficiency of Removal of Biochemical Oxygen Demand by Sand Locations (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Sand 1	7	62.0	52.50	7.826238	8.857143
Sand 2	7	43.0	52.50	7.826238	6.142857

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	62.0000	Chi-Square	1.4735
Normal approximation		*df*	1
Z[a]	1.1500	*pr* > Chi-Square	0.2248
One-sided *pr* > Z	0.1251		
Two-sided *pr* > Z|	0.2502		
t Approximation			
One-sided *pr* > Z	0.1354		
Two-sided *pr* > |Z|	0.2709		

[a] Z includes a 0.5 continuity correction.

TSS (Table 27 and Figure 27)

When the same null hypothesis and α are used that were used with the previous BOD analysis, H_0 again cannot be rejected. Therefore, for overall TSS removal, there is no statistically significant difference in the performance ability of these two sand system locations to remove TSS during treatment (mean TSS Sand 1 μ = 76.59%, Sand 2 μ = 64.55%). There is considerable variance in the TSS sample results with the data from both system locations; again, however, the degree of variance is much larger among the Sand 2 sample data. Again, although μ_{Sand1} and μ_{Sand2} are different, there is far too much variance to reject H_0.

Table 27

Efficiency of Removal of Total Suspended Solids by Sand Locations (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Sand 1	7	55.0	52.50	7.826238	7.857143
Sand 2	7	50.0	52.50	7.826238	7.142857

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	55.0000	Chi-Square	0.1020
Normal approximation		*df*	1
Z[a]	0.2556	*pr* > Chi-Square	0.7494
One-sided *pr* > Z	0.3991		
Two-sided *pr* > Z|	0.7983		
t Approximation			
One-sided *pr* > Z	0.4011		
Two-sided *pr* > |Z|	0.8023		

[a] Z includes a 0.5 continuity correction.

FC (Table 28 and Figure 28)

When using the same null hypothesis and α are used that were used with the previous BOD analysis, H_0 cannot be rejected. Therefore, for overall FC removal, there is no statistically significant difference in the ability of these two sand system locations to remove FC bacteria during treatment, (mean FC Sand 1 μ = 99.87%, Sand 2 μ = 99.97%). There is considerable variance in the FC sample results with the data from both system locations, however, this time, the degree of variance is much larger among the Sand 1 sample data. As with the BOD and TSS results, although FC μ_{Sand1} and μ_{Sand2} are different, there is far too much variance to reject H_0.

Table 28

Efficiency of Removal of Fecal Coliforms by Sand Locations (Wilcoxon's Rank Sum for Types, Wilcoxon's Two-Sample Test, and Kruskal-Wallis Test)

Location	*n*	Sum ofsco	Expectedun	SDunder	Meanscore
Sand 1	7	55.50	52.50	7.7049	7.9289
Sand 2	7	49.50	52.50	7.7049	7.0714

Wilcoxon's Two-Sample Test		Kruskal-Wallis Test	
Statistic	55.5000	Chi-Square	0.1515
Normal approximation		*df*	1
Z[a]	0.3245	*pr* > Chi-Square	0.6970
One-sided *pr* > Z	0.3728		
Two-sided *pr* > Z|	0.7456		
t Approximation			
One-sided *pr* > Z	0.3754		
Two-sided *pr* > |Z|	0.7507		

[a] Z includes a 0.5 continuity correction.

Among Peat Locations

BOD (Table 29 and Figure 29)

This analysis is the same analysis performed earlier, with the null hypothesis (H_0) being $\mu_{Peat3} = \mu_{Peat4} = \mu_{Peat5} = \mu_{Peat6}$ and with $\alpha = 0.05$. When chi-square is used as the test statistic, H_0 is rejected. For overall BOD removal, Peat 3 performed at an inferior efficiency level (mean rank score 20.97), and Peat 5 performed at the best efficiency level (mean rank score 49.35; Peat 3 μ = 78.25%, Peat 4 μ = 89.11%, Peat 5 μ = 93.10%, Peat 6 μ = 91.02%). There is considerable variance in the BOD sample results with the data from all four system locations, but the variance among the data from Peat 3 is the greatest.

Table 29

Efficiency of Removal of Biochemical Oxygen Demand by Peat Locations (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	*n*	Sum of scores	Expected under H_0	SD under H_0	Mean score
Peat 3	17	356.50	578.0	69.40089	20.9706
Peat 4	17	530.50	578.0	69.40089	31.2059
Peat 5	17	839.00	578.0	69.40089	49.3530
Peat 6	16	552.00	544.0	67.99869	34.5001
		Kruskal-Wallace Test			
		Chi-Square	18.5166		
		df	3		
		Pr > Chi-Square	0.0003		

TSS (Table 30 and Figure 30)

When the same null hypothesis and α are used that were used with the previous BOD, analysis H_0 again cannot be rejected. Therefore, for overall TSS removal, there is no statistically significant difference in the performance ability of these four peat filtration sample locations (Peat 3 μ = 76.05%, Peat 4 μ = 68.40%, Peat 5 μ = 85.99%, Peat 6 μ = 76.71%). There is considerable variance in the TSS sample results with the data from all four system locations. Although μ_{Peat3}, μ_{Peat4}, μ_{Peat5}, and μ_{Peat6} are different, there is far too much variance to reject H_0.

FC (Table 31 and Figure 31)

Again, when the same null hypothesis and α are used that were used with the previous analysis, H_0 again cannot be rejected. Therefore, for overall FC removal, there is no statistically significant difference in the performance ability of these four peat filtration

Table 30

Efficiency of Removal of Total Suspended Solids by Peat Locations (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Peat 3	17	574.50	578.0	69.4001	33.7941
Peat 4	17	435.50	578.0	69.4001	25.6176
Peat 5	17	749.00	578.0	69.4001	44.0588
Peat 6	16	519.00	544.0	67.9980	32.4375
		Kruskal-Wallace Test			
		Chi-Square	7.7818		
		df	3		
		Pr > Chi-Square	0.0507		

Table 31

Efficiency of Removal of Fecal Coliform by Peat Locations (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Peat 3	17	642.50	578.0	69.3987	37.7941
Peat 4	17	637.00	578.0	69.3987	37.4706
Peat 5	17	403.00	578.0	69.3987	23.7059
Peat 6	16	595.50	544.0	67.9966	37.2187
		Kruskal-Wallace Test			
		Chi-Square	6.3660		
		df	3		
		Pr > Chi-Square	0.0951		

sample locations (Peat 3 μ = 91.04%, Peat 4 μ = 96.22%, Peat 5 μ = 91.05%, Peat 6 μ = 96.72%). There is considerable variance in the FC sample results with the data from all four system locations, but the variance is greatest among the data from Peat 3. Although μ_{Peat3}, μ_{Peat4}, μ_{Peat5}, and μ_{Peat6} are different, there is far too much variance to reject H_0.

Among Constructed-wetland Locations

BOD (Table 32 and Figure 32)

This analysis is again the same as the analysis performed earlier, with the null hypothesis (H_0) now being $\mu_{Clark} = \mu_{Leiser} = \mu_{Zywicki}$ and with $\alpha = 0.05$. When chi-square is used as the test statistic, H_0 cannot be rejected. For overall BOD removal, there is no statistically significant difference in the performance ability of these three constructed-wetland sample locations (Clark $\mu = 76.89\%$, Leiser $\mu = 80.07\%$, Zywicki $\mu = 73.01\%$). There is considerable variance in the FC sample results with the data from all three sys-

Table 32

Efficiency of Removal of Biochemical Oxygen Demand by Constructed-Wetland Locations (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	*n*	Sum of scores	Expected under H_0	SD under H_0	Mean score
Clark	14	320.50	329.0	41.8874	22.8928
Leiser	16	462.00	376.0	43.3576	28.8750
Zywicki	16	298.50	376.0	43.3576	18.6562
		Kruskal-Wallace Test			
		Chi-Square	4.6782		
		df	2		
		Pr > Chi-Square	0.0964		

tem locations. Although μ_{Clark}, μ_{Leiser}, and $\mu_{Zywicki}$ are different, there is far too much variance to reject H_0.

TSS (Table 33 and Figure 33)

When the same null hypothesis and α are used that were used with the previous BOD analysis, H_0 again cannot be rejected. Therefore, for overall TSS removal, there is no statistically significant difference in the performance ability of these three constructed-wetland sample locations (Clark μ = 78.30%, Leiser μ = 82.53%, Zywicki μ = 68.79%). There is considerable variance in the FC sample results with the data from all three system locations. Although μ_{Clark}, μ_{Leiser}, and $\mu_{Zywicki}$ are different, there is far too much variance to reject H_0.

Table 33

Efficiency of Removal of Total Suspended Solids by Constructed-Wetland Locations (Wilcoxon's Rank Sum and Kruskal-Wallis Test)

Subtype	n	Sum of scores	Expected under H_0	SD under H_0	Mean score
Clark	14	354.00	329.0	41.8874	25.2857
Leiser	16	438.50	376.0	43.3576	27.4062
Zywicki	16	288.50	376.0	43.3576	18.0312
		Kruskal-Wallace Test			
		Chi-Square	4.2591		
		df	2		
		Pr > Chi-Square	0.1189		

FC (Table 34 and Figure 34)

Again, when using the same null hypothesis and α are used that were used with the previous analysis, H_0 cannot be rejected. Therefore, for overall FC removal, there is no statistically significant difference in the performance ability of these three constructed-wetland sample locations (Clark μ = 94.20%, Leiser μ = 91.48%, and Zywicki μ

= 87.93%). There is considerable variance in the FC sample results with the data from all three system locations. Again, although μ_{Clark}, μ_{Leiser}, and $\mu_{Zywicki}$ are different, there is far too much variance to reject H_0.

Table 34

Efficiency of Removal of Fecal Coliform by Constructed-Wetland Locations (Wilcoxon-'s Rank Sum and Kruskal-Wallis Test)

Subtype	*n*	Sum of scores	Expected under H_0	SD under H_0	Mean score
Clark	14	354.0	329.0	41.8861	25.2857
Leiser	16	383.0	376.0	43.3563	23.9375
Zywicki	16	344.0	376.0	43.3563	21.5000
		Kruskal-Wallace Test			
		Chi-Square	0.6201		
		df	2		
		Pr > Chi-Square	0.7334		

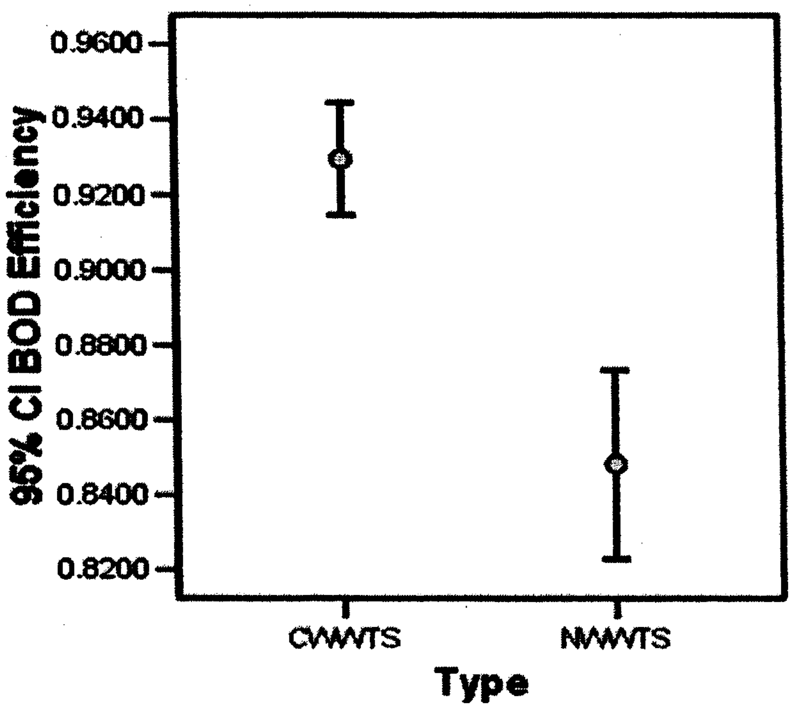

Figure 14. Efficiency of removal of biochemical oxygen demand (BOD) by centralized wastewater treatment systems (CWWTS) and noncentralized wastewater treatment systems (NWWTS). 95% CI = 95% confidence interval.

