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Vegetative submerged beds : appropriate on-site residential sewage treatment?

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VEGETATIVE SUBMERGED BEDS:
APPROPRIATE ON-SITE RESIDENTIAL SEWAGE TREATMENT?

A Thesis
Presented to
The Faculty of the Department of Environmental Science
San Jose University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Paripurna Rustin
May 2004

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ABSTRACT

TITLE: VEGETATIVE SUBMERGED BEDS: APPROPRIATE ON-SITE RESIDENTIAL
SEWAGE TREATMENT?

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This thesis studied an alternative secondary sewage treatment system called a vegetative submerged bed or a plant rock filter. The study area was located in Harrison County, Mississippi. Twenty-two sites were chosen for observation. Only 17 of those sites had their wastewater analyzed.

This study found the vegetative submerged beds were not initially built well, as 27% exhibited pooling or backflow (septate flowing over the head of the system). Typically, they were not maintained after installation, as 54% had $\leq 70\%$ vegetative cover and 31% showed structural damage.

This study found qualitative and quantitative data only agreed on the best and worst vegetative submerged beds. Only one vegetative submerged bed met USEPA guidelines and that was probably due to structural problems not the performance of the vegetative submerged bed.

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INTRODUCTION

This study explores the performance of an alternative secondary sewage treatment system called a vegetative submerged bed. This system is characterized by a gravel bed filled with vegetation, which has an active part in wastewater purification. In Mississippi, this system is also known as a plant-rock filter. This study evaluated a number of existing vegetative submerged bed systems using observations and one wastewater test per site to determine if these systems meet USEPA guidelines.

Worldwide, thousands of vegetative submerged beds accepting large flows such as those found at wastewater treatment plants have been built and studied. On the other hand, residential vegetative submerged beds have not been well evaluated. Researchers either constructed or supervised the construction of the vegetative submerged beds they evaluated and their studies only lasted a few years. The rest of the residential vegetative submerged bed systems installed by contractors have only been assessed by local authorities using visual criteria.

The study area, Harrison County, Mississippi, was chosen because it has approximately 350 vegetative submerged beds currently in use. The ages of the beds selected for this study, range from 4 to 12 years with an average of 8.4 years. In a Florida study by Sherman, Varnadore and Forbes (1998, 47), most on-site system failures that needed repairs, occurred at 4, 10, and 25 years after construction. Thus, four years is expected to be enough time for the biological system to be well established and to start showing problems due to poor

construction, lack of maintenance, and wear (Reed, Crites and Middlebrooks 1995, 191).

This study area is so replete with vegetative submerged beds because B. C. Wolverton, a major vegetative submerged bed researcher, lives near Harrison County and greatly influenced the study area. His home is a model of a smoothly working vegetative submerged bed system. The bed is located inside his home in a sunroom, which provides his home with additional heat and air purified by the vegetative submerged bed plants. The wastewater leaves his home and continues underground to irrigate trees and shrubs.

This thesis provides a literature review of on-site systems and legislation, presents data collection and evaluation to determine vegetative submerged bed performance in Harrison County, Mississippi, and evaluates these findings based on USEPA guidelines. Finally, recommendations for improving performance are presented.

Brief History of Sewage

Disposal of human excrement has been a problem since *Homo sapiens* started living in groups. Two thousand years ago in Athens and China, the residents used human waste to fertilize crops. The ancient Romans made underground drainage systems to remove storm water, which also removed sewage (Wolverton and Wolverton 2002, 33-4). In the late 1700s, city officials built sewers to drain storm water. Human excreta was not included in the city sewer systems until 1815 in London, 1833 in Boston, and 1880 in Paris (Wolverton and Wolverton 2002, 35).

In the United States, on-site human excrement disposal began with simple outhouses, advanced to cesspools, then to septic tanks around 1876 (Reed, Crites and Middlebrooks 1995, 2). An important point in the development of wastewater treatment occurred after World War II, with the postwar housing boom. Because housing outpaced central sewage construction, new homes used on-site wastewater systems. These systems' design was a septic tank followed by a gravity subsurface soil adsorption system or leachfield (Figure 1 and Appendix I, Figure 6) (Rock et al. 1981, 116 and Reed, Crites and Middlebrooks 1995, 387). In the septic tank, solids settle to the bottom of the tank where they are digested by bacteria and other organisms. Septic tanks often contain sections or cells so that solids are retained longer and can decompose further. A scum layer floats to the surface and is left in the tank to decompose. A pipe leads the effluent to a series of perforated pipes in rock trenches which are covered with soil. Usually, grass is planted over the leachfield. Sometimes a distributor is used at the head of the leachfield to keep the effluent flow uniform. The effluent flows through the rocks and percolates through the soil below the leachfield. The effluent is always kept underground. Figure 1 is a diagram of a typical septic leachfield system.

The septic leachfield system works well at many sites. However, this system does not fit all cases. In the 1950's, on-site systems were based on percolation tests, local practices, and local experience. The common belief of government officials and installers was that all sites meeting a certain minimum criteria could use a prescribed design and protect public health (Otis 1994, 1). Installers were untrained and had limited knowledge in installation,

design, and performance. Government regulations contained only vague guidelines for septic leachfield systems. Once built, all operation and maintenance of the systems were left solely to the homeowner. This situation resulted in many systems being installed in unsuitable locations using inappropriate designs. They were often neglected by the homeowners until there was a problem (Otis 1994, 1). Additional management was not considered necessary because on-site wastewater systems were expected to be replaced by a central sewer (Otis, 1994, 1). Problems occurred with the design of these systems, because biological mechanisms, climate, and the complex interrelationships between soil characteristics and conditions and the character of the wastewater were ignored.

Figure 1: Septic Tank and Leachfield System

Septic tanks usually work extremely well. The only maintenance normally needed is pumping every three to five years. Malfunctions are rare. However, septic tanks can be overloaded if wastewater exceeds the design or they can malfunction if harmful chemicals that kill microbial populations are used. In *So ... Now You Own a Septic System* (2000) by the National Small Flows Clearinghouse, it is advised not to use caustic drain cleaners, harsh cleaners, bleach, and septic additives or commercial septic cleaner. The Clearinghouse also advises not to dump grease or fats or other hazardous solutions down the drain. Sewered sites should be just as careful of what goes down their drain, even though costly repairs are less likely.

Most problems with on-site wastewater systems occur with leachfields. All on-site secondary sewage systems can malfunction due to the amount of water exceeding the design (Adams, Hoover and Young 1998, 31), improper construction, installation or design, clogging (Angoli 1998, 6), high organic loads (Barrett and Malley 1998, 520), and age (Sherman, Varnadore and Forbes 1998, 47). Additionally, leachfields fail to protect the environment when there is bedrock near the soil surface, high groundwater, steep slopes, and either shallow or slowly permeable soil (Rock et al. 1981, 116 and Reed, Crites and Middlebrooks 1995, 388). If the soil is too impermeable or too near bedrock, wastewater cannot percolate through the soil fast enough and it begins running laterally or upward. On the other hand, wastewater can flow through fissures or percolate through the soils so quickly that the wastewater is not adequately treated before it reaches ground water. In Harrison County, Mississippi rains are often heavy, saturating the soil and forcing wastewater to the surface into waterways and Biloxi Bay then the Mississippi Sound. According to the Mississippi Commission on Marine Resources (Ordinance

1.016 and personal communication with Mr. Dale Diaz, Mississippi Dept. of Marine Resources, 2003) the back part of Biloxi bay has been restricted from shell fishing due to sewage contamination for at least 35 years.

Otis (1998, 22) states that because of these failures, on-site wastewater systems are accused of keeping wastewater below ground, rather than meeting water quality guidelines and thereby, contaminating ground and surface water. According to White and Shirk (1998, 198) on-site septic and leachfield systems represent the most important cause of groundwater contamination due to bacteria and viruses that resulted in disease outbreaks (USEPA 1986, 2).

However, alternative systems can be used where leachfields are inappropriate. When alternative systems are properly managed, designed, installed, and maintained, they provide environmentally sound, cost-effective, and permanent means of wastewater treatment and disposal (Staudt and Niehus 1981, 229).

The goal of early wastewater treatment was to prevent disease transmission and obnoxious odors. Today, wastewater treatment must meet these goals and reduce bio-chemical oxygen demanding substances (BOD), total suspended solids (TSS), ammonia nitrogen as well as inactivate any pathogenic microorganisms (Wolverton and Wolverton 2002, 34 and Johns et al 1998, 237). Current wastewater treatment is concerned with prevention of eutrophication of lakes and prevention of pollution in and refreshment of aquifers (Reed et. al. 1995, 433 and McCarthy et al. 1998, 446-7). Aquatic and wetland concepts, such as vegetative submerged beds, are essentially new developments in the United States regarding the treatment of wastewater and sludge (Reed, Crites and Middlebrooks 1995, 2). Vegetative submerged beds offer a simple, energy

efficient, largely passive, highly reliable means of removing nutrients from wastewater (Hague, Reneau and Hagedorn 1994, 66). However, like all methods, vegetative submerged beds must meet USEPA guidelines to insure public health.

Clean Water Regulations

Due to problems with on-site septic leachfield systems, as well as many other water quality issues, in 1972, the U.S. Congress passed The Federal Water Pollution Control Act, known as the Clean Water Act of 1972 (Baird and Smith 2002, 9), which established standards for wastewater treatment (Table 1). A primary goal of the Clean Water Act of 1972 was to move from unregulated wastewater discharge toward zero discharge. At first, the USEPA believed that lower discharge levels could be obtained at wastewater treatment plants with a combination of mechanical treatment units capable of advanced wastewater treatment. It quickly became apparent that using current technology was not only too expensive but incapable of achieving the new standards expected for wastewater (Reed, Middlebrooks and Crites 1988, 2). Serious interest in innovative and alternative methods for wastewater treatment emerged. Alternative methods (Appendix I) include natural methods of treating wastewater such as created wetlands, mounds, intermittent sand filters, and evapotranspiration systems (Duff 1978, 61-67, Reed, Crites and Middlebrooks 1995, 1 and Bernhart 1978, 185).

The Clean Water Act of 1972, also established the National Pollutant Discharge Elimination System (NPDES). This system requires discharge monitoring and regulates fecal coliform bacteria (FC), pH, five-day biological

oxygen demand (BOD₅), and total suspended solids (TSS) (Baird and Smith 2002, 9). In 1974, Congress enacted the Safe Drinking Water Act. This Act was amended in 1986 to expand the United States Environmental Protection Agency's (USEPA) role in protecting public health from disease-causing organisms (USEPA 1989, 1).

Amendments in 1976 to the Clean Water Act included provisions to encourage the use of small, innovative, and alternative wastewater systems. Small alternative systems include on-site residential systems. These amendments granted direct monetary incentives and empowered the USEPA to promote such wastewater systems through construction grants, developing technologies, seminars, and public education (Staudt and Niehus 1981, 230).