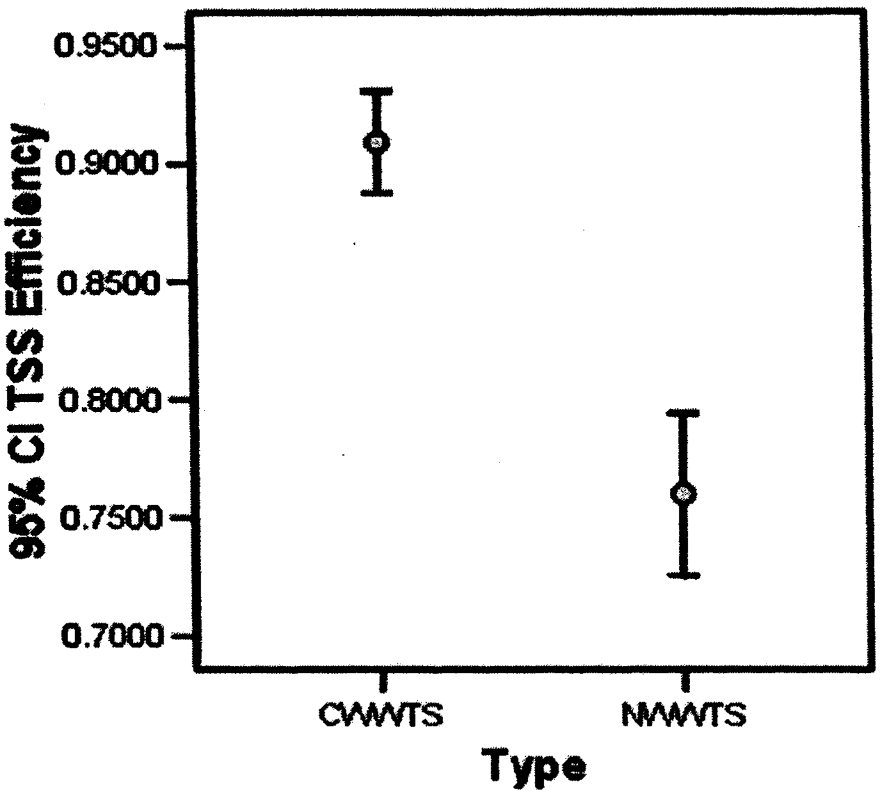

Figure 15. Efficiency of removal of total suspended solids (TSS) by centralized wastewater treatment systems (CWWTS) and noncentralized wastewater treatment systems (NWWTS). 95% CI = 95% confidence interval.

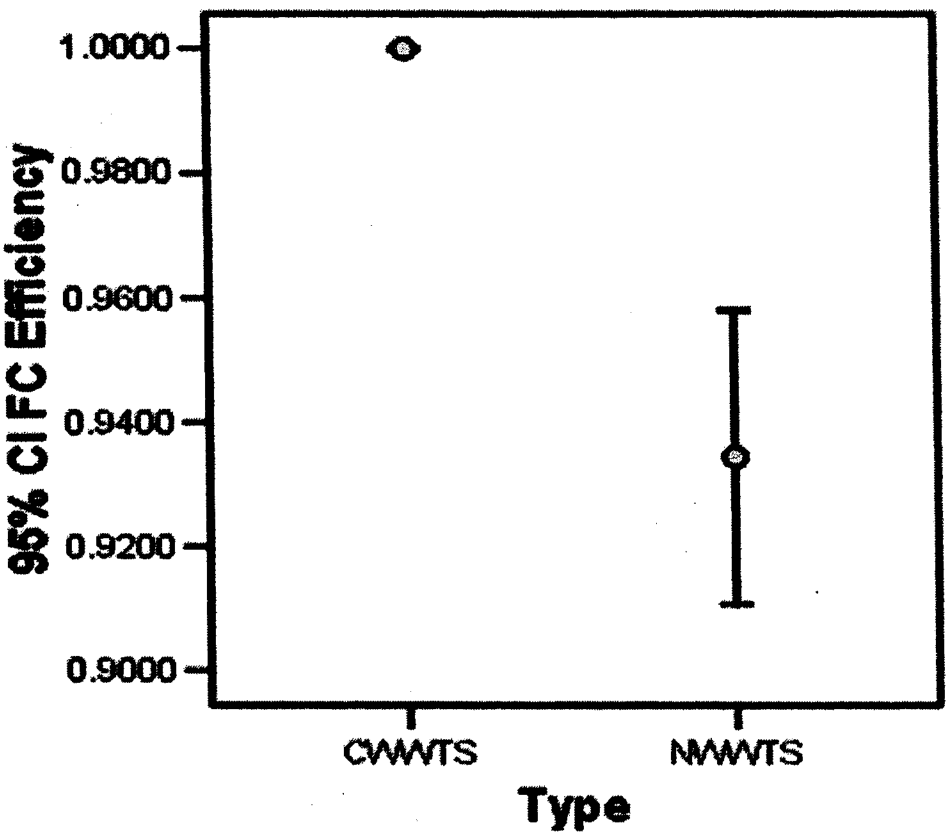

Figure 16. Efficiency of removal of fecal coliform (FC) by centralized wastewater treatment systems (CWWTS) and noncentralized wastewater treatment systems (NWWTS). 95% CI = 95% confidence interval.

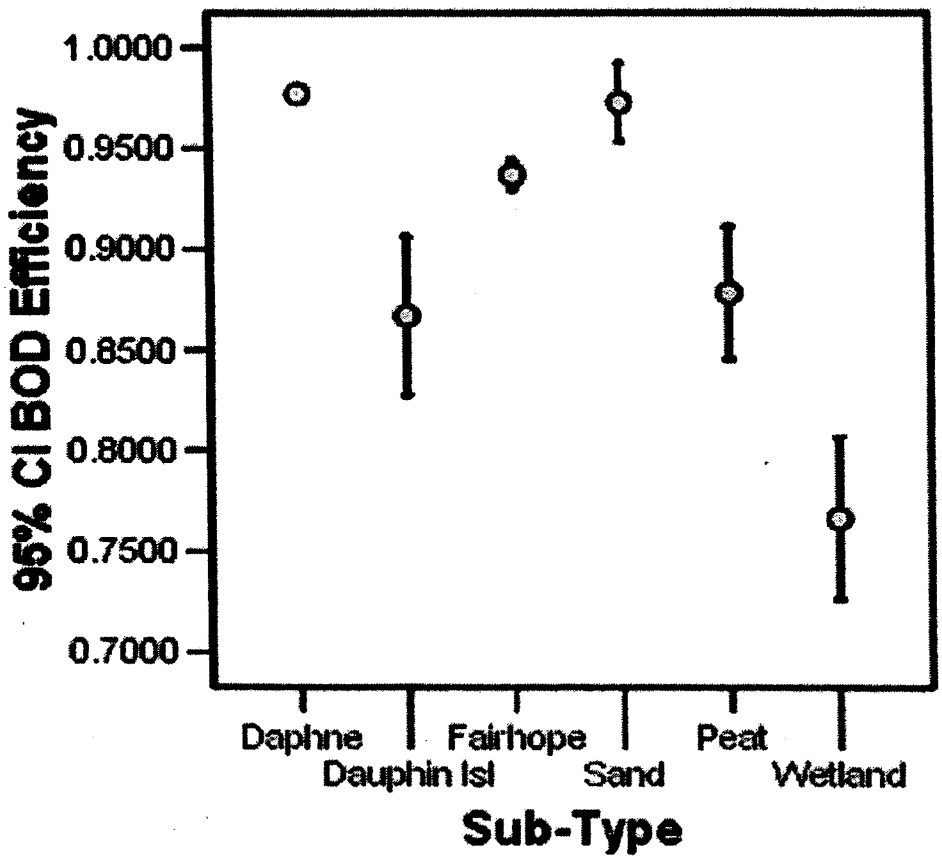

Figure 17. Efficiency of removal of biochemical oxygen demand (BOD) by subtypes of centralized wastewater treatment system and of noncentralized wastewater treatment system. 95% CI = 95% confidence interval.

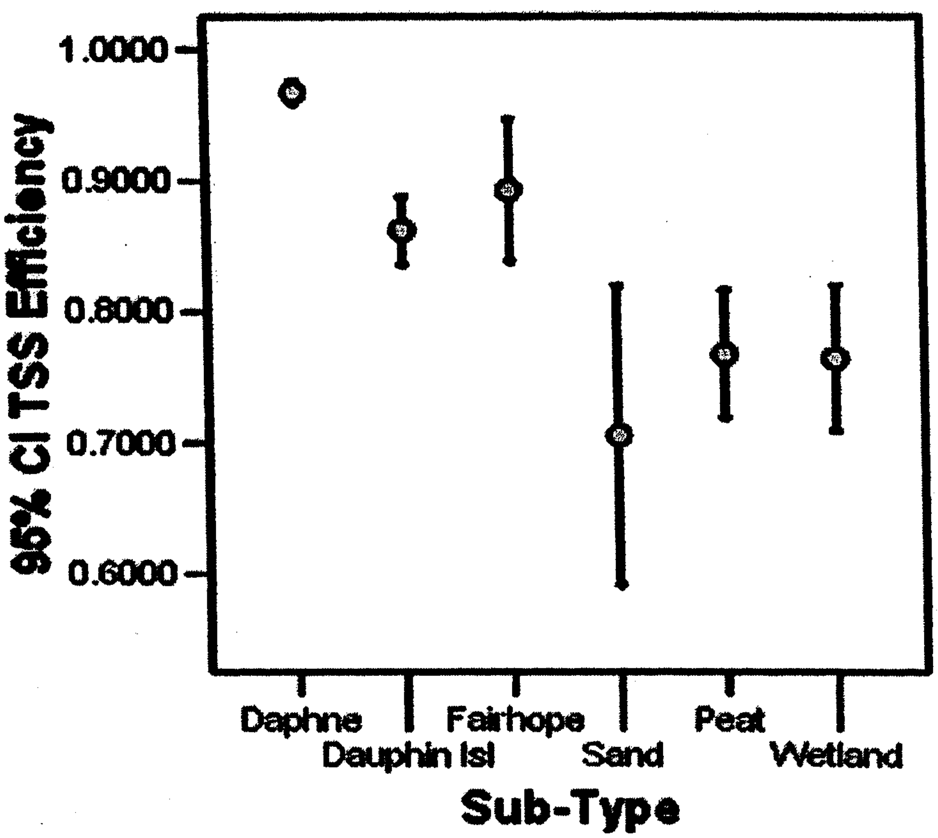

Figure 18. Efficiency of removal of total suspended solids (TSS) by subtypes of centralized wastewater treatment system and of noncentralized wastewater treatment system. 95% CI = 95% confidence interval.

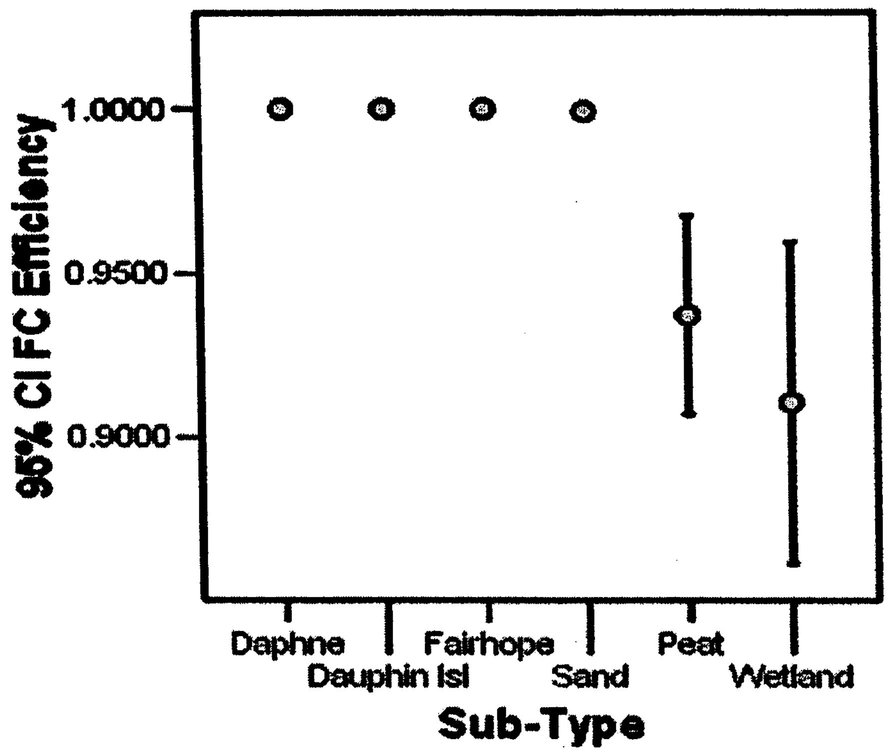

Figure 19. Efficiency of removal of fecal coliform (FC) by subtypes of centralized wastewater treatment system and of noncentralized wastewater treatment system. 95% CI = 95% confidence interval.

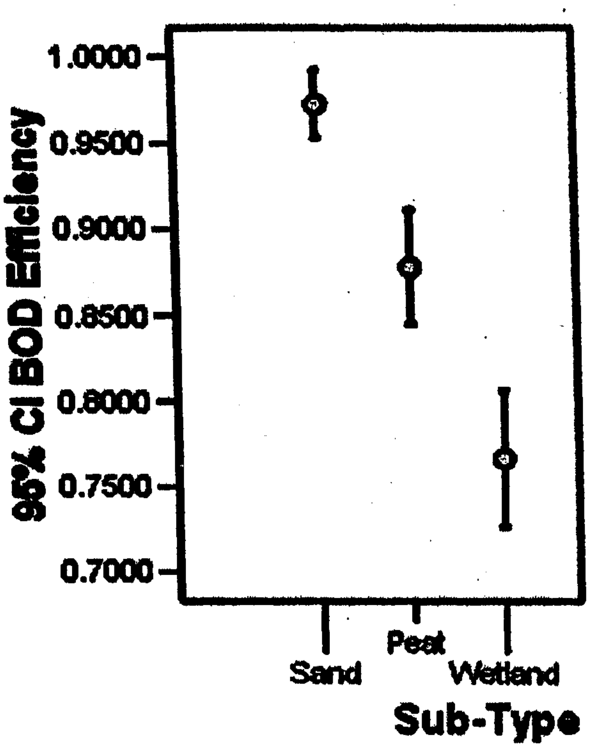

Figure 20. Efficiency of removal of biochemical oxygen demand (BOD) by subtypes of noncentralized wastewater treatment. 95% CI = 95% confidence interval.

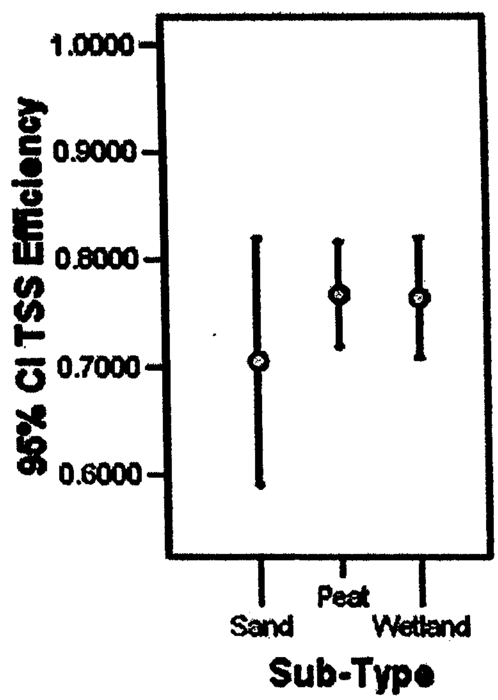

Figure 21. Efficiency of removal of total suspended solids (TSS) by subtypes of noncentralized wastewater treatment. 95% CI = 95% confidence interval.

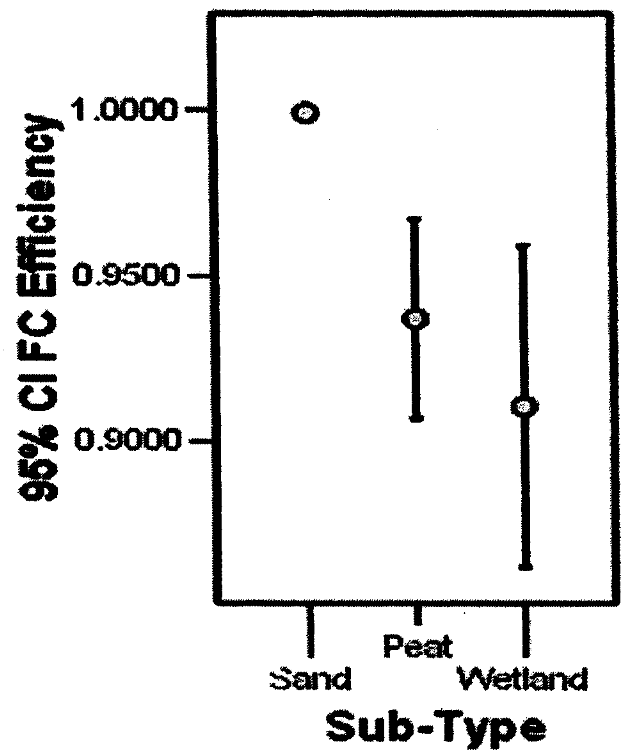

Figure 22. Efficiency of removal of fecal coliform (FC) by subtypes of noncentralized wastewater treatment. 95% CI = 95% confidence interval.

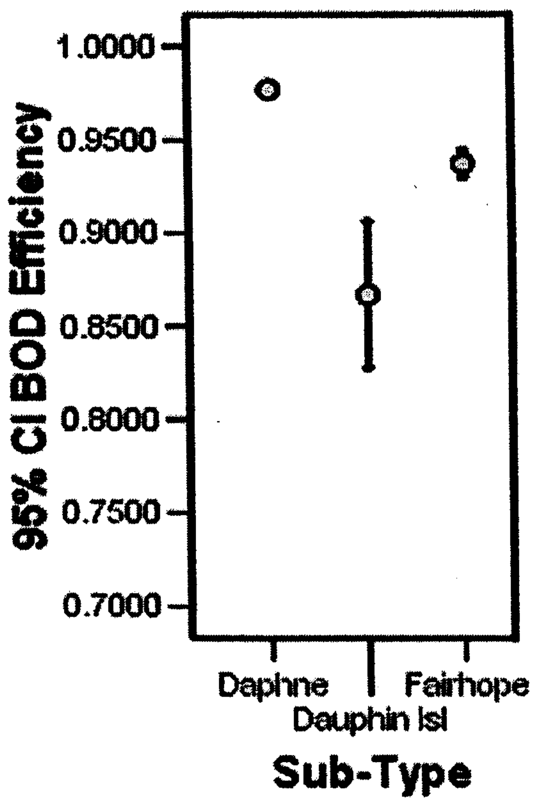

Figure 23. Efficiency of removal of biochemical oxygen demand (BOD) by subtypes of centralized wastewater treatment. 95% CI = 95% confidence interval.

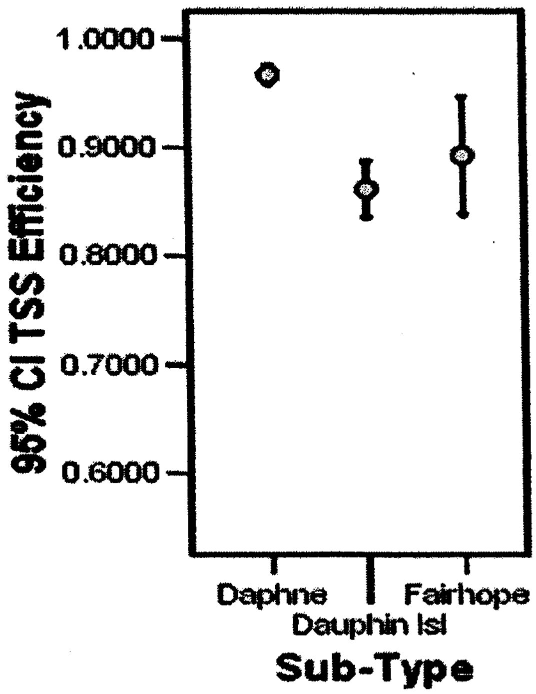

Figure 24. Efficiency of removal of total suspended solids (TSS) by subtypes of centralized wastewater treatment. 95% CI = 95% confidence interval.