Table 1

USEPA Wastewater Guidelines

BOD ₅	10-30 mg/l
FC	200-400 colonies per 100 ml
P	1-10 mg/l
TKN	1-10 mg/l
TSS	10-30 mg/l

(Burgan and Sievers 1994, 83, USEPA 2000, 2 and Griffin, Price and Pennison 1994)

The Clean Water Act of 1977 required extensive monitoring for groundwater pollution potentially produced by on-site wastewater systems (Dearth 1978, 273) and funding for small systems. This funding included

grants for individual on-site systems, 85% grants for alternative systems, and 100% insurance grants for failures (Dearth 1978, 271 and 275 and Tourbier and Pierson 1976, 303-312). Because of this funding, research on vegetative submerged beds for secondary wastewater treatment increased dramatically.

State Regulations

To keep wastewater on the owner's property, Mississippi and most other state's laws require horizontal set backs of 30.5 meters (100 feet) from property lines. They also require a distance of 15.2 meters (50 feet) from any private well or suction line to prevent contamination of drinking water (Reed, Crites and Middlebrooks 1995, 11 and Otis 1998, 24). Since Mississippi allows discharging systems, set backs in Mississippi are from the discharge's surface flow or run. Set backs may be greater when the discharge's run is near sensitive waters.

State law determines the type of allowable wastewater system: discharging or non-discharging. Non-discharging wastewater systems eliminate water by evaporation, transpiration or percolation (Sherman, Varnadore and Forbes 1998, 46). In a discharging system, the water is assumed treated well enough to be discharged onto the surface of the owner's property. Mississippi allows discharging systems and therefore, it is especially important, that wastewater be treated adequately so as not to expose people to untreated wastewater, which may contain many pathogenic organisms.

On-Site Systems

Both sewer and on-site wastewater systems have a place in wastewater treatment. Central sewer is an excellent choice for mixed, high-density developments. On-site systems are best for relatively small, remote sites and can be much less expensive than central sewer. Central sewers are advantageous because they remove the wastewater and it is no longer the property owner's concern. However, on-site systems keep the wastewater on-site, so it replenishes the ground water below. Wastewater is more uniformly and slowly distributed into the environment than large outflows at a central wastewater plant. Residents that use well water return the wastewater near where it originated. Central systems are run by professionals, discharges can be easily monitored, and costs are predictable. On-site system repairs or replacement are expensive, unpredictable, disruptive, and owners usually have little knowledge of what to do (Otis 1998, 22 and 25). In a sewer area, biosolids are handled by the wastewater treatment plant. On-site septic tanks need to be pumped every three to five years. Residents with on-site wastewater systems have to be more careful about what they put down their drains or expensive repairs may result.

As of the 1990 census, 25% of all housing units in the United States depended on on-site wastewater systems for disposal of domestic wastewater (Staudt and Niehus 1981, 48 and 229). The 2000 US Census Division of Historical Information on Sewage Disposal reports that of 105.5 million households, 24.67 million have on-site septic systems and 1.34 million have non-sewered systems. Thus twenty-five percent of all households were still unsewered as of the 2000 U. S. Census.

In Harrison County, Mississippi the 1990 census showed the number of households to be 55,015, of which 12,379 had on-site systems and 419 had other types of non-sewered systems. Twenty-three percent of all households were unsewered in 1990. This is similar to the national average.

On-site sewered and unsewered information was not yet available for 2000 for Harrison County. However, in Harrison County the US Census 2000 showed a population of 189,601 in 71,538 households, an increase of 30% from 1990 to 2000. Increasing population may have increased the households on unsewered systems to higher than 23% because public works projects to expand wastewater systems have not kept up with the new housing construction.

The USEPA estimates only 32% of soils are suitable for conventional septic leachfield systems (White and Shirk 1998, 196 and Rock et al. 1981, 116). Yet, the majority of new housing in rural areas is unsewered. Sites never previously considered for on-site septic systems are being purchased, planned, and developed using on-site systems (Angoli 1998, 8). Alternative wastewater treatment systems are needed because areas are being developed that will not support traditional septic and leachfield systems.

Ground and surface waters are being polluted and sensitive ecological areas are being affected by human wastewater. On-site septic and leachfield systems represent the most important cause of groundwater contamination due to bacteria and viruses that resulted in disease outbreaks (White and Shirk 1998, 198 and USEPA 1986, 2). Also, the USEPA's Beach Watch Program reports nationwide in 2001 on-site septic systems contributed to 4% of beach closing (USEPA 2002, 2).

Ineffective sewage treatment in coastal areas harms commercial and recreational fishing including harvesting of oysters, crabs, shrimp, and fish. As of 1993, there were approximately 1.2 million hectares (3.0 million acres) of shellfish-growing waters in the Gulf of Mexico. Fifty-seven percent of this total acreage was permanently or conditionally closed to harvesting because of poor water quality, partially due to improperly treated wastewater (White and Shirk 1998, 195). In Florida, the USEPA identified domestic wastewater as a major source of nutrient loading (Anderson et al. 1998, 436). As recently as the summer of 2003, beaches in Biloxi were closed to swimming due to high fecal coliform counts (SunHerald, 2002). Margaret Hase reported in personal communication (2004) that beaches are closed annually in Harrison County because bacteria are able to persist in the environment longer when the salinity and temperature of the sea water closely resemble human blood.

Vegetative Submerged Beds

Figure 2: Longitudinal Cross Section of Vegetative Submerged Bed

In very general terms, a vegetative submerged bed is a long, shallow trench filled with plants and rocks (Figure 2 and Appendix I, Figure 16). This filter bed provides treatment through the action of micro-organisms on the rock media, absorption by the roots of aquatic plants, and the unique relationship between the plants and the micro-organisms. The goal of the system is to optimize physical, chemical, and biological processes. Although the filter bed must remain open to the atmosphere, there should be no objectionable odors and plants provide an aesthetically pleasing appearance (Sherman, Varnadore and Forbes 1998, 46, Amberg 1990, 6, Cooper, Hobson and Jones 1989, 3, Haung, Remeau and Hagedon 1994, 66 and Reed, Crites and Middlebrooks 1995, 176 and 178).

A septic tank, located between the home and the vegetative submerged bed, begins the treatment. The septic tank provides primary wastewater treatment for the vegetative submerged beds. The septic tank retains organic solids, which settle and are metabolized by microbes. The effluent flows to the vegetative submerged bed and is distributed into and across the width of the bed. To protect groundwater quality, the bed is lined unless the soil is nonporous clay. The water level is maintained below the top of the gravel in the bed. Microbes attach to subsurface substrates such as the gravel and plant roots. These microbes purify the wastewater as they metabolize its constituents. The vegetation roots deliver oxygen to the substrate, provide more surface area for microbial growth, provide carbon (via detritus), and prevent substrate clogging. The upper parts of the vegetation provide shade. The entire plant metabolizes or adsorbs nutrients and heavy metals (Sherman, Varnadore and Forbes 1998, 46, Amberg 1990, 6 and Reed, Crites and Middlebrooks 1995, 176, 178 and 187).

The constituents of wastewater can include simple carbonaceous organics (dissolved and suspended), toxic and hazardous organics, pathogens, trace metals, nutrients (nitrogen, phosphorus, and potassium), and other micronutrients (Reed, Crites and Middlebrooks 1995, 43). Spooner et al. (1998, 462) showed that constructed wetlands were effective in removing most pollutants. Other studies of vegetative submerged beds such as that by White and Shirk (1998, 195) showed up to 90% removal of BOD₅, FC, and TSS.

Vegetative submerged bed research draws information from many different fields including microbiology, botany, and flow dynamics. In the United States, there are three main sources of vegetative submerged bed research: B. C. Wolverton (a researcher), the Tennessee Valley Authority (TVA), and engineers who claimed to have independently derived criteria based on all available literature (Reed and Brown, 1992, 777).

Wolverton worked at NASA, National Space Technology Laboratories, now called the John C. Stennis Space Center located in Hancock County, Mississippi adjacent to Harrison County. His work spanned over 15 years and focused on the utilization of vascular plants as an economical treatment of domestic and chemical wastewater generated at the Center (Wolverton 1982, NASA report, 2-3, Amberg 1990, 1 and Wolverton, Bounds and Keith 1988, 71). The vegetative submerged bed systems established there are still in operation. Wolverton's work has been used throughout USEPA region VI, especially Louisiana, but also in Arkansas, New Mexico, Texas, and Oklahoma (Reed and Brown, 1992, 777). A modified version of the Wolverton design was introduced in Mississippi in 1984 (Wolverton, Myrick and Johnson 1984, 19-20). The Mississippi legislature and state health department officially approved the use of vegetative submerged beds as an alternative disposal system in 1992.

However, the official design criteria used in Mississippi is that recommended by the TVA as found in Design Standard VII Plant Rock Filter (Mississippi 1997, iv and Frass and Hicks 1995, 5).

One advantage of vegetative submerged beds is that they are self contained and can be used in areas that do not meet percolation standards for leachfields. Wastewater is isolated from the time it goes down the drain until it leaves the vegetative submerged bed. By then, the effluent should be clean enough to discharge into the environment. Property unsuited for leachfields can still be available for housing. Like leachfields, most vegetative submerged beds use gravity to move wastewater to the bed and require no additional energy. However, a few systems require a pump to move the wastewater to the vegetative submerged bed because the distance to the bed is too great or the slope is too small (Reed, Middlebrooks and Crites 1988, 8, Wolverton and Wolverton 2002, 4 and Cooper, Hobson and Jones 1989, 3). Pumps usually need to be replaced every two years.

Unlike leachfields or mechanical systems, vegetative submerged beds remove minerals from wastewater (Wolverton and Wolverton 2002, 55). The plants use minerals, such as phosphorus, potassium, calcium, magnesium, and iron, for their growth (Wolverton and Wolverton 2002, 47). Lastly, a well-maintained vegetative submerged bed can be very beautiful. In Harrison County, vegetative submerged beds are filled with flowering plants that bloom throughout the summer with no need for fertilizer or irrigation (Davis and Holland 1998, 13).

Although vegetative submerged beds perform well anywhere in the United States, the majority of systems occur in the southeastern and south

central states (Reed and Brown 1992, 777). White and Shirk (1998, 196) found vegetative submerged bed systems particularly well suited to the southern United States because of the mild climate, which favors year-round vegetation growth. However, Reed and Brown (1992, 777) found southern preference for vegetative submerged bed systems only minimally related to the favorable climate. Vegetative submerged bed locations might have been influenced by Wolverton and the TVA, both located in the southern United States.

While vegetative submerged beds have a number of advantages, only careful attention to hydraulic design and proper construction can achieve good vegetative submerged bed systems (Reed, Crites and Middlebrooks 1995, 203). A perfect hydraulic flow is difficult to achieve (Reed and Brown 1992, 779) and wastewater must always be maintained below the top of the gravel. Also, vegetative submerged beds are delicate and cannot compensate for large wastewater fluctuations (Amberg 1990, 7).