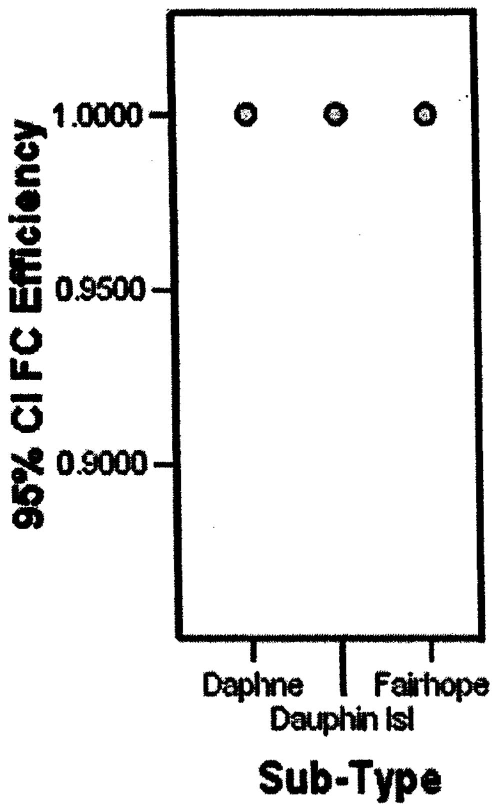

Figure 25. Efficiency of removal of fecal coliform (FC) by subtypes of centralized wastewater treatment. 95% CI = 95% confidence interval.

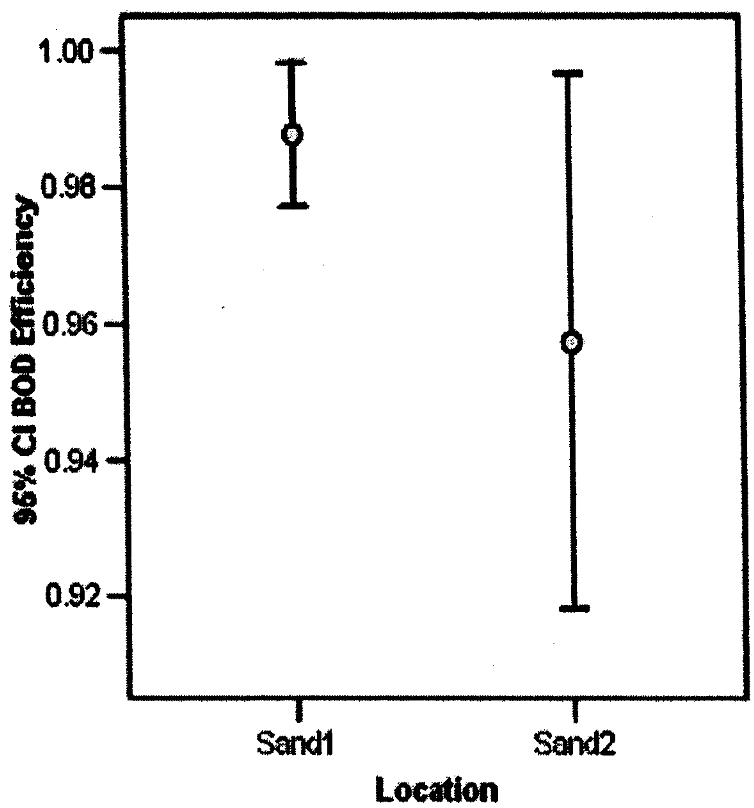

Figure 26. Efficiency of removal of biochemical oxygen demand (BOD) at locations of sand filtration system. 95% CI = 95% confidence interval.

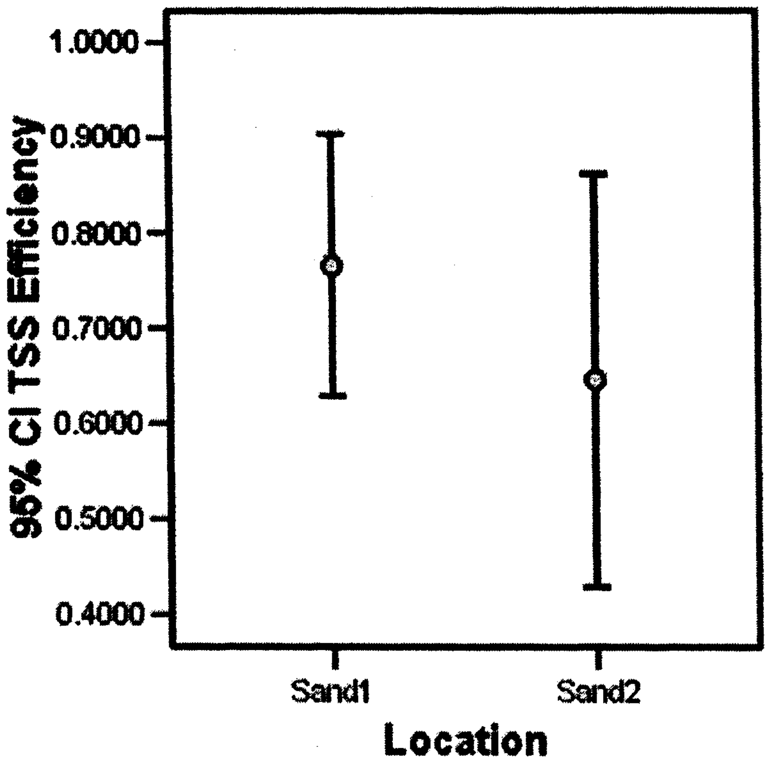

Figure 27. Efficiency of removal of total suspended solids (TSS) at locations of sand filtration system. 95% CI = 95% confidence interval.

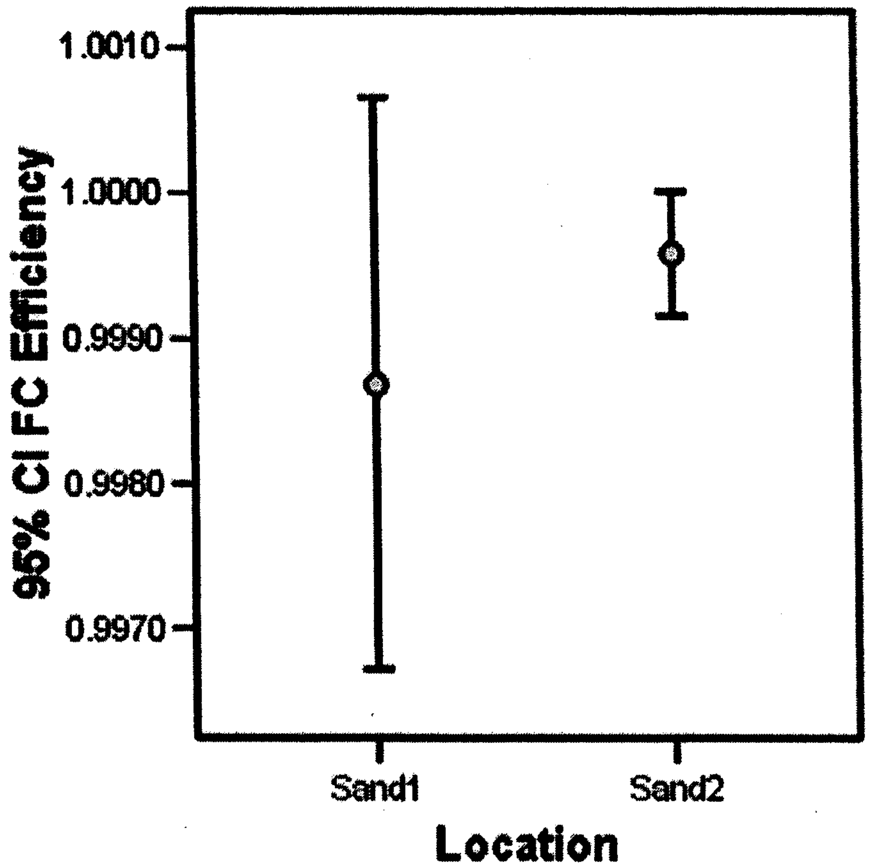

Figure 28. Efficiency of removal of fecal coliform (FC) at locations of sand filtration system. 95% CI = 95% confidence interval.

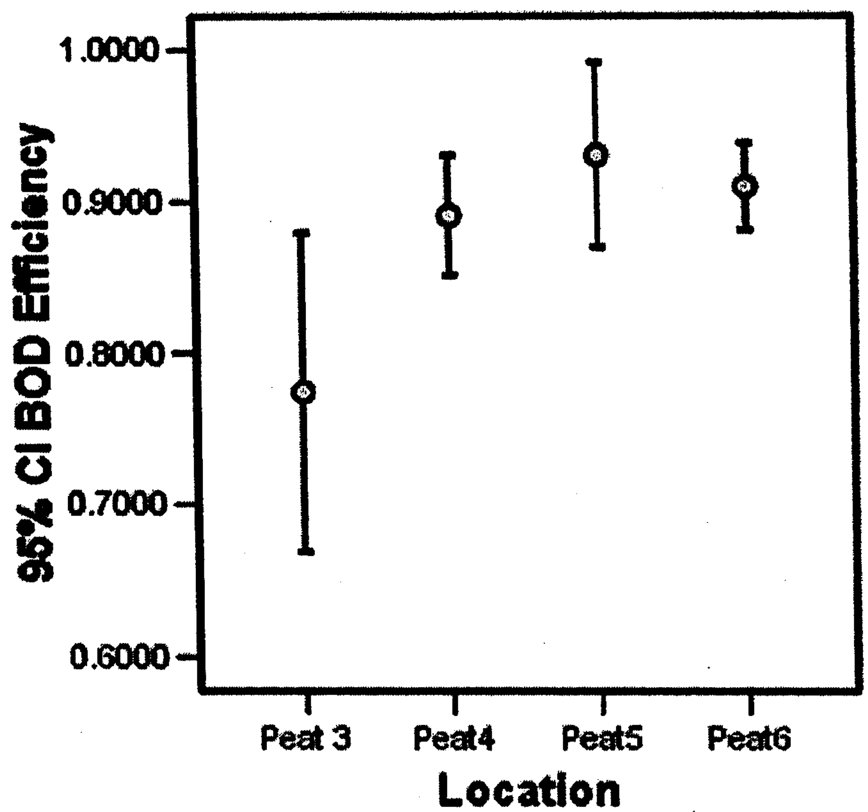

Figure 29. Efficiency of removal of biochemical oxygen demand (BOD) at locations of peat filtration system. 95% CI = 95% confidence interval.