Vegetative submerged beds must be carefully constructed so they do not clog. Reed, Crites and Middlebrooks (1995, 41 and 43) found that improper flow in the systems they studied was due to inadequate hydraulic design and obstructions caused by materials deposited during construction, not from the accumulated wastewater solids or plant roots. Gravel needs to be washed and care must be taken not to introduce other materials during construction. The primary wastewater system must be adequate to prevent solids from entering the secondary system. All septic systems preceding a vegetative submerged bed require a second septic tank or many cells in one septic tank especially households with a garbage disposal (Mississippi 1997, 5 and Wolverton and Wolverton 2002, 53). Coarse gravel was found to be the best medium as opposed

to sand or pea gravel (Kruzic and White 1996, 498, 501 and White and Shirk 1998, 501).

Vegetative submerged beds require more land than leachfields (USEPA 2000, 3). In the Gulf states, gravel can be costly to procure, deliver, and place in the bed (Reed, Crites and Middlebrooks 1995, 176). Imported gravel can be 50% of the construction costs (USEPA 2000, 7). New regulations, which enlarged the beds to 350 square feet and increased rock size, make vegetative submerged beds an expensive alternative. According to personal communication with Pansy Maddox, Environmentalist for Harrison County Environmental Health, no systems are currently being constructed, partially due to the cost of gravel.

Vegetative submerged beds require care in planting and maintenance of vegetation after installation. All soil should be washed from the roots before planting. Vegetation should be evenly spaced with a maximum spacing of 7.1 meters (18 inches) with roots below the liquid level. The homeowner needs to maintain the vegetation in the bed, which may include replanting, thinning, and weeding. Dead vegetation must be removed yearly (Amberg 1990, 7).

Another possible problem with vegetative submerged beds is disease and herbivory by animals such as muskrat, nutria, and insects (USEPA 2000, 2). The use of vegetation native to the area is highly recommended because it can provide habitat and food for local animals. However, if herbivory is severe, non-native species can be used. Non-native plants may not be eaten by local animals or subject to local diseases. However, care must be taken not to

introduce species that are invasive and cause habitat destruction (Davis and Holland 1998, 13).

PROBLEM STATEMENT AND OBJECTIVES

This thesis evaluated the performance of vegetative submerged beds in Harrison County, Mississippi. Specifically, this research was designed to answer these questions:

1. Did wastewater tests of pollutants correlate to the age of system, length and width of bed, pH, and/or percent cover of vegetative as expected from the literature?
2. Is a visual assessment of the dimensions and the maintenance of the vegetative submerged bed an adequate method for determining if the system is meeting USEPA wastewater guidelines and protecting public health?
3. Did a random sample of vegetative submerged beds in Harrison County, Mississippi meet USEPA wastewater guidelines for residential sewage treatment systems?
4. Have vegetative submerged beds deteriorated over time and are they currently well maintained?
5. Did government agencies adequately train designers and installers such that vegetative submerged beds were built correctly?
6. Does Harrison County Environmental Health continue to regulate vegetative submerged bed in Harrison County?
7. Should vegetative submerged beds continue to be used as on-site secondary sewage systems?

North American Data Base (NADB) is a compilation of data from large flow vegetative submerged beds ≤ 3780 cubic meters per day (1 million gallons per day). There are a few studies of small systems that were designed and constructed by researchers and studied for a few years (Venhuizen 1998, 470-479, Zavoda 1995, 17-18). However, very few studies have measured the performance of vegetative submerged beds once installed at residences by commercial contractors. This study will look at vegetative submerged beds installed 4 to 12 years ago in Harrison County, Mississippi. Planners and public officials will benefit from knowing how on-site residential vegetative submerged beds perform and whether the residents will maintain these systems once installed.

RELATED RESEARCH AND LITERATURE REVIEW

Previous Studies

Mankin and Powell (1999, 228) monitored three residential on-sites vegetative submerged beds in southeast Kansas for two years. These researchers found that BOD₅, FC, TP, and TSS averaged secondary treatment levels. Although the wastewater did on the average comply with USEPA guidelines, sometimes the vegetative submerged beds exceeded USEPA wastewater guidelines. This study concluded vegetative submerged beds need more consistent reliable treatment. To be on par with conventional on-site treatment systems, vegetative submerged beds needed improved oxygen transfer, improved filtration, increased surface area for attached microbial

growth, increased detention time, and decreased inflow of extraneous precipitation and runoff.

A coastal Alabama study by White and Shirk (1998, 195) monitored 9 on-site vegetative submerged beds for a year. These vegetative submerged beds showed excellent removal of BOD₅, FC, and TSS. White and Shirk (1998, 199-200) advise two stages, one for treatment and one for disposal. The vegetative submerged bed could be the treatment bed then an underground rock filter, irrigation system or sand filter could be the disposal area. Soil conditions would determine the disposal area's size.

Design

The benefits of correct design of on-site wastewater systems are greater protection of watershed and public health, preserving groundwater at the site, responsible and rational land use planning, and greater availability of affordable housing because of lower building costs (Otis 1994, 3-4). Jantrania, Robertson and Katz (1998, 480) demonstrated that fragile coastal water can be protected by alternative wastewater systems. The city of Gloucester, Massachusetts replaced 7 cesspools with alternative systems and found they were effective in reducing BOD₅, FC, TN, TP, and TSS to levels acceptable for release into the coastal environment.

Although the design for vegetative submerged beds seems relatively simple, natural systems such as vegetative submerged beds are quite complex and numerous variables come into play. Each site is unique and a cookbook approach to building vegetative submerged beds does not consider the unique characteristics of each site and current information. Even the authorities on

vegetative submerged beds such as, Sievers, Cooper, Reed, TVA, Kadlec & Knight and Wolverton, differ widely in design recommendations (Appendix II) as they strive to find the ideal design for each site. For example, water depth recommendations vary from 31 cm (12 inches) to 62 cm (24 inches) and width from 0.49 meters (1.6 feet) to 3.0 meters (10 feet). Even gravel size recommendations vary greatly from 0.54 cm (0.25 inches) to 7.6 cm (3 inches).

There are three different design techniques: multiple regression analysis, the areal loading approach, and the bio-chemical approach (Reed, Crites and Middlebrooks 1995, 177). Multiple regression analysis studies derive design criteria from already operating systems and use that information to create more systems. The areal loading approach was derived from land application or applying wastewater to the surface of the land and determines performance as related to the volume of water or mass of a particular constituent per unit time divided by the surface area of the bed. The bio-chemical approach to vegetative submerged beds assumes that the biological reactions are similar to other attached-growth wastewater treatment processes. This approach uses a first-order plug flow design model, which is based on hydraulic residence time (HRT) and contact opportunities and is regulated by oxygen and temperature (Reed, Middlebrooks and Crites 1988, 170). This thesis evaluates vegetative submerged beds using the third approach.

One of the most important factors to consider in vegetative submerged bed design is the hydraulic retention time (HRT). The hydraulic retention time is the time the wastewater stays in the vegetative submerged bed. Consistent secondary treatment levels are achieved if the HRT is adequate to allow the microbes to purify the wastewater (USEPA 2000, 2). Slope, length,

and width of the bed, gravel size, amount and location of vegetative roots and debris, age of the bed, and quality and amount of the wastewater all determine the HRT.

The slope of the bed must be great enough for the water to flow through the system, but not so great that the wastewater flows through the system without adequate treatment. Reed, Crites and Middlebrooks (1995, 12) recommend a slope between 1 and 3%. Cooper, Hobson and Jones (1989, 8) estimate a slope of 2-8% is needed to achieve the system's goals. Mississippi State Department of Health (1997, 40) recommends a slope between 0.5 -1.11%. The bottom of the bed must be graded flat and uniform to ensure even wastewater flow. Compaction of subsoil might be necessary (Reed and Brown 1992, 780). The contractor needs to be knowledgeable and careful enough to achieve these requirements (Reed, Crites and Middlebrooks 1995, 276).

A feature in the design that helps control the wastewater flow is the length-to-width ratio. A vegetative submerged bed should be wide enough that, at maximum loading, the wastewater stays below the surface. The bed must be long enough so that the wastewater stays in the bed long enough for adequate treatment. The minimum bed length recommended is 20 meters (66 feet) (Reed, Crites and Middlebrooks 1995, 193).

Entry and exit zones are usually trenches filled with crushed rock that go along the entire width of the bed. Correctly designed inlet and outlet zones are critical for uniform distribution of wastewater in the bed. Uniform distribution helps ensure the entire bed is used and maximum purification is achieved (Reed, Crites and Middlebrooks 1995, 150-1).

Vegetative submerged beds have berms and timbers designed to isolate the bed from outside water. Natural precipitation is usually not of concern if the berms are intact. However, water runoff from any other source such as lawn sprinklers, water spouts, and drain pipes must be routed away from the vegetative submerged bed (Amberg 1990, 7) because excess water entering the system might overload it, shorten HRT, and cause surface flow of wastewater.

Berms around the bed need to be about 0.5 meters (1.5 feet) above the bed's surface to allow for the accumulation of sludge and plant detritus (Reed, Middlebrooks and Crites 1988, 198 and 199). Berms protect the environment outside the bed from wastewater intrusion as well as protect the bed from outside water entering the system. Outside water can overload the vegetative submerged bed as well as carry soil and organic matter into the system, which reduces the bed's effectiveness.

Another design feature is the depth of the vegetative submerged bed. This is determined by the chosen plants' root penetration and freezing winter temperatures. Maximum depth of 0.6 meters (2 feet) maybe required where harsh winters freeze below the surface (Cooper, Hobson and Jones 1989, 7). However, shallower beds ≤ 0.3 meters (1 foot) achieve better nitrogen removal because they promote complete healthy root penetration (Cooper, Hobson and Jones 1989, 7 and Reed, Crites and Middlebrooks 1995, 243). Healthy root penetration of the entire bed is important to ensure uniform flow and maximum oxygenation. If plant roots do not penetrate, wastewater flowing through the area without roots moves faster, is exposed to less oxygen, and is therefore, less purified than the wastewater moving through the root zone.

Vegetative submerged beds are anaerobic except at the top of the bed and at microsites on the hair roots. These microsites provide oxygen for microbial and chemical reactions (Reddy, D'Angelo and DeBusk 1989, 261). Five to 45 grams $O_2/m^2 \cdot \text{day}$ is the standard estimate of available oxygen (Reed, Crites and Middlebrooks 1995, 242 and Reddy, Patrick and Lindau 1989, 1004).