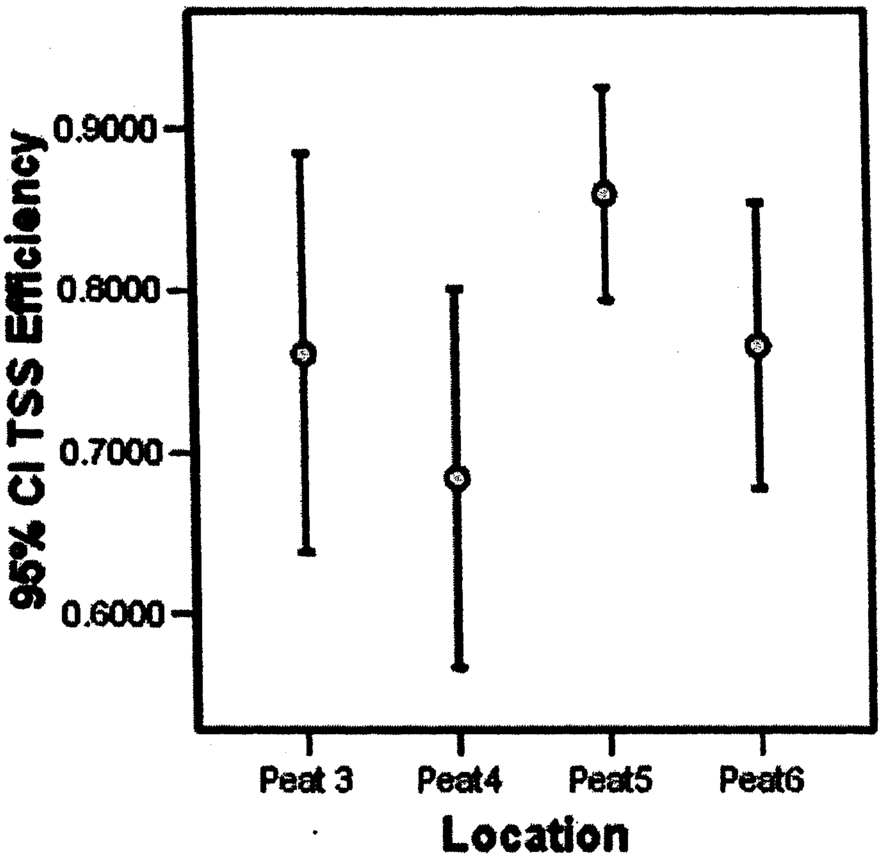

Figure 30. Efficiency of removal of total suspended solids (TSS) at locations of peat filtration system. 95% CI = 95% confidence interval.

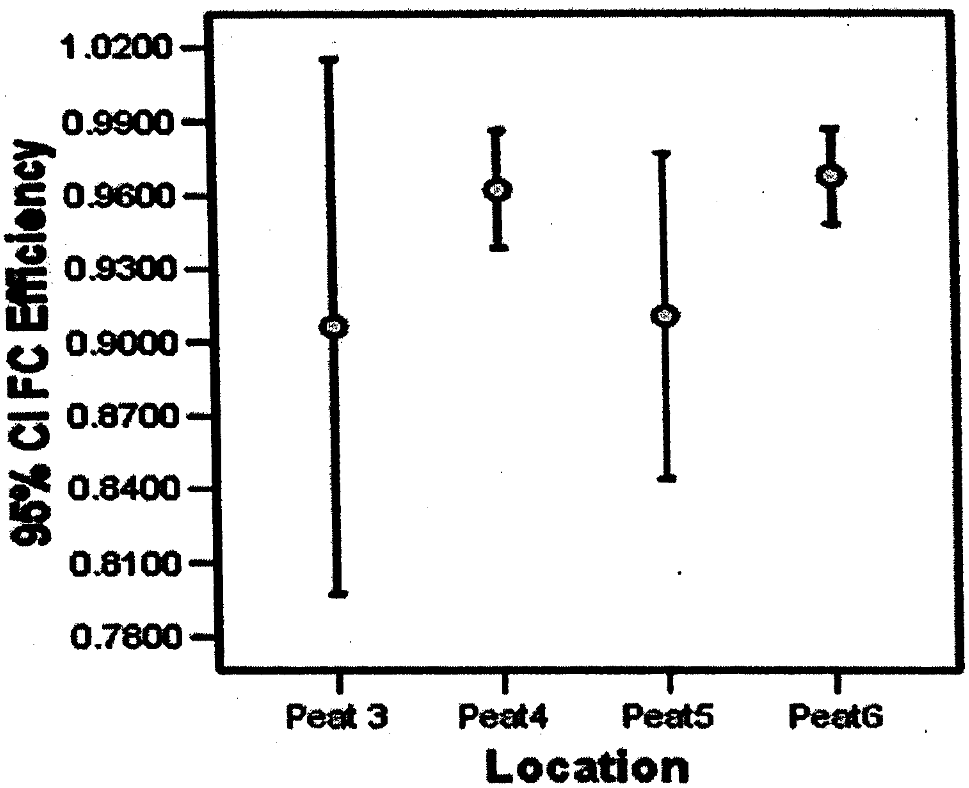

Figure 31. Efficiency of removal of fecal coliform (FC) at locations of peat filtration system. 95% CI = 95% confidence interval.

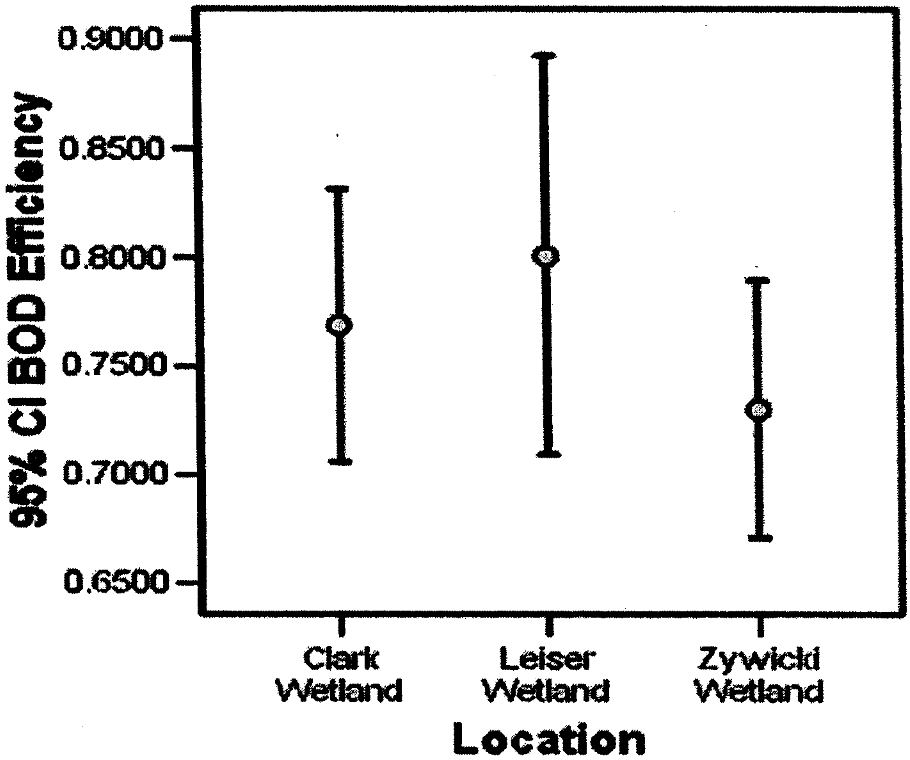

Figure 32. Efficiency of removal of biochemical oxygen demand (BOD) at locations of constructed-wetland treatment system. 95% CI = 95% confidence interval.

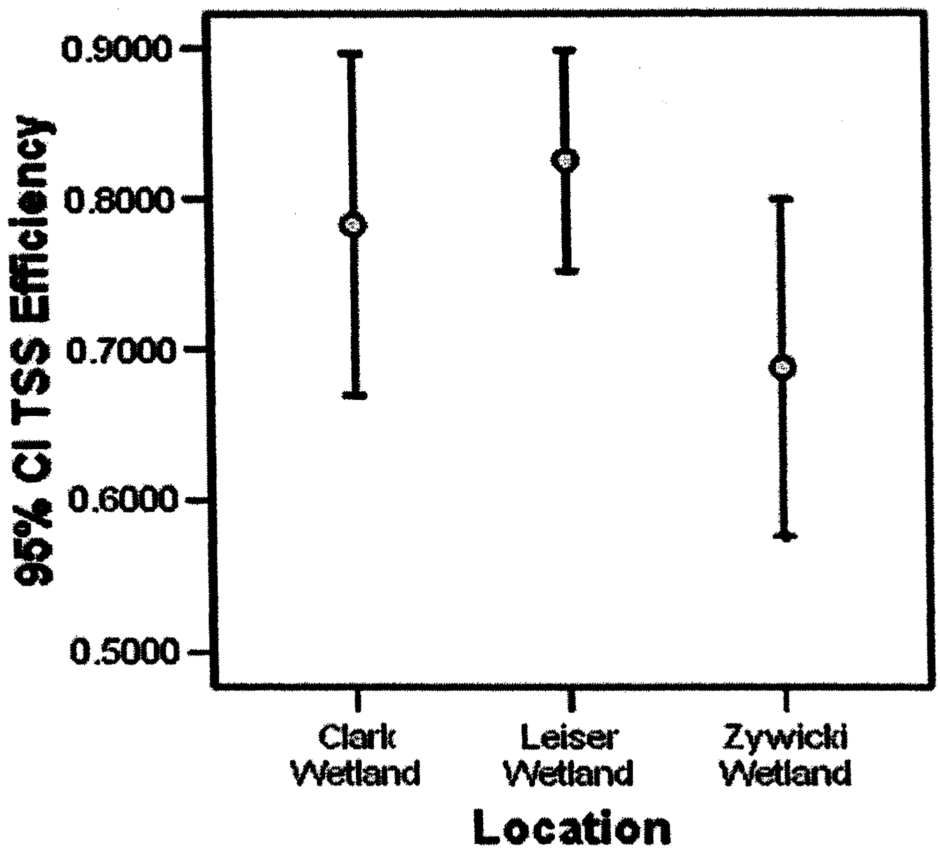

Figure 33. Efficiency of removal of total suspended solids (TSS) at locations of constructed-wetland treatment system. 95% CI = 95% confidence interval.

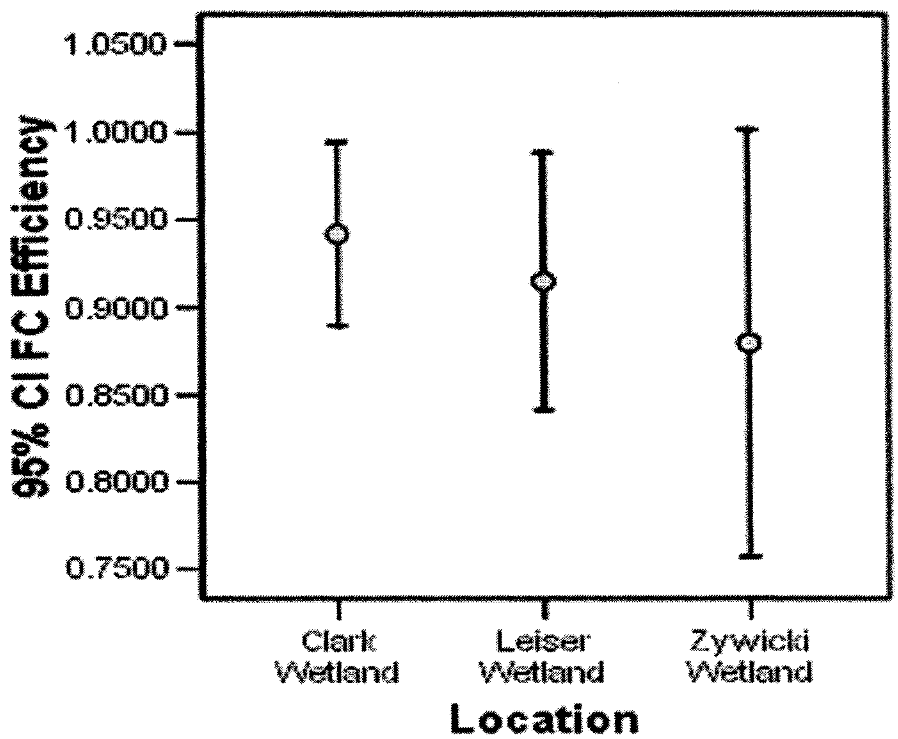

Figure 34. Efficiency of removal of fecal coliform (FC) at locations of constructed-wetland treatment system. 95% CI = 95% confidence interval.