Gravel size, the amount and location of vegetative roots, and debris in the bed determine the physical flow of the wastewater. If the gravel is large, water flows more easily and is less likely to clog, but a larger bed is needed to compensate for the decreased HRT. Smaller gravel slows the wastewater but can result in clogging. However, after one to three growing seasons, roots should have penetrated the entire bed of even the smallest sand and provide a uniform flow rate through the system. Even if the gravel is a heterogeneous mix, it still provides uniform flow because the mixed spaces between the gravel are the same throughout the system and settling of any constituents in the gravel is very minimal and can be neglected (Reed, Crites and Middlebrooks 1988, 180-183).

Reed, Crites and Middlebrooks (1995, 190) found that malfunctioning beds resulting in surface overflow was due to inadequate hydraulic design and inorganic materials brought to the site during construction activities. At some sites, Reed, Crites and Middlebrooks (1995, 190) found pore spaces 80% filled with inorganic materials brought to the site during construction. They did not find a biomat, which is the typical reason for wastewater clogging. A biomat is gelatinous material caused by bacteria and bacterial extracellular polysaccharides (EPS) associated with clogged soil pores (Ronner and Wong

1998, 37-38) and identified by black slimy layer or organic solids (Reed and Brown 1992, 780).

Surface flow will occur on all vegetative submerged beds in response to major storms. However, the pollutant concentrations are proportionally reduced and treatment efficiency is not usually affected (Reed, Crites and Middlebrooks 1995, 210). Nevertheless, it is not advisable to use vegetative submerged bed in flood plains. Structural damage can occur to the bed and polluted wastewater might be released into the environment (Reed, Crites and Middlebrooks 1995, 12 and 27).

An important consideration when choosing plants for a vegetative submerged bed is suitability to the climate and ability of the vegetation to survive freezing temperatures. Native plants, already adapted to the regional environment, are preferred if available (Reed, Crites and Middlebrooks 1995, 277). Other considerations are root penetration capabilities, bed depth, rapid year round growth, competition if more than one species is used, ability to grow in secondary effluent, available solar radiation, disease and predation, wildlife desired, available indigenous species, and aesthetics (Sherman, Varnadore and Forbes 1998, 52 and Hargis 1998, 19).

Vegetative submerged bed plant species used in Harrison County, Mississippi, such as elephant ears (*Collocasia esculenta*) and canna lilies (*Canna* sp.) are very active consumers of nitrogen (Johns et al 1998, 243). Other commonly-used species are calla lilies (*Zantedischia aethiopica*), ginger lily (*Hedychium coronarium*), and water iris (yellow and blue flag) (*Iris* sp.). All of these are flowering species have soft tissue and create very beautiful beds. Some of the literature reports softer vegetation has an advantage in that

it adds carbon to the system (Sherman, Varnadore and Forbes 1998, 52 and Liehr et al. 2000, 3-2). However, soft tissue plants decompose very quickly when the emergent portion dies back in the fall. The rapid decomposition results in a measurable increase in BOD and nitrogen (Reed, Crites and Middlebrooks 1995, 184). Also, soft tissue species require more maintenance than *Typha* (cattails), *Scipus* (bulrushes), *Pharagmites* (reeds), *Juncus* (rushes), and *Carex* (sedges). The root penetration of these soft tissue species is around 0.3 meters (12 inches), which is shallower than bulrushes 0.6 meters (24 inches), and reeds 0.4 meters (24-30 inches). Reed, Crites and Middlebrooks (1995, 184) recommend using only one hardy plant species for optimum water treatment. Soft tissue species can be added around the perimeter of the bed for aesthetics. The Mississippi Department of Health (1997, 22) now recommends Typhacaceae (cattail family), Cyperaceae (sedge family), Poaceae (grass family), Junacaea (rush family), and (*Scipus validus*) softstem bulrushes. Genera native to Mississippi can be found for each hard stem species.

The soft tissue plants used in Harrison County dieback each year, even though the climate is temperate. However, dieback should not greatly affect the vegetative submerged bed because the major growth period for buried rhizomes and roots is in the winter (Reed, Middlebrooks and Crites 1988, 199). All the subsurface components are functioning as usual. Nevertheless, the plants selected should be cold-hardy so they will not be killed by freezing temperatures. In Harrison County temperatures can occasionally go below freezing for a week or more. In colder weather, pollution removal rates slow but the HRT increased due to increased viscosity (Reed, Crites and Middlebrooks 1995, 204).

On a bio-chemical level, vegetative submerged beds need two to three years to become stabilized. Plant roots in older systems are more extensive, providing more microsites where oxygen is available for rich microbial growth (Reed, Middlebrooks and Crites 1988, 170). Dead roots and plant material provide carbon required for nitrogen removal. The potential for nitrogen removal develops in 2-3 growing seasons while the plants and root systems grow and microorganisms reach equilibrium (Reed, Crites and Middlebrooks 1995, 191).

The quality of wastewater affects HRT and therefore, the size of the vegetative submerged bed. The pollutant requiring the largest area for removal determines the bed size (Reed, Crites and Middlebrooks 1995, 202). However, most residential on-site systems produce similar wastewater and do not need different considerations due to wastewater components. The quality of the wastewater can be considered the same for each household.

The quantity of wastewater affects HRT and therefore the size of the vegetative submerged bed. The National Small Flows Clearinghouse pamphlet, *So ... Now You Own a Septic System*, advises water conservation to prevent overloading your wastewater treatment system. However, residences using well water cannot use some low flow devices such as low flow shower heads because of reduced water pressure.

Appropriate vegetation is central to the functioning of vegetative submerged beds. Plants achieve these goals: substrate for attached microbial growth, plant-biofilm interactions, microsites for oxygen, and users of wastewater nutrients (Stein, Biederman and Hook 1998, 207 and Reed and Brown 1992, 776). Oxygenation at plant roots and plant uptake helps reduce

high levels of BOD, carbon, N, P, TSS, and significant levels of metals, trace organics, and pathogens (Lezczynska and Dzurik 1994, 129 and Stein, Biederman and Hook 1998, 207). Vegetation provides an extensive root system that helps prevent clogging and provides flow channels. Mats of vegetation insulate the bed in winter and moderate gravel temperatures with shade in the summer (Burgoon, Reddy, D'Angelo and DeBusk 1995, 857). Vegetation provides a source of organic carbon for denitrification (Liehr et al. 2000, 2-7 and Burgoon, Reddy and DeBusk (1985, 857-258). McIntyre and Riha (1991, 262) found nitrogen removal in unplanted beds 4 to 12% and in planted vegetative submerged beds 31 to 47%. They also found evapotranspiration loss was as high as 32 mm d⁻¹ in the planted beds and only 6 mm d⁻¹ in the unplanted beds.

Evapotranspiration is an important factor when studying vegetative submerged beds. The evapotranspiration rate in a vegetative submerged bed is dependent on humidity and the amount of vegetation as measured by percentage cover as well as the vegetation's size, type, and growth rate. In the summer evapotranspiration can significantly decrease water in the vegetative submerged bed system (Reed, Crites and Middlebrooks 1995, 181-182 and Staudt and Niehus 1981, 229), concentrating pollutants in the wastewater. Although evapotranspiration concentrates the wastewater, the treatment is still very effective on a mass-removal basis (Reed, Crites and Middlebrooks 1995, 182).

Chemistry of Vegetative Submerged Beds

Nitrogen is an important element to remove from wastewater. As ammonia, it can produce a significant oxygen demand in receiving water due to the oxidation of ammonia to nitrate. Nitrogen can stimulate plant growth

resulting in a high oxygen demand, odor, and alga's growth that raises TSS. Eutropism can result from excess un-ionized ammonia nitrate and nitrite. Ammonia is toxic to aquatic organisms, especially the higher forms such as fish, at concentrations as low as 0.5 mg l^{-1} (Reed, Crites and Middlebrooks 1995, 234). Excess nitrogen can get into surface or ground waters used for drinking. If nitrogen levels are high enough, cardiac malfunction and infant methemoglobinaemia can occur (USEPA 1986, 2 and Kennedy 1981,105). Methemoglobinaemia is a condition that prevents the blood from carrying oxygen and can cause retardation in infants. USEPA and state law generally limit nitrates in drinking waters to 10 mg l^{-1} (Barnes and Bliss 1983, 3). Ammonia in water supplies increases the amount of chlorine needed to achieve a free chlorine residual for disinfection (Barnes and Bliss 1983, 3).

Reed, Crites and Middlebrooks (1995, 84) state nitrogen in wastewater is composed of ammonium (about 60%), organic nitrogen (about 40%), and less than 1% nitrate and nitrite. Nitrogen is often measured as total Kjeldahl nitrogen (TKN) which includes NH_3 , NO_2 , and NO_3 . Septic tanks remove organic nitrogen, which is associated with settleable solids (dissolved and colloidal organic nitrogen). Dissolved inorganic forms of nitrogen are not removed until secondary treatment such as vegetative submerged beds (Barnes and Bliss 1983, 8).

Vegetative submerged beds achieve nitrogen removal through plant uptake, immobilization in microbial biomass (Reed, Crites and Middlebrooks 1995, 234), nitrification, denitrification (biochemical), and volatilization (a physico-chemical process where nitrogen is released as a gas and lost to the

atmosphere) (Reed, Crites and Middlebrooks 1995, 84 and 462, Frankenbach and Meyer 1999, 403 and Johns et al 1998, 245 and 237). The removal of nitrogen depends on the supply of ammonium to the aerobic zone, pH, temperature, presence of nitrifying bacteria, depth of bed, and HRT (USEPA 2000, 2 and Reed, Crites and Middlebrooks 1995, 84). Vegetative submerged beds can remove nitrogen to 10 mg/ml (USEPA secondary wastewater guidelines) if the retention time is long enough (USEPA 2000, 2).

Early researchers of vegetative submerged beds harvested plants to remove them as sources of nitrogen (Reed, Crites and Middlebrooks 1995, 84 and 85). Data on the amount of nitrogen used by plants vary greatly. Johns et al. (1998, 238) Gersberg et al. (1985) and Herskowitz (1986) (as cited in Reed and Brown 1992, 776) all state plants remove 10% of all available nitrogen. However, Frankenbach and Meyer (1999, 403) found 7% while, Reddy and DeBusk (1985, 462) found 18-39% nitrogen uptake in summer and 16-25% in winter.

Although thinning, weeding, and grooming softer tissue flowering species such as canna lilies (*Canna* sp.), calla lilies (*Zantedeschia aethiopica*), ginger lilies (*Hedychium coronarium*), and water iris (yellow or blue flag) (*Sagittaria* sp.) used in Harrison County is essential for proper bed operation, plant removal eliminates very little nitrogen, because only a relatively small amount of plant material is removed. Since vegetative submerged beds function better without the bed being disturbed, minimal amounts of harvesting are recommended (Reed, Crites and Middlebrooks 1995 154).