CHAPTER 6

DISCUSSION

Overview

When the overall performance of the centralized systems was compared with the overall performance of the noncentralized systems, the CWWTSs were found to be superior to the NWWTSs ($p = < .0001$ for BOD reduction, TSS reduction, and FC reduction). However, as mentioned in chapter 5, this finding is at least partially erroneous because the NWWTSs have additional tertiary treatment (i.e., the soil) that was not measured. The effluent measures for the CWWTS were taken after the final treatment when the effluent was being discharged to the environment [water]. The effluent measures for the NWWTSs in this study were taken after the secondary treatment, before discharge to the tile field for further treatment via the soil before entry into the groundwater. Measuring the final effluent at the point of entry into the groundwater would have required almost a laboratory situation.

However, valid comparisons can be made among the three subtypes of CWWTSs and the three subtypes of NWWTSs. Additionally, valid comparisons can be made among the various NWWTS sample sites.

NWWTS Subsystems

In terms of overall BOD reduction, sand filtration was found to be superior to both peat filtration and constructed-wetland ($p = < .0001$). In terms of overall TSS reduction, no subsystem was found to be better than another ($p = .2959$). All three subsystems performed at about the 75% efficiency level. In terms of overall FC reduction, sand filtration was again found to be superior to both peat filtration and constructed-wetland filtration ($p = < .0001$).

CWWTS Subsystems

In terms of overall BOD reduction, the Daphne STP was found to be superior to both the Fairhope STP and the Dauphin Island STP ($p = < .0001$). Also, in terms of overall TSS reduction, the Daphne STP was found to be superior to both the Fairhope STP and the Dauphin Island STP ($p = < .0001$). In terms of overall FC reduction, no plant was found to be better than another ($p = .5211$). All three subsystems performed at the >99% efficiency level.

NWWTS Sample Locations

Sand Filtration

Two different sample locations were evaluated. For all three parameters (BOD, TSS, and FC), no difference was noted ($p = .2709$, .8023, and .7507 respectively).

Peat Filtration

Four different sample locations were evaluated. In terms of overall BOD reduction, Peat 5 received the highest Wilcoxon's rank sum score, whereas Peat 3 received the lowest. The Kruskal-Wallace test revealed a statistically significant difference in the BOD removal performance among these sample locations ($p = .0003$). For the other two parameters (TSS and FC), no difference was noted ($p = .507$, and .0951, respectively).

Constructed-wetland

Three different sample locations were evaluated. For all three parameters (BOD, TSS, and FC) no difference was noted ($p = .0964$, .1189, and .7334, respectively).

Scoring System

Presently, no methodology is in effect to express the performance of these systems in a format that would allow an educated comparison to be made among the various systems presently on the market. Although local public health departments do recommend "approved" systems for consumer installation, the consumer has little to no useful information about which system may perform better in reducing contamination before discharge of the effluent into the environment. Because environmental consciousness has increases in the United States, this public health information may now be important to Americans.

This dissertation represents the first published work to introduce such a methodology. The use of this simple rank scoring system would allow public consumers to compare the treatment performance of various noncentralized sewage treatment systems.

This methodology has the potential to enable the American public to select the most environ-mentally sound system for installation at their homesite. The development of this scoring methodology was based on experimentation conducted with evaluation/assessment data obtained on several NWWTSs.

Development

A scoring system was developed to rank the efficiency of each system with a single number. This score is similar in concept to that given to refrigeration equipment for energy ratings. With this calculation, the lower the numerical score is, the better the performance of the system. The methodology for the equation is based on several existing ranking calculations such as the Wet Bulb-Black Globe Temperature Index and the wind chill factor.

The Equation.

The equation for calculating the ranking score is as follows.

$$Score = \left[L_N \; \frac{FC_M}{FC_S} + \frac{TSS_M}{TSS_S} + \frac{BOD_M}{BOD_S} + \left(\frac{1}{FC_E}\right) + \left(\frac{1}{TSS_E}\right) + \left(\frac{1}{BOD_E}\right)\right],$$

where

FC_M = the measured concentration of fecal coliforms, expressed as colonies per 100 ml measured at effluent.

FC_S = the USEPA recommended maximum standard concentration of fecal coliforms for human contact with recreational waters. This value is 200 colonies/100 ml of sampled water.

TSS_M = the measured value for total suspended solids expressed as milligrams per liter measured at the effluent-sampling point.

TSS_S = the USEPA recommended maximum standard concentration for total suspended solids to permit effluent discharge from final treatment to surface waters. The permited effluent discharge maximum standard for TSS is 30 mg/L (based upon a 30-day average).

BOD_M = the measured value for biochemical oxygen demand of the wastewater after 5 days of incubation at 20 °C (BOD_5) expressed as mg/l measured at the effluent sampling point.

BOD_S = The USEPA recommended maximum standard concentration for BOD_5, to permit effluent discharge from final treatment to surface waters. The permited effluent discharge maximum standard for BOD_5 is 30 mg/L (based upon a 30-day average).

FC_E = the efficiency (percentage of reduction) in fecal coliform concentration which is calculated as $[\frac{C_I - C_E}{C_I}]$ where C_I = influent concentration and C_E = effluent concentration. Because the intent of the score is to rank system performance in such a manner that the low score represents the best system, the value calculated is then reciprocated (1/x).

TSS_E = the efficiency (percentage of reduction) in total suspended solid median concentration, which is calculated as $[\frac{C_I - C_E}{C_I}]$ where C_I = influent concentration and C_E = effluent concentration. Again, because the intent of the score is to rank system performance in such a manner that the low score represents the best system, the value calculated is then reciprocated (1/x).

BOD_E = the efficiency (percentage of reduction) in biochemical oxygen demand of the wastewater after 5 days of incubation at 20 °C (BOD_5), median concentration, which is calculated as $[\frac{C_I - C_E}{C_I}]$ where C_I = influent concentration and C_E = effluent concentration. The value calculated is again reciprocated (1/x).

Equation Components

Effluent Quality

The first three components forming the equation for the ranked score were derived from data obtained in regard to the wastewater treatment systems' final effluent quality compared to the USEPA maximum permissible standard for discharge of effluent into the environment from an STP that has obtained a permit. To quantify the effluent quality, each measured parameter was compared against the USEPA maximum allowable value for compliance with the permitting for STPs under the National Pollutant Discharge Elimination System.

Efficiency (Percentage of Reduction)

The last three components of the equation deal with the wastewater system's ability to reduce contamination from the influent concentration to the effluent concentration. Each resultant parameter efficiency value was reciprocated to yield a number that was skewed so that lower numbers indicate superior efficiency. Therefore, a lower overall score means a better system.

Application of the Scoring Process to Wastewater Treatment Systems

Research Sample Data

NWWTSs. The sand filtration systems performed the best, achieving a score of 1.04. The constructed-wetland systems scored 3.42, and the peat filtration systems scored 3.56. The performances of the peat filtration system and the constructed-wetland system are essentially the same but are inferior to that of the sand filtration system.

CWWTSs. The Daphne wastewater treatment plant performed the best, achieving a score of 0.53. The Dauphin Island wastewater treatment plant attained the second-best score of 0.69, followed by the Fairhope wastewater treatment plant, which scored 0.72.

NSF Reports

Purpose of the reports. The NSF Standard 40, Standard 41, and Criteria C-9 contain the results of the foundation's testing of various wastewater treatment systems. All new atypical wastewater treatment systems are evaluated by the NSF. This evaluation is similar to Underwriter's Laboratory testing.

Data contained in the reports. These analysis reports provide information concerning numerous parameters, including indicator organism data as either TC counts or FC counts, BOD_5, and TSS. These data were readily available at the local health department's office that issues septic-system permits for numerous atypical wastewater treatment augmentations.

Application of the data to the rank score . From these NSF reports, mean values were obtained for influent and effluent BOD, TSS, and FC. These values were entered into the calculation, and a rank score was obtained (Table 35).

Table 35

Rank of Atypical Systems by Score (Best Performing System at the Top

Atypical Wastewater Treatment System	Score	Type
Multi-flo Model FTB-0.5	0.69	Aerobic digestion and synthetic filtration
Whitewater Aerobic Treatment	1.49	Aerobic digestion
Puraflo Peat Biofilter	1.52	Peat filtration
Premier Ecoflo ST-650 Biofilter	1.64	Peat filtration
Ekofinn Bioclere MODEL BP3	1.65	Synthetic filtration
Waterloo Biofilter	1.71	Synthetic filtration
Nayadic MODEL M-6A	2.11	Aerobic digestion
Cajun Aire 500	2.24	Aerobic digestion
Clearstream Wastewater MODEL 500N	2.28	Aerobic digestion

Utility of the score. The calculated rank scores indicate that the Multi-flo Model FTB-0.5 wastewater treatment system is the best performing system (score = 0.69), whereas the Clearstream Model 500N wastewater treatment system (score = 2.28) performs least effectively in terms of removing contaminants. Scores for wastewater treatment systems approved for installation by the local health department could be posted on the health department's web site or on other wastewater-related web sites such as that of D. Venhuizen (D. Venhuizen, personal communication, March 17, 2004).

Conclusions

Currently, there are no standards (federal, state, or local) concerning how efficiently wastewater is treated by NWWTSs. Although these systems have been used in the United States for literally decades, performance seems of little concern to the general public. All that appears to matter to the public is that the waste leaves the home easily. After reviewing the literature and/or participating in scientific discussions on this topic, I concluded that, from the public health perspective, the main focus continues to hinge upon the issue of whether pathogen contamination is present. Quantification has remained nonrelative.

For the most part, the declaration of "no contamination" is proclaimed only when no FCs are detected in the effluent sample. Conversely, the presence of pathogen contamination is immediately proclaimed probable if any FC organisms are detected in the sample. Although this method is simple for the general public to understand, it surely is not an adequate means of conveying public health information to the public.

In this study, sand filtration was found to provide an overall superior secondary treatment when compared with peat filtration or constructed-wetland. This finding is well supported by other previous works (Anderson, 1985; Ball, 1995; H. Ball, personal communication, July 5, 2001; Cagle, 1993; J. Converse, personal communication, August 6, 2000; Sievers, 1998; D. Venhuizen, personal communication, July 9, 2001; K. White, personal communication, July 9, 2001). Also, the results of this study show that the Daphne STP is an overall superior centralized sewage treatment system when compared with the system of the Fairhope plant or the Dauphin Island plant.