Microbial growth is basic to the successful operation of all biological wastewater treatment processes. The availability of carbon and oxygen is crucial to chemical and biological processes. In nitrification, organisms remove a small amount of nitrogen by assimilation, as well as carrying out their characteristic oxidation of inorganic nitrogen. These reactions are temperature, and pH dependent. Saturation of *Nitrosomonas* and *Nitrobacter*, the main organisms removing nitrogen, with respect to both inorganic nitrogen and dissolved oxygen, increase with increasing temperature with a maximum range of 20° C to 30° C (Barnes and Bliss 1983, 35). Although studies differ, the optimum range of pH for *Nitrosomonas* and *Nitrobacter* lies between 7.2 and 8.5 (Barnes and Bliss 1983, 51, Middlebrooks et al. 1999, 5 and 84 and Ogden 1994, 120). Chemically, at pH 7 essentially only ammonium ions are present, but as the pH increases to 12 only dissolved ammonia gas is present (Reed, Crites and Middlebrooks 1995, 84). Gaseous ammonia is relatively low at near neutral pH levels. However, as nitrogen gas is lost to the atmosphere, additional ammonium ions shift to the ammonia form to maintain equilibrium. Although, the unit rate of conversion and loss may be very low, long HRT compensates, resulting in very effective removal over the long term.

Carbon is a limiting factor in vegetative submerged beds (Barnes and Bliss 1983, 9). Major carbon sources are dead and decaying roots and rhizomes, organic detritus, and residual wastewater BOD (Reed, Crites and Middlebrooks 1995, 240 and Weisner et al. 1994, 363). According to Laak (1981, 108) gray water (laundry and kitchen wastewater) is a good source of organic carbon. Laak (1981, 110) showed gray water from a typical home contains soluble carbon, which biodegrades at the same rate as methanol. Surface litter

contributes very little to the system. Plant litter rests on top of the media and most of the litter never goes below the surface of the bed (Reed, Crites and Middlebrooks 1995, 195). Also, the litter decomposes aerobically and loses considerable carbon before reaching the wastewater (Gersberg, Elkins and Goldman 1983, 1010). Gersberg, Elkins and Goldman (1983, 1009) and Liehr et al. (2000, 2-8) found that using methanol as a carbon source reduced nitrogen by 95%, mulch reduced nitrogen by 85% (Liehr 86%), and without any supplemental carbon, nitrogen was reduced only by 25%. Phosphorous is often a limiting factor in plant growth (Liehr 2000, 8-1). Therefore, excess phosphorous can cause overgrowth and result in eutrophication of surface waters. The two primary sources are polyphosphates and orthophosphates, which are usually found in industrial wastewater and not domestic wastewater (Reed, Crites and Middlebrooks 1995, 85).

Phosphorous is usually not a significant part of household wastewater (Boyd 1970, 697), especially since laundry detergents no longer contain significant amounts of phosphorous. However, some dishwasher detergents still contain phosphorous and can elevate phosphorous levels in the wastewater. If necessary, phosphorous can be removed with special soils such as limestone (McCarthy et al. 1998, 450), clay, peat soils with oxides of iron and aluminum, and calcium or some other phosphorus absorbing materials. However, fine textured soils are likely to clog the bed and cause overflow at low hydraulic loading rates (Reed, Crites and Middlebrooks 1995, 186). It may take up to 3 years and require manipulation of the water level in the bed to encourage deeper penetration so that clogging will not occur (Reed, Middlebrooks and Crites 1988, 198). Frequent plant harvests, especially during

flowering, help sustain a significant level of phosphorus removal (Reed, Crites and Middlebrooks 1995 154 and Breen 1990, 695), and lengthen the life of the system (Breen 1990, 695). The optimum pH range for phosphorus availability is 6.0 to 7.0 (Plaster 1992, 226).

Problems with Contamination

On-site septic systems in the U.S. represent the largest reported cause of groundwater contamination that resulted in disease outbreaks from bacteria and viruses (USEPA 1986, 2). These disease outbreaks include acute gastrointestinal illness, hepatitis A, and typhoid (USEPA 1986, 2). Other pathogens that can cause illness include bacteria, viruses, protozoans, and helminths (Geary and Gardner 1998, 15).

Reed, Crites and Middlebrooks (1995, 70-73) found natural wetland treatment provides very effective control of pathogens. Vegetative submerged beds remove pathogens through a combination of filtration, desiccation, absorption, radiation, and predation. Viral concentrations in the effluent were consistently low although removal efficiency dropped in the winter (Reed, Crites and Middlebrooks 1995, 70-73).

Mary Currier, the State of Mississippi's epidemiologist, notes that 148 million gallons of wastewater are produced daily in Mississippi by homes not on central sewage collection and treatment systems (2002 speech recorded in Mississippi Environmental Health files). These systems contribute to the contamination of coastal waters as shown by shell fish with hepatitis A, rotavirus, and other disease carrying pathogenic bacteria such as cholera bacterium. Salmonella, Shigella, V. cholerae, and E. coli are also present in

coastal waters. While studying vegetative submerged bed in Harrison County in the summer of 2002, beaches were closed due to sewage contamination. The back of Biloxi bay has been restricted at least 35 years from shell fishing due to sewage contamination for per Mississippi Commission on Marine Resources Ordinance 1.016 and personal communication 2003.

Vegetative submerged beds remove harmful bacteria through physical entrapment and filtration. Actual removal is more effective due to the additional filtration provided by the plants (Reed, Crites and Middlebrooks 1995, 199). Reed, Crites and Middlebrooks (1995, 74) do not recommend chlorination before discharging wastewater because they believe chlorinated organic compounds are a greater threat to groundwater than potential transmission of a few bacteria.

While vegetative submerged beds typically are 70-98% effective at removing pathogens, some bacteria, viruses, and other harmful living organisms (Reed, Middlebrooks and Crites 1988, 199-200) can go through the vegetative submerged bed and cause disease. In Harrison County, Mississippi, hard chlorine tablets that dissolve slowly are used as a disinfectant. Chlorine tablets act in a reasonable time, can be made readily available, are safe, and are easy to handle, are considered non-toxic, affect pathogenic organisms more than non-pathogens, and disinfect with reasonable dosage levels to produce safe water (Drinan and Whiting 2001, 89-90-92). However, they are far from ideal. When effluent is chlorinated, suspended solids degrade and create objectionable byproducts (Drinan and Whiting 2001, 21) such as trihalomethanes (THMs). One of these THMs, chloroform, is a suspected carcinogen. Other common trihalomethanes are chemically similar to

chloroform and raise concerns (Drinan and Whiting 2001, 95). However, an economical competitive alternative to chlorine tablet disinfection has not been found.

Figure 3: Diagram of Chlorination Stack and Retaining Tank

Chlorination is perhaps the most effective and proven means of disinfection (Mitchell and Iverson 1987, 171). However, for residential on-site systems, its use is still not ideal because the resident has to buy chlorine and maintain chlorine tablets in the chlorination stack. The chlorination stack is a tube at the down slope of the vegetative submerged beds where hard chlorine tablets are placed (Figure 3). The effluent flows over the chlorine tablets, dissolving enough chlorine to disinfect the wastewater.

Seasons effect vegetative submerged bed and show monthly fluctuations of BOD₅, FC, pH, P, TKN (NH₃, NO₂, and NO₃), and TSS (Wolverton, Myrick and Johnson 1984, 23). Even though each vegetative submerged bed is unique

(Burgan and Sievers 1994, 117), seasonal differences occur with general trends that apply to all vegetative submerged beds. BOD₅, P, TKN, and TSS should have their lowest concentrations in the summer. BOD₅ is lower in summer and fall because of low plant detritus and higher temperatures (McCarthy et al. 1998, 453). Nitrogen and phosphorous concentrations are lowest in the summer because microorganisms and chemical reaction rates increase at higher temperatures. Plant utilization of nitrogen and phosphorous is highest in the summer when plants are growing and flowering. TSS decreases in the summer when there is little dead vegetation being released into the wastewater in the bed (Frankenbach and Meyer 1999, 406-7 and 409). However, fecal coliform rates are higher in the summer because the higher summer temperatures promote microbial growth (Frankenbach and Meyer 1999, 406-7 and 409).

Although on-site septic systems were initially used only for scattered rural homes, regulations and management for such systems did not change when higher density housing, such as subdivisions, started to use on-site wastewater treatment systems (Otis 1994, 2). Some areas restrict on-site systems to properties with a certain number of hectares (acres) per house. Required property size can range from 2 hectares (5 acres) to just 0.2 hectares (0.5 acres) (Harrison County, Mississippi and Santa Cruz, County Environmental Health Regulations). However, minimum acreage does not ensure purified wastewater or public safety (Angoli 1998, 10 and USEPA 1986, 13). On-site systems need on-going management to be sure all wastewater systems are working well and not relying on acreage to spread out the pollution.

Failure of on-site wastewater systems occurs too often because of lack of education and training for designers and installers, lack of supervision of design and construction, lack of inspections once installed, and lack of education of the homeowner. Alternative systems require knowledgeable site evaluators, designers, installation personnel, and management (Otis 1994, 8, USEPA 1986, 1 and Jantrania, Robertson and Katz 1998, 409). Designers must understand conventional systems and whether they are or are not appropriate. The designer must understand numerous alternative systems and the advantages and disadvantage of each. Each site is unique and needs a system designed for the particular conditions encountered at that site (Otis 1994, 1). Requirements must be comprehensive, yet flexible enough to accommodate the wide range of conditions encountered (USEPA 1986, 1).

Slope and soil type are essential aspects in vegetative submerged bed design. Most installers never had to consider soil and problems of daily flow exceeding design flow (Jantrania, Robertson and Katz 1998, 408 and USEPA 1986, 8). Training and educating local contractors, more accustomed to installing leachfields, helps them understand the systems that they design and install so they can be efficient, build reliable systems, and reduce cost (Jantrania, Robertson and Katz 1998, 408).

Guidelines and performance standards need to be clear and specific. There needs to be technical guidelines for site evaluation, design, construction, and operation. It is essential the governmental agencies regulating on-site wastewater systems have a well-trained technical staff. This staff must review and process vast amounts of information and make educated decisions for solving wastewater problems in a cost effective manner

(Jantrania, Robertson and Katz 1998, 408). The government agency must ensure that the most appropriate system is chosen. The responsible government agencies must supervise design, construction, and construction materials (Jantrania, Robertson and Katz 1998, 409).

Once construction and installation are completed, usually on-site systems are not revisited unless the property is transferred or the home is sold (Angoli 1998, 10 and Otis 1994, 1). Most on-site systems are ignored unless the system fails or there is a complaint (Otis 1994, 1). However, periodic inspections of vegetative submerged beds are crucial to ensure the systems are maintained and stay in good working order (Otis 1994, 1). The vegetative submerged bed's water depth must be controlled, inlet and outlet structures cleaned, berms inspected, and vegetation managed (USEPA 2000 6). Jantrania, Robertson and Katz (1998, 408) propose that the local government agency take responsibility for alternative systems similar to the management of sewered areas. This would include yearly fees, close supervision, and implementation of strong enforcement programs (USEPA 1986, 1 and Otis 1994, 2 and 7).

Professionals working with vegetative submerged beds require continuous training in design, maintenance, and troubleshooting (Loomis and Dow 1998, 420 and Cooper and Hobson 1989, 85-86) because alternate wastewater systems are still evolving and new information is still being discovered. Licensing and periodic renewal can ensure continuing education if classes and examinations require that the applicant demonstrate basic knowledge, skills, and experience necessary to perform on-site treatment systems services (Otis 1994, 8). All personnel providing such services need to be licensed or certified.

Introducing alternative wastewater systems presents not only technical but social changes (Jantrania, Robertson and Katz 1998, 407). Vegetative submerged beds require water conservation, maintenance of vegetation and the bed's structure, and awareness of what goes down the drain that can harm the vegetation. Homeowners must work around partially treated wastewater during vegetative maintenance. "Homeowners concerns are different from engineers or the city -- they aren't very concerned about the system's function or how much treatment is achieved - they care about cost to install, to operate and to maintain, potential for odors, and aesthetics" (Jantrania, Robertson and Katz 1998, 490). Public participation and public education are the key to successful implementation of any alternative systems programs (Jantrania, Robertson and Katz 1998, 407).

METHODS

Research Questions

The data collected was used to answer these research questions:

1. Did wastewater tests of pollutants correlate to the age of system, length and width of bed, pH, and/or percent cover of vegetative as expected from the literature?
2. Is a visual assessment of the dimensions and the maintenance of the vegetative submerged bed an adequate method for determining if the system is meeting USEPA wastewater guidelines and protecting public health?
3. Did a random sample of vegetative submerged beds in Harrison County, Mississippi meet USEPA wastewater guidelines for residential sewage treatment systems?

4. Have vegetative submerged beds deteriorated over time and are they currently well maintained?
5. Did government agencies adequately train designers and installers such that vegetative submerged beds were built correctly?
6. Does Harrison County Environmental Health continue to regulate vegetative submerged bed in Harrison County?
7. Should vegetative submerged beds continue to be used as on-site secondary sewage systems?

Site Description

Harrison County is on the Mississippi Gulf Coast and includes the barrier islands of Ship, Cat, and Deer, located in the Mississippi Sound, which flows into the Gulf of Mexico (Figure 4).

Harrison County is sub-tropical and has a temperate climate. Climatological data was obtained from four collection stations located in Harrison County during the on-site study period (July to August 2002). Two weather stations are located in Gulfport (sites GB and GN), one in Biloxi (site B), and one in Saucier (site S) (Figure 4). For July and August 2002 maximum high temperatures were 34-37°C (93-98°F) and minimum low temperatures 19-22°C (66-71°F).

Rain falls year-round in Harrison County and precipitation can be heavy. Rainfall averages about 62.3 inches a year (US Dept. of Agriculture 1975, 76). On June 26, 2002, 7.8 cm (3.07 inches) of rain fell in 24 hours. Average rainfall for Harrison County, Mississippi was 20.2 cm (8.1 inches) in July 2002 and 16.2 cm (6.5 inches) in August 2002.

Figure 4: Soil, Sites, and Weather Stations in Harrison County, Mississippi

In Harrison County, “soil is loamy and sandy on the flats and flood plains, loamy soils with loamy subsoil on the uplands, and sandy soils on upland along the coast” (Smith 1975, 1, Figure 4) Around Biloxi Bay, the water table is high and flooding occurs in the lower areas.

Sampling Strategy

From 1990 to 1998, 369 applications were submitted for vegetative submerged bed in Harrison County, Mississippi. From July 1, 2002, to August 15, 2002, 95 owners of vegetative submerged beds or approximately 25% of the applications for vegetative submerged beds in Harrison County were attempted contact, so observations and data collection could be made on their system. These 98 applications included all (53) 1995 inspection reports and 45 original applications randomly chosen from all initial applications. The inspection reports had updated address' and owners' names. The other original applications did not have any updated information, such detailed locations, addresses or current owner's name. Most of the houses were not built or the trailers were not yet on-site and an address had not been assigned.

The original applications and accompanying material of the 95 sites chosen were examined for the following information: application date (age of system), lot size, number of bedrooms, general location map, soil conditions, thickness of plastic liner, and required size of septic, vegetative submerged bed, and retaining tank. Twenty six sites or about 27% of the sites could not be found, even using inspection reports with updated names and locations. Three residences were vacant of which 2 sites no longer had homes. An additional 3 residents were no longer using vegetative submerged beds, 1 returned to a

leachfield and 2 had spray systems (Appendix I, Figure 21). Of the remaining 58 sites, 23 homeowners gave permission for observations and water tests. Of these 23 sites, 16 were inspected in 1995, 6 were not inspected in 1995, and one was a reference.

Seventeen vegetative submerged beds, whose retaining tank could be reached, had their wastewater analyzed. One of these site's history was known and this site was used for a reference because it was in good condition. However, it was not included in any of the quantitative analysis.

Visual observations and measurements were taken for each bed. Beds were visually examined for percentage of cover, condition of plants, and type of plants (vegetative submerged bed plants, trees or weeds). The general condition of each bed's structure was noted. A vegetative submerged bed in good condition has berms about 0.5 meters (1.5 feet) above the bed, no erosion, especially into the bed, and the landscape timbers surrounding the bed are linear and not rotten. The shape of the bed was noted because a non-rectangular or amoebae shape bed shows that during previous flooding, sand underneath the bed shifted causing structural damage (Appendix V, Figure 53). Pooling was noted because it indicated the system was clogged, improperly sloped, not wide enough or too small for the amount of wastewater it receives. Odors were noted because they indicate improperly treated sewage. Unfortunately, slope, depth, and root mass could not be ascertained due to the possibility that the 22-24 millimeter plastic liner might break during the inquiry. Whether a liner was broken or not could only be determined through circumstantial evidence. For example, trees growing in and around the vegetative submerged bed may puncture the liner with growing plant roots

(Reed, Crites and Middlebrooks 1995, 12). Also, beds with sudden lack of vegetation and nearby ponds with large amounts of algae indicate a broken liner (Appendix V, Figures 22 and 23).

Gravel was visually examined to see if the sizes were similar among all the beds. Measurements were made of the length and width of the bed. If there was a second bed, it was recorded as well as whether it was part of the design or an unplanned bed in the drainage area.

Soil type and indications of wet conditions such as wetland plants, soggy soil or crayfish mounds were noted to determine whether the area might support a leachfield system. Houses on stilts were noted, because stilts indicate flooding. All observations were collected before sampling for water quality was conducted.

One wastewater sample of each of 17 vegetative submerged beds was collected at the retaining tank on August 13 and 14, 2002. Wastewater was collected in a bailer that was rinsed with distilled water between sites or by using a pump that was cleaned by allowing the next site's water to flow through for two minutes to thoroughly clear out all the water from the previous site. One liter of wastewater was put into labeled plastic bottles, then immediately put on ice. The time of sampling was noted. These samples were delivered for analysis to Magnolia Scientific, USEPA certified laboratory and were processed within 6 hours of collection. The wastewater was tested for chlorine, pH, BOD₅, fecal coliform(FC), phosphorous (P), TKN, and TSS using USEPA procedures. The wastewater was tested for chlorine to see if this chemical was being used to purify the wastewater. Single regressions compared each wastewater component, BOD₅, FC, P, TKN, and TSS to the age of

system, length and width of bed, pH, percent cover of vegetative submerged bed vegetation, and percent vegetation of all vegetation present in the bed.

To determine if visual assessments of the vegetative submerged beds are adequate for determining compliance with USEPA wastewater guidelines, ranked wastewater test results were compared to ranked visual impressions of each site based on the parameters measured. The quantitative data for each site was ranked based on BOD₅, P, TKN, and TSS. The lowest rank corresponds to the highest water quality. For example, site 7 had BOD₅ of 6g/ml, TSS of 15 g/ml, TKN of 3.0 g/ml, and P of 1.75 g/ml. Ranked against the other wastewater tests, site 7 was the lowest site in BOD₅, TKN, and P and 6th in TSS. BOD₅, TKN, and P each received ranks of 1 and TSS received a rank of 6. When these ranks were averaged ($(1+1+1+6)/4 = 2.25$), site 7 showed the lowest number and was the site with the least wastewater components that needed purification. Linear regressions compared quantitative data, including and excluding fecal coliform counts, to qualitative data.

Qualitative analysis of each vegetative submerged bed was based largely on appearance and type of vegetation in the bed. Appearance was rated not only by type of vegetation and amount of cover but size, age, and robustness of the vegetation. Advantages such as the bed having a length of 30.5 meter (100 feet) or disadvantages such as pooling were noted.

To answer the question of whether vegetative submerged beds are well maintained, inspection reports were compared to observations from this study on bed structure, percent cover, trees in the bed, and reported pooling or backflow.

Determining if government agencies adequately trained designers, contractors, and installers and continue to regulate vegetative submerged beds

in Harrison County was answered by county files, the conditions of the vegetative submerged beds, Pansy Maddock, Environmentalist for Harrison County Environmental Health, and county inspectors.

RESULTS

Table 2				
<u>P-Values for Regression Results of Water Quality Variables</u>				
Waster Quality Variables	Age of System	Length of Bed	Width of Bed	
BOD ₅	p = 0.51	p = 0.99	p = 0.80	
Fecal coliform	0.00	0.25	0.87	
P	0.47	0.28	0.80	
TKN	0.39	0.47	0.48	
TSS	0.58	0.78	0.33	
Wastewater Tests	pH	Percent Cover VSB plants	Percent Cover All Vegetation	Total VSB Veg
BOD ₅	p = 0.45	p = 0.21	p = 0.18	p = 0.55
Fecal coliform	0.01	0.63	0.63	0.31
P	0.07	0.00	0.02	0.01
TKN	0.21	0.27	0.06	0.14
TSS	0.39	0.08	0.09	0.27
(α = 0.05)				

Table 2 shows the results of the single regressions comparing each wastewater component, BOD₅, FC, P, TKN, and TSS to the age of system, length and width of bed, pH, and vegetation. Only fecal coliform correlated to age of the system (p = 0.00). No correlation was found between bed length and BOD₅ (p = .99) or TSS (p = 0.78).

Results showed that the vegetative submerged beds tested had a pH range from 6.28 to 7.54. A strong correlation to pH was shown by fecal coliform ($p = 0.01$) and a trend was shown to P ($p = 0.07$) but TKN did not correlate ($p = 0.21$). Only two sites were in the optimum pH range for nitrogen removal.

In an attempt to reflect the root mass below the surface, three methods of measuring vegetation were used: percentage cover of all vegetation, percentage cover of only vegetative submerged bed plants, and percentage cover of all vegetation, with weeds counting 50% (Table 4). Phosphorus showed a strong correlation to all three ways of calculating vegetation ($p = 0.00, 0.02$, and 0.01). A trend was shown to TKN ($p = 0.06$) when compared to the percent cover of all vegetation.