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APPENDIX A

ATYPICAL NWWTS RAW DATA

Table A1

Sand filtration raw data (K. White, 1996, unpublished)

Date	Sample ID No.	BOD-1	BOD-3	FC-1	FC-3	TSS-1	TSS-3
1-17-96	S1	240.0	1.20	2.11e+07	3.00e+03	100.0	30.0
1-17-96	S2	135.0	16.50	1.70e+06	6.60e+02	59.0	17.0
2-21-96	S1	210.0	2.64	6.10e+05	3.40e+03	75.0	28.0
2-21-96	S2	144.0	1.56	6.90e+05	1.00e+02	44.0	8.0
3-20-96	S1	135.0	4.80	4.10e+06	8.00e+01	137.0	39.0
3-20-96	S2	60.0	3.60	3.50e+06	3.20e+02	55.0	23.0
4-24-96	S1	174.0	1.14	2.80e+05	1.80e+02	69.0	26.0
4-24-96	S2	207.0	1.35	2.30e+05	3.00e+01	70.0	14.6
6-20-96	S1	390.0	4.80	3.40e+05	9.50e+02	1.38e+03	42.0
6-20-96	S2	204.0	12.00	2.20e+06	4.50e+02	142.0	40.0
7-16-96	S1	243.0	0.15	1.15e+07	1.00e+02	99.0	25.0
7-16-96	S2	18.0	0.66	1.05e+07	5.60e+03	56.0	48.0
8-9-96	S1	163.5	2.28	1.00e+06	0.00e+00	47.0	1.0
8-9-96	S2	132.0	0.42	2.20e+05	3.10e+02	61.0	15.0

Note: ID = identification; BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; S1 = sand filter location 1; S2 = sand filter location 2; -1 = influent into septic tank; -3 = after sand filter treatment.

Table A2

Peat filtration raw data (K. White, 1998, unpublished)

Date	Sample No.	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
06/25/97	1	105.00	16.80	48.0	5.0	2.60e+05	7.20e+04
06/25/97	2	100.50	1.80	2.6e+03	5.0	2.50e+05	8.50e+03
06/25/97	3	96.00	5.40	94.0	10.0	7.20e+05	1.40e+04
06/25/97	4	51.75	8.85	19.0	111.0	2.70e+05	3.70e+04
07/17/97	5	123.00	9.57	57.0	8.0	6.80e+04	4.40e+03
07/17/97	6	180.00	5.00	97.0	N.D.	3.70e+06	8.00e+02
07/17/97	7	64.50	3.90	89.0	6.0	2.20e+06	8.50e+04
07/17/97	8	12.60	5.00	47.0	7.0	3.80e+05	8.00e+02
08/21/97	11	75.80	14.00	53.0	15.0	2.20e+05	1.70e+04
08/21/97	12	369.00	N.S.	124.0	N.S.	2.40e+05	4.00e+02
08/21/97	13	175.50	8.25	88.0	4.0	8.40e+05	6.80e+04
08/21/97	14	81.75	3.15	50.0	6.0	2.70e+05	3.00e+02
09/24/97	15	78.00	5.00	54.0	5.0	1.70e+05	5.50e+03
09/24/97	16	285.00	6.00	170.0	N.S.	3.70e+05	2.30e+04
09/24/97	17	114.00	6.00	80.0	10.0	7.80e+05	9.10e+04
09/24/97	18	36.80	5.00	44.0	N.S.	1.09e+06	2.90e+04
10/29/97	21	96.60	5.00	77.0	5.0	1.40e+05	2.20e+03
10/29/97	22	187.90	5.00	58.0	0.0	5.20e+05	1.30e+04
10/29/97	23	34.80	5.00	19.0	11.0	5.10e+05	3.70e+03
10/29/97	24	57.30	5.00	35.0	24.0	3.90e+05	3.00e+02
11/25/97	25	N.S.	N.S.	7.0	5.0	8.00e+04	1.80e+03
11/25/97	26	N.S.	N.S.	51.0	3.0	1.60e+05	3.00e+02
11/25/97	27	N.S.	N.S.	17.0	0.0	6.60e+05	2.70e+03
11/25/97	28	N.S.	N.S.	36.0	3.0	6.10e+05	1.10e+03
12/18/97	31	54.00	5.00	80.0	17.0	1.00e+05	6.60e+03
12/18/97	32	177.00	5.00	152.0	N.S.	5.00e+05	2.20e+03
12/18/97	33	51.00	5.00	60.0	24.0	2.40e+06	2.40e+04
12/18/97	34	54.00	5.00	90.0	16.0	2.10e+06	2.90e+03
01/21/98	35	67.20	5.00	60.0	14.0	1.09e+05	3.50e+04
01/21/98	36	176.00	5.00	128.0	18.0	2.20e+05	5.80e+03
01/21/98	37	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
01/21/98	38	56.90	1.60	68.0	34.0	6.20e+05	2.40e+03
02/23/98	41	87.00	6.00	62.0	24.0	3.10e+05	5.20e+03
02/23/98	42	228.00	12.60	146.0	20.0	1.30e+05	3.90e+03
02/23/98	43	76.50	12.90	64.0	22.0	8.00e+05	5.40e+03
02/23/98	44	31.50	7.50	50.0	26.0	1.50e+05	6.90e+03
03/24/98	45	96.00	16.5	19.0	7.0	4.20e+04	2.00e+03
03/24/98	46	252.00	12.00	43.0	N.D.	7.00e+05	6.00e+02
03/24/98	47	282.00	28.80	38.0	2.0	2.10e+06	1.60e+04
03/24/98	48	31.50	3.30	16.0	3.0	1.70e+05	1.20e+03

Table A2 (Continued)

Date	Sample No.	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
04/15/98	51	97.50	21.72	54.0	10.0	2.90e+04	2.30e+03
04/15/98	52	241.80	N.S.	72.0	32.0	3.10e+06	8.90e+04
04/15/98	53	190.20	20.16	68.0	10.0	4.50e+05	3.60e+03
04/15/98	54	39.90	5.04	10.0	2.0	2.80e+06	2.20e+04
05/30/98	55	105.00	6.00	72.0	18.0	1.10e+05	1.00e+04
05/30/98	55	105.00	6.00	72.0	18.0	1.10e+05	1.00e+04
05/30/98	56	246.00	36.00	116.0	N.D.	5.60e+04	7.70e+03
05/30/98	57	180.00	24.00	34.0	69.0	1.01e+06	7.30e+05
05/30/98	58	72.00	N.D.	50.0	N.D.	7.90e+06	9.00e+02
06/25/98	61	111.00	28.08	61.0	24.0	2.40e+05	1.20e+05
06/25/98	62	381.00	31.68	155.0	18.0	6.30e+05	5.80e+04
06/25/98	63	183.00	15.60	94.0	4.0	4.70e+06	8.90e+04
06/25/98	64	104.40	2.55	51.0	17.0	N.D.	1.28e+04
07/28/98	65	81.00	7.95	55.0	11.0	1.30e+05	1.20e+04
07/28/98	66	245.40	9.42	134.0	4.0	1.00e+05	1.50e+03
07/28/98	67	146.40	N.S.	66.0	76.0	3.90e+06	2.40e+05
07/28/98	68	91.20	N.D.	55.0	N.D.	5.10e+05	N.D.
08/20/98	71	107.70	7.32	54.0	22.0	1.10e+05	4.60e+03
08/20/98	72	222.00	5.55	158.0	40.0	5.30e+04	1.50e+03
08/20/98	73	108.90	N.S.	64.0	15.0	2.50e+06	1.00e+05
08/20/98	74	85.50	11.55	52.0	40.0	4.40e+05	1.00e+02
09/25/98	75	117.30	6.96	77.0	7.0	6.70e+05	5.60e+04
09/25/98	76	208.20	103.80	127.0	N.D.	2.10e+05	3.10e+03
09/25/98	77	0.78	0.780	86.0	6.0	6.30e+06	2.00e+05
09/25/98	78	57.90	1.35	40.0	5.0	5.80e+05	1.00e+02
10/22/98	79	124.20	5.64	55.0	2.0	2.30e+05	1.40e+04
10/22/98	80	182.40	4.56	110.0	4.0	3.50e+05	3.10e+03
10/22/98	81	143.40	12.18	92.0	24.0	5.80e+06	3.40e+05
10/22/98	82	95.40	5.37	67.0	2.0	6.20e+05	1.00e+03
11/23/98	83	132.60	18.42	81.0	12.0	4.60e+05	5.60e+04
11/23/98	84	228.00	5.34	149.0	26.0	2.20e+05	3.20e+03
11/23/98	85	172.80	9.00	81.0	38.0	4.30e+06	3.80e+04
11/23/98	86	100.8	6.66	101.0	130.0	1.90e+06	3.70e+03

Note: Sample No. = sample number; BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; N.S. = no sample; N.D. = no data.

Table A3

Constructed-wetland raw data (K. White, 1997, unpublished)

Date	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
12/18/95	129.0	82.5	N.S.	N.S.	N.S.	0.0
12/18/95	117.0	40.8	N.S.	N.S.	N.S.	0.0
12/18/95	60.0	26.4	N.S.	N.S.	N.S.	0.0
04/11/96	147.0	47.4	90.0	30.0	1.12e+06	5.00e+01
04/11/96	156.0	55.5	84.0	26.0	1.50e+05	5.00e+01
04/11/96	25.5	16.8	72.0	41.0	7.30e+04	1.70e+02
04/11/96	156.0	78.0	79.0	23.0	2.30e+04	3.00e+02
06/24/96	204.0	18.0	26.0	18.0	2.80e+05	8.30e+02
06/24/96	45.0	12.6	34.0	13.0	2.00e+05	1.00e+03
06/24/96	171.0	11.4	26.0	16.0	2.40e+04	1.00e+03
06/24/96	204.0	42.0	48.0	0.0	2.60e+04	1.00e+03
07/10/96	195.0	27.3	51.0	13.0	3.00e+03	1.00e+03
07/10/96	142.5	4.7	82.0	7.0	9.10e+06	1.00e+03
07/10/96	19.5	2.7	14.0	6.0	4.80e+04	1.10e+03
07/10/96	133.5	24.0	35.0	22.0	7.00e+03	1.30e+03
09/10/96	111.0	16.2	54.0	14.0	2.40e+05	1.30e+03
09/10/96	75.0	4.5	47.0	2.0	4.70e+04	1.50e+03
09/10/96	27.0	0.9	30.0	10.0	3.00e+05	1.80e+03
09/10/96	72.0	18.0	41.0	9.0	6.80e+04	1.90e+03
10/09/96	105.0	17.7	46.0	1.0	3.30e+04	2.00e+03
10/09/96	130.5	14.7	86.0	24.0	2.60e+05	2.00e+03
10/09/96	1.1	0.0	15.0	3.0	5.00e+04	2.10e+03
10/09/96	54.0	21.3	22.0	3.0	3.20e+05	2.10e+03
11/26/96	67.5	12.0	35.0	2.0	1.48e+05	2.10e+03
11/26/96	156.0	16.8	61.0	0.0	3.80e+04	2.30e+03
11/26/96	0.0	0.0	0.0	27.0	0.00e+00	2.40e+03
11/26/96	51.0	13.8	39.0	26.0	6.00e+05	2.50e+03
03/01/97	66.0	22.1	11.0	2.0	1.80e+04	2.50e+03
03/01/97	135.0	17.4	64.0	8.0	2.70e+04	2.60e+03
03/01/97	53.3	8.3	15.0	6.0	1.00e+04	2.80e+03
03/01/97	95.7	23.1	47.0	6.0	4.80e+04	3.10e+03
07/03/97	77.3	31.5	45.0	9.0	3.20e+06	5.80e+04
07/03/97	6.8	5.0	21.0	5.0	7.10e+04	5.80e+04
07/03/97	54.0	20.5	25.0	8.0	3.60e+04	5.90e+03
08/08/97	66.0	21.8	17.0	7.0	2.65e+07	6.80e+03
08/08/97	58.4	21.8	43.0	6.0	1.02e+06	7.00e+03
09/10/97	28.4	6.0	23.0	3.0	8.40e+05	9.00e+03
09/10/97	126.0	23.4	72.0	8.0	1.18e+07	1.08e+04
09/10/97	121.5	7.4	49.0	4.0	5.50e+05	1.33e+04
10/08/97	78.0	54.7	65.0	31.0	5.30e+05	4.00e+02