Table 4
Different Ways of Determining Vegetation

Site wastewater tested	% all vegetation	% vsb only	% vsb + 50 non-vsb
2	25	25	25
3	10	10	10
4	100	0	50
6	60	60	60
7	95	95	95
9	9	9	9
11	100	100	100
12	95	95	95
13	1	0	0.5
14	90	90	90
15	98	33	66
16	100	100	100
18	98	98	98
19	80	80	80
21	70	70	70
22	100	0	50

Each bed is ranked two ways in Table 5. First, sites were listed from best to worst, based on the results of all quantitative water quality tests including and excluding fecal coliform. Then sites were ranked from best to worse based on robustness of vegetation and condition of the bed. When compared, only the best sites, 7 and 6, and the worst sites, 9, 3, 4, and 13 were ranked the same. The rest of the beds' visual ranking and water quality ranking did not correspond as well. A linear regression of the data showed $p = 0.015$ when water quality tests compared to the visual rankings included fecal coliform counts and $p = 0.777$ when water quality tests compared to the visual rankings excluded fecal coliform counts.

Table 5

Each Site Ranked by Quantitative and Qualitative Results

Order	Quantitative Results:		Visual Assessment: Site #
	Site #: With FC	Without FC	
1	7	7	7
2	6	6	15
3	2	22	6
4	22	2	21
5	16	16	12*
6	15	21	11*
7	21	15	14
8	12	12	19*
9	19	14	18
10	14	18	2#*
11	18	19	16
12	11	9	22
13	9	11	9
14	3	3	3
15	4	4	4*@
16	13	13	13@

only bed wastewater tested that was ≥ 20 meters (66 feet)

* pooling or backflow

@ possible break in liner due to tall trees

Only one site met USEPA guidelines for wastewater treatment. Two other sites met USEPA guidelines for BOD₅, TSS, P, and TKN. Four sites met USEPA guidelines for BOD₅, TSS, and P. Four sites met two water quality parameters and the other five sites met only one wastewater parameter. The percentage of systems that passed each wastewater component were: BOD₅ 62%, FC 19%, P 94%, TKN 31%, and TSS 56%.

Table 6

Percentage of Sites Not Meeting Standards for Six Attributes in 1995 and 2002

Table 7

Comparison of 1995 Inspection Reports to Observations in 2002

Qualitative analysis of: 1995 Inspections			Study sites of 2002	
	# of sites	%	# of sites	%
Structural degradation ₁	10	19%	11	50%
Needs weeding ₂	37	70%	15	68%
Needs more vsb plants ₃	20	38%	13	59%
Plants need thinning ₄	6	11%	2	9%
No or incorrect chlorine ₅	30	57%	16	94%
Trees in beds ₆	5	9%	5	23%
2 trailers @ bed	2		1	
Insect damage	1		2 (minor)	
Gray water system	1		1	
Out of a total of:	53 sites		22 sites

Figure 5: Minor Insect Damage (scale: 1 decameter between dark lines)

Both Tables 6 and 7 compare all 53 of the 1995 inspection reports to my observations in 2002 to show how the vegetative submerged beds have fared from 1995 until my observations in 2002. Table 6 compares graphically how six attributes of vegetative submerged beds have fared. Table 7 gives numerical data of the above attributes identified by subscript and three other attributes not shown graphically. Vegetative submerged beds showed deterioration since being inspected in 1995. The number of sites with structural degradation such as rotten or nonlinear timbers, increased from 19% to 50%. The number of sites with trees presents in the vegetative submerged bed increased from 9% to 29%. The number of systems needing more vegetative submerged bed plants increased from 38% to 59%. Chlorine

was not detected in 94% of the sites that were quantitatively tested (Appendix IV, Table 10). The number of beds that needed weeding and thinning and the amount of minor insect damage (Figure 5) remained approximately the same.

Whether government agencies adequately trained designers and installers was answered by government officials and the problems noted with the vegetative submerged beds. Pansy Maddock, inspectors and other personnel at Harrison County Environmental Health stated installers and contractors were not trained in designing or constructing alternative systems. They only knew about designing and installing leachfields. The degree of designers' and installers' knowledge of vegetative submerged beds was assessed by placement of the bed, berm construction, dimensions of the bed, and presence of water pooling or flowing backward (Table 8).

Table 8

Indications of Incorrect Construction and Lack of Maintenance

Indicates Improper Construction

Clogged	2/22	(9%)
Pooling/Backflow	6/22	(27%)

Indicates Incorrect Construction or Lack of Maintenance

Erosion	5/22	(23%)
Berms	5/22	(23%)

Indicates of Lack of Maintenance

VSB cover < 80%	11/22	(50%)
Landscape Timbers		
Nonlinear	4/22	(18%)
Eroded	6/22	(27%)
Beds with Trees	5/22	(23%)

There were 5 beds with berms level with the lawn. The homeowners at site 3 (Appendix V, Figure 26) replaced the landscape timbers with decorative bricks (Appendix IV, Table 12). Six sites had wastewater surfacing (pooling) or water flowing out the head of the bed (backflow). The top of the bed at site 11 (Appendix V, Figure 35) was markedly slanted towards the head of the bed. Twenty-seven percent of liners were likely perforated and leaking as determined by the presence of trees in the bed (Appendix, Table 13) or the sudden end to vegetation and overgrowth of algae in nearby ponds.

Untrained installers and compliance with required setbacks caused beds to be placed in odd places in yards. For example site 11 (Appendix V, Figure 35) lost the use of its entire side yard because the vegetative submerged bed was in the middle. More useable space would be available if vegetative submerged beds were placed on the property boundary and the discharge routed away from the property's edge. More careful placement by installers would help with spatial concerns and aesthetics. For example, site 6 (Appendix V, Figure 29) had excellent placement of their system. It bordered an open carport forming a natural screen between it and the back yard.

DISCUSSION AND RECOMMENDATIONS

Table 2 showed the results of the single regressions comparing each wastewater component, BOD₅, FC, P, TKN, and TSS to the age of system, length and width of the bed, pH, and percent cover of vegetative in the bed.

If systems were functioning normally, certain trends would be expected as shown in Table 9. Research has shown that the longer the bed, the more BOD₅ and TSS are eliminated due to physical straining (USEPA 2000, 2, Reed, Crites

and Middlebrooks 1995, 84 and McCarthy et al. 1998, 453). However, only one of the sites wastewater tested, site 2 was the recommended length of ≥ 20 meters (66 feet) and this site's wastewater test was much better than expected from the site's appearance. The rest ranged from 9.1 meters (30 feet) to 18.6 meters (61 feet). Gravel sizes were visually judged to all be similar heterogeneous mixes and should not have affected the HRT.

Reed, Crites and Middlebrooks (1988, 180-183) report that vegetative submerged beds stabilize in 2 - 3 years. However, this study found fecal coliform levels were strongly correlated to age.

Table 9		
<u>Expected Trends</u>		
Pollutant	Related to	Why
BOD ₅	Length of bed	partially eliminated by physical straining
TSS	Length of bed	eliminated by physical straining
BOD ₅	Width of bed	if lengths are related and all beds are the same area then width would be related
TSS	Width of bed	if lengths are related and all beds are the same area then width would be related
P	Vegetation	flowering vegetation uses P
TKN	Vegetation	growing vegetation uses N and the more roots in the bed, the more oxygen, the more purified the wastewater
FC	pH	optimum range = 6.4 - 7.8
P	pH	optimum range = 6.0 - 7.0
TKN	pH	optimum range = 7.2 - 8.5

A number of researchers have found that pH affects P, TKN, and FC in the vegetative bed system because pH affects P, TKN, and FC in the laboratory (USEPA 2000, 2 and Reed, Crites and Middlebrooks 1995, 5 and 84, Barnes and

Bliss 1983, 35 and 51, Ogden 1994, 120, Soil Improvement Committee 1990, 68 and Plaster 1992, 226). Optimal pH range for removal of N is 7.2 - 8.5, P is 6.0 - 7.0, and FC is 6.4 - 7.8. Phosphorous removal correlated to pH ($p = 0.00$) and plant cover ($p = 0.00 - 0.02$). Nitrogen removal was much lower than expected perhaps because only 2 out of 17 sites were in the optimal pH range for nitrogen removal.

The vegetative submerged beds' waster quality tests did not correlate as well as expected to the attributes of the vegetative submerged beds possibly because of the poor conditions of the vegetative submerged beds and this study's inability to determine the quantity of wastewater generated in the household. Further study of properly designed, installed, and maintained beds and accurate data on wastewater generated may show better correlations.

The water quality testing for this thesis had many confounding factors including small sample size, probable leaks in some of the beds, rainfall, evapotranspiration, and poor maintenance. Humidity was high and the evapotranspiration rate was also high due to hot temperatures. Rainfall before the wastewater tests was minimal. Two stations, Biloxi (site B) and Saucier (site S), reported no rain 6 days prior to water testing, Gulfport Naval station (site GN) reported rain of (0.05 centimeters) 0.02 inches 4 days before testing and Brentwood in Gulfport (site GB) reported (0.07 centimeters) 0.03 inches 3 days before water testing. Although it rained frequently the previous month, the vegetative submerged bed systems should have stabilized before wastewater testing. Evapotranspiration may have concentrated the wastewater in those systems with vegetation. These factors are the major reasons that certain expected regressions did not occur. However, what is shown is high levels of pollutants are being released in to the surrounding

environment, wastewater is not being disinfected and nitrogen removal is poor even though these systems were designed to remove nitrogen.

The most serious problem with on-site vegetative submerged beds as indicated by wastewater quality tests is the high fecal coliform counts (Appendix IV, Table 10). Only three vegetative submerged beds (18%) produced test results of ≤ 400 colonies per ml and two others were close (620 and 700 colonies per ml). This is due, in part, to the lack of regular chlorine treatments. Only one system tested positive for chlorine. Regular use of chlorine was estimated to be near 6%. The data strongly recommends against relying on residents to add chlorine to their vegetative submerged bed systems. Public service announcements, reminders by mail, inspections, easily accessible chlorine or even mailing chlorine to the households that do not pick up their chlorine, might help increase the usage of chlorine. A yearly fee could cover the cost of these services.

White and Shirk (1998, 199-200) suggest a second bed or tertiary treatment system may be necessary to solve many problems with vegetative submerged beds identified here. Although more land and expense are required, additional treatment can be added to a vegetative submerged bed to enhance wastewater treatment. One approach is to add a sand filter (Appendix I, Figure 13). TSS, organic matter, and fecal coliform are removed through physical straining and biological degradation. Sand filters are especially useful for a final polish of the wastewater (Mote and Ruiz, 1994, 339-340 and 345, Sandy, Sack and Dix 1978, 161-162, Venhuizen, Wiersma and Williams 1998, 470, Boyle 1981, 176, Carlile 1994, 244 and Boyle et al. 1994, 186 and Reed, Crites and Middlebrooks 1995, 120-1). Another solution is to use the wastewater for

underground irrigation, which combines advantages of water reuse, irrigation efficiency, and more effective wastewater treatment especially for coastal developments (Carlile 1994, 244). However, in Harrison County, Mississippi, this approach may not be applicable, as 18 out of 22 sites (78%) were too wet to use an irrigation system (Appendix IV, Table 10).

Quantitative and qualitative data both indicate that the two worst sites were 4 and 13, (Appendix V, Figures 27, 38, and 39). Site 13 was clearly the most deteriorated site. This site was in an overgrown area, had no vegetative submerged bed plants, only a few surface weeds and a poplar tree growing in the bed. Its first bed (Appendix IV, Table 11) was only 62 square meters (205 square feet) not the required 91 square meters (300 square feet). An additional bed was later built to comply with the required footage. The first bed was eroded, especially at the head of the first bed where timbers were rotten and wastewater was exposed. Site 4 was in very bad condition with a tall pine tree in the bed, no vegetative submerged bed plants, deteriorating berms, and a soggy bed surrounded by a bog. These two sites had the worst wastewater tests. Sites 3 and 9 also rated poorly quantitatively and qualitatively, just above site 4 and 13.

Although sites 2, 4, 11, 12, and 16 all had pooling, which would expose the wastewater to more oxygen, this exposure did not seem to assist purification of the wastewater. Site 2's long bed may have been the reason its wastewater test ranked 2 and 3 for wastewater quality tests and only 10 visually. The owner of site 2 cleared most of one side of the bed just before observations were made and cleared all the way to the chlorination stack during observations.

Quantitatively and qualitatively, the best sites were sites 6 and 7 (Appendix V, Figures 29 to 31). They both ranked number 1 and 2 for the wastewater quality tests and 1 and 3 for being visually a good vegetative submerged bed.

Visual assessments of vegetative submerged beds were a good method of determining if the vegetative submerged beds were operating as well as possible. Vegetative submerged beds that were full of the proper vegetation had lower pollution levels than those with little or no vegetation. However, visual assessments were not an adequate method for determining if the system meets USEPA wastewater guidelines. Even systems that had good structure, were full of the proper plants, and did not show clogging or pooling, did not meet all USEPA guidelines. Although these beds do not work as well as hoped it is still important to keep them functioning as effectively as possible.

Although visual examinations are not adequate for determining compliance with USEPA guidelines, visual examinations are important in evaluating the structure of the beds and inlet and outlet structures. For example, site 22 (Appendix V, Figure 51) was the only site that met all USEPA water quality standards (Appendix IV, Table 10). It had 100% cover of weeds with no vegetative submerged bed plants. It was overgrown until the owner cleared the area of brush and tall weeds around a week before observations. The bed was elevated with its berms intact. However, visual examination showed that site 22 had an open trench from the septic to the vegetative submerged bed that allowed wastewater to seep into the soil before entering the system..

Observations in 2002 showed maintenance of vegetative submerged beds was poor (Tables 6 and 9). Fifty percent of the beds had structural degradation, 68% needed weeding, 59% needed more vegetative submerged bed vegetation, 60% of the vegetative submerged beds had less than 80% appropriate plant cover, 23% of the beds were either currently overgrown by vegetation outside the bed or recently cut for the study, and 23% had trees in the bed.

If chlorine tablets were being added, they would be effective for one to two months and traces of chlorine should be found in the wastewater tests. Only 1 out of 17 (6%) site's wastewater tested showed any trace of chlorine (Appendix IV, Table 10). From the inspections reports, sometimes other chlorine such as pool and household bleach was added to the chlorine stack. Even if chlorine tablets were added, their application was not always effective. For example, site 3's disinfecting stack was filled with chlorine tablets that were too large for the stack and none of the chlorine reached the wastewater as indicated by the wastewater test (Appendix IV, Table 10). Only 3 out of 17 (18%) sites met USEPA guidelines for fecal coliform. Even site 23, that I knew to be well maintained had a fecal coliform level of 123,000 colonies per ml. This is far above the USEPA guidelines of 200 - 400 colonies per ml.

Fluctuating water use is an important factor that determines the functioning of on-site residential wastewater systems. When water units change rapidly, microbes can not adjust quickly. For example, site 23, the known site (Appendix V, Figures 52 and 53) has a well-kept bed and was expected to have wastewater results within USEPA guidelines. However, the fecal coliform count was 123,000 colonies per milliliter, the highest count of all the wastewater tests. This site had wide fluctuations in number of persons

using the system. Sometimes only one person was using the system, other times as many as eight persons or more would be using the system. With large flows to a public treatment system, fluctuations are evened out but with small on-site wastewater systems, the biological system cannot adjust quickly enough to adequately purify the water. One solution to even out fluctuating water use where housing is close together, such as subdivisions is to combine many households into one cluster system. However, cluster systems require cooperation and land held in common for the wastewater disposal.

Most vegetative submerged beds deteriorated over time and were not well maintained by the homeowner. Fourteen out of 21 beds (67%) needed maintenance. Better maintenance could be obtained with yearly inspections. These inspections could help ensure that the beds are full of the correct vegetation, the structure of the bed is in good condition and chlorine is being added. In 1995, in Harrison County, Mississippi, approximately 30% of the vegetative submerged beds were inspected. Only 25% of the systems were classified as being satisfactorily maintained (Frass and Hicks 1995, 10). There were no other inspections after 1995. Good management was shown through inspecting the vegetative submerged bed in 1995. Lack of continuing management was shown by not having inspections since 1995. Lack of management was shown by most files, excluding the 1995 inspections, not having an address or detailed location of the property.

According to Pansy Maddock, Environmentalist for Harrison County Environmental Health, plants were absent in some vegetative submerged beds because the beds were built before the site was occupied and the vegetative submerged bed vegetation died because of lack of water. When the 1995 inspections were done, county inspectors made sure every vegetative

submerged bed inspected was planted with appropriate vegetation. The environmental health staff even replanted some of the beds. Sixteen out of 22 sites (73%) used in this study were inspected in 1995. Therefore, as of 1995, most of this study's beds were planted with vegetation. If the inspection reports had not been included, the amount of vegetative submerged bed plants might have been lower.

Designers, contractors, installers, and government officials need to be trained and that training needs to be updated periodically. No such training was given to the contractors in Harrison County, Mississippi. Ill-constructed beds with backflow and pooling should not occur. For example, a design feature such as minimum length suggested by Reed, Middlebrooks and Crites (1988, 193) was not followed. Reed, Middlebrooks and Crites (1988, 193) recommend that in all cases, the bed length (parallel to the direction of flow) should be at least 20 meters (66 feet) to ensure adequate HRT. TSS removal is almost entirely due to physical processes, sedimentation, and filtration. Solids have either settled in the septic tank or are filtered in the first 20% of the bed (Reed, Crites and Middlebrooks 1995, 189). As shown in Appendix IV, Table 11 only 2 out of 22 (9.1%) vegetative submerged beds observed had bed lengths $\geq$ 20 meters (66 feet) and only one these had its wastewater tested.

Alternative secondary systems are needed when leachfields are inappropriate due to slow water percolation through the soil or a high water table. Visual observations, as indicated by wet conditions such as crayfish mounds, wetland vegetation, and signs of flooding (Appendix IV, Table 13) and soil reports from initial applications showed that 19 out of 22 sites (82%) were unsuitable for a leachfield as their secondary sewage treatment. However, all

alternative systems available should have been considered carefully, not just vegetative submerged beds. Other alternative systems, such as mound systems (Gunn 1987, 131) or evapotranspiration systems, might work better than a vegetative submerged bed. The USEPA (1990) document, *Small wastewater systems: Alternative systems for small communities and rural areas*, has a summary of those and other prevalent alternative wastewater systems (Appendix I).

Lack of vegetation, tall trees, structural maintenance, surface wastewater flow, and low chlorine use could be prevented or lessened by yearly inspections and continuing education. Trees could be removed before they break the liner, vegetation could be replanted, and chlorine could be added at least once a year. Continuing education and reminders could emphasize plant maintenance, not to use harmful chemicals such as glyphosphate, why it is necessary to use chlorine, and what kind and how often to use chlorine. Money for inspections could come from fees paid by alternative secondary sewage systems. Alternative systems such as vegetative submerged beds should not be built then ignored.

Vegetative submerged beds should only be recommended for secondary sewage treatment if they are well constructed, well maintained, well managed, followed by further treatment, and are nondischarging. Other more passive systems should be considered first and vegetative submerged beds only considered in certain controlled circumstances.

Identification of Further Research

Many questions arose out of this study. The fecal coliform count was extremely high at most sites. Were these counts high because the effluent arriving at the retaining tank was high or did breeding happen in the retaining tank? To what degrees are anti-bacterial soaps and other common cleaning compounds adversely affecting microbes in the vegetative submerged beds? Further studies need to be done to determine why the fecal coliform rate was so high and what could elevate this problem.

Of the 17 sites whose wastewater was tested, 4 sites (for example sites 21 and 23) had additional beds by design and 6 vegetative submerged beds had voluntary beds (for example site 14 had voluntary vegetative submerged bed plants in the drainage area). An additional bed should provide additional treatment. Except for the fecal coliform, seven more of the sites (12, 14, 15, 16, 18, and 19) were close enough to USEPA guidelines that only a small amount of additional treatment would be needed. This study took wastewater samples from the retaining tanks only, to achieve a consistent comparison. An additional study testing the wastewater after the second bed could be done to see if it meets USEPA guidelines.

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This is the most common system used on level land with adequate soil depth above the water table. Heavy solids in the liquid settle and greases float to the top of the tank. Bacteria break down some solids. The liquid flows from the tank through a closed pipe into perforated pipe and into gravel-filled trenches where it seeps into the soil. Bacteria and oxygen purify the liquid as it slowly moves through the soil. Inspection ports permit checking liquid depth. Regular pumping of the tank reduces the solids discharged into the trenches and extends the life of the system. Using two compartment septic tanks and resting the trenches (#4) are also recommended to extend trench life.

Figure 6

Starting with the highest, each trench fills completely, then overflows through one drop box to the next. The effluent floods all soil surfaces. The drop box enables inspection of the system and control of discharge into each trench. Capping the pipe outlets in the upper trench forces resting. Serial distribution automatically loads upper trenches and minimizes the loading on lower trenches. Used on gently to steeply sloped sites.

Figure 7

Appendix I

Common On-site Systems

3 Septic Tank & Leaching Chambers

Open bottom concrete chambers or arched plastic chambers create an underground cavern that stores effluent. The effluent floods the soil surface prior to seeping vertically through the bottom of the chamber.

Figure 8

4 Septic Tank With Alternating Trenches

One set of trenches rests while the other treats the liquid