Table A3 (Continued)

Date	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
10/08/97	93.0	27.0	98.0	54.0	1.60e+05	6.80e+02
10/08/97	28.5	1.8	71.0	42.0	6.40e+04	6.80e+02
10/08/97	261.0	51.8	57.0	32.0	6.50e+04	8.00e+02
12/16/97	51.8	18.3	52.0	4.0	8.50e+05	1.80e+04
12/16/97	24.0	4.8	8.0	5.0	7.10e+05	1.80e+04
12/16/97	103.5	13.4	78.0	2.0	3.60e+05	2.20e+04
02/12/98	33.0	9.0	24.0	5.0	5.60e+05	2.50e+04
02/12/98	114.0	3.8	87.0	11.0	5.80e+05	2.70e+04
02/12/98	33.0	9.0	24.0	5.0	5.60e+05	2.50e+04
04/22/98	4.5	1.5	17.0	4.0	2.90e+04	3.00e+03
04/22/98	114.0	3.8	87.0	11.0	5.80e+05	2.70e+04
04/22/98	104.1	6.2	20.0	8.0	6.70e+04	3.00e+04
05/21/98	251.4	13.1	143.0	6.0	5.40e+06	8.70e+03
05/21/98	106.5	18.3	49.0	15.0	7.70e+06	3.40e+04
05/21/98	57.8	13.8	61.0	12.0	6.10e+05	3.40e+04
06/18/98	71.0	29.6	50.0	12.0	1.06e+05	4.10e+04
06/18/98	31.5	77.3	45.0	9.0	3.20e+06	5.80e+04
06/18/98	6.8	5.0	21.0	5.0	7.10e+04	5.80e+04
07/15/98	117.0	18.9	56.0	17.0	2.50e+06	7.50e+04
07/15/98	93.0	9.0	49.0	6.0	8.50e+05	8.10e+04
08/13/98	140.4	33.2	76.0	4.0	2.05e+05	8.30e+03
08/13/98	93.0	17.1	54.0	13.0	2.10e+04	8.00e+03
08/13/98	46.5	13.5	49.0	9.0	1.68e+05	1.50e+05
09/10/98	187.0	20.0	58.0	4.0	6.90e+05	3.20e+05
09/10/98	19.2	5.0	14.0	4.0	2.51e+06	1.60e+03
09/10/98	117.0	18.9	56.0	17.0	2.50e+06	7.50e+04
09/10/98	104.1	26.3	52.0	10.0	5.10e+06	N.S.

Note: BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform; N.S. = no sample.

APPENDIX B

CWWTS RAW DATA

Table B1

Raw data from Alabama Department of Environmental Management (1998, unpublished) STP Daphne (AL0027561)

Date	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
Dec-95	185	4.0	169	9.0	1.46e+06	15
Jan-96	196	6.0	199	8.0	1.46e+06	7
Feb-96	169	5.0	204	6.0	1.46e+06	4
Mar-96	179	8.0	203	18.0	1.46e+06	6
Apr-96	134	5.8	162	9.7	1.46e+06	8
May-96	209	4.3	174	8.8	1.46e+06	5
Jun-96	204	3.8	183	6.1	1.46e+06	3
Jul-96	209	6.8	191	11.5	1.46e+06	20
Aug-96	172	8.0	162	18.9	1.46e+06	74
Sep-96	208	3.5	193	4.8	1.46e+06	5
Oct-96	200	3.2	191	3.4	1.46e+06	8
Nov-96	183	4.1	162	5.8	1.46e+06	12
Dec-96	201	4.5	219	5.9	1.46e+06	8
Jan-97	233	6.6	288	6.4	1.46e+06	10
Feb-97	168	4.2	192	3.8	1.46e+06	14
Mar-97	168	4.0	136	2.0	1.46e+06	8
Apr-97	184	3.8	161	2.5	1.46e+06	11
May-97	196	3.0	147	3.7	1.46e+06	6
Jun-97	186	2.5	165	2.1	1.46e+06	5
Jul-97	157	3.0	141	3.3	1.46e+06	8
Aug-97	158	1.5	162	1.2	1.46e+06	7
Sep-97	160	3.0	136	1.5	1.46e+06	8
Oct-97	162	2.6	141	2.9	1.46e+06	4
Nov-97	195	4.2	174	5.7	1.46e+06	5
Dec-97	179	3.4	146	3.9	1.46e+06	10
Jan-98	161	7.2	134	7.7	1.46e+06	11
Feb-98	159	5.1	121	3.9	1.46e+06	20
Mar-98	139	5.8	117	8.8	1.46e+06	8
Apr-98	161	2.9	138	2.3	1.46e+06	21
May-98	162	2.6	160	5.2	1.46e+06	13
Jun-98	178	1.8	156	1.8	1.46e+06	2
Jul-98	150	1.6	142	1.6	1.46e+06	4
Aug-98	151	1.4	120	1.2	1.46e+06	3
Sep-98	146	1.0	129	1.2	1.46e+06	2

Note: BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform.

Table B2

Raw data from Alabama Department of Environmental Management (1998, unpublished) STP Fairhope (AL0020842)

Date	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
Dec-95	217	17	224	27	1.46e+06	60
Jan-96	222	22	237	23	1.46e+06	86
Feb-96	171	18	28	27	1.46e+06	60
Mar-96	215	17	217	32	1.46e+06	60
Apr-96	176	16	178	25	1.46e+06	16
May-96	250	22	205	22	1.46e+06	83
Jun-96	247	20	225	14	1.46e+06	104
Jul-96	240	15	182	12	1.46e+06	60
Aug-96	274	21	179	15	1.46e+06	60
Sep-96	249	16	203	13	1.46e+06	35
Oct-96	226	8	210	11	1.46e+06	77
Nov-96	271	10	288	12	1.46e+06	25
Dec-96	275	22	240	22	1.46e+06	76
Jan-97	278	11	212	16	1.46e+06	276
Feb-97	238	14	195	12	1.46e+06	197
Mar-97	293	19	230	19	1.46e+06	60
Apr-97	335	18	181	23	1.46e+06	133
May-97	261	10	228	11	1.46e+06	29
Jun-97	258	16	258	12	1.46e+06	42
Jul-97	205	14	232	22	1.46e+06	388
Aug-97	265	18	289	21	1.46e+06	51
Sep-97	210	11	242	30	1.46e+06	114
Oct-97	202	7	281	19	1.46e+06	1.0e+03
Nov-97	221	11	216	18	1.46e+06	15
Dec-97	212	17	231	18	1.46e+06	44
Jan-98	186	11	210	20	1.46e+06	96
Feb-98	174	15	244	29	1.46e+06	51
Mar-98	193	14	257	21	1.46e+06	127
Apr-98	193	14	257	21	1.46e+06	60
May-98	239	9	295	16	1.46e+06	141
Jun-98	237	14	284	15	1.46e+06	89
Jul-98	203	8	245	13	1.46e+06	35
Aug-98	213	6	253	12	1.46e+06	7
Sep-98	186	7	222	13	1.46e+06	147

Note: BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform.

Table B3

Raw data from Alabama Department of Environmental Management (1998, unpublished)
STP Dauphin Island (AL0050547)

Date	Influent BOD	Effluent BOD	Influent TSS	Effluent TSS	Influent FC	Effluent FC
Dec-95	72	11.0	77	7.0	1.46e+06	77
Jan-96	69	6.0	82	6.0	1.46e+06	25
Feb-96	76	6.0	74	7.0	1.46e+06	18
Mar-96	74	7.0	71	8.0	1.46e+06	40
Apr-96	72	5.0	76	7.0	1.46e+06	66
May-96	74	5.0	81	8.0	1.46e+06	11
Jun-96	72	6.0	77	7.0	1.46e+06	500
Jul-96	74	6.0	74	11.0	1.46e+06	450
Sep-96	76	7.0	85	11.0	1.46e+06	60
Oct-96	78	6.0	83	10.0	1.46e+06	46
Nov-96	74	5.0	79	8.0	1.46e+06	33
Dec-96	83	4.5	115	14.5	1.46e+06	20
Jan-97	83	7.0	119	15.0	1.46e+06	41
Feb-97	82	9.0	82	13.0	1.46e+06	56
Mar-97	108	12.0	148	18.0	1.46e+06	60
Apr-97	108	17.0	133	16.0	1.46e+06	400
May-97	162	13.0	157	16.0	1.46e+06	800
Jun-97	139	11.0	137	16.0	1.46e+06	65
Aug-97	112	14.0	90	12.0	1.46e+06	22
Sep-97	104	9.0	122	20.0	1.46e+06	46
Oct-97	155	15.0	170	58.0	1.46e+06	20
Nov-97	85	18.0	94	31.0	1.46e+06	10
Dec-97	75	12.0	90	16.0	1.46e+06	32
Jan-98	95	10.0	119	17.0	1.46e+06	51
Feb-98	86	14.2	160	21.0	1.46e+06	1
Mar-98	155	27.0	227	15.0	1.46e+06	660
Apr-98	96	25.0	189	22.0	1.46e+06	1.1e+03
May-98	45	28.0	77	24.0	1.46e+06	60
Jun-98	67	10.0	135	13.0	1.46e+06	10
Aug-98	139	29.0	220	23.0	1.46e+06	90

Note: BOD = biochemical oxygen demand; TSS = total suspended solids; FC = fecal coliform.

GRADUATE SCHOOL
UNIVERSITY OF ALABAMA AT BIRMINGHAM
DISSERTATION APPROVAL FORM
DOCTOR OF PUBLIC HEALTH

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Graduate Program Public Health

Title of Dissertation An Evaluation of the Human Pathogen Transmission Potential of Selected Wastewater Treatment Systems, With the Development of a Rating System for Public Use in Selecting a System for Home Installation

I certify that I have read this document and examined the student regarding its content. In my opinion, this dissertation conforms to acceptable standards of scholarly presentation and is adequate in scope and quality, and the attainments of this student are such that he may be recommended for the degree of Doctor of Public Health.

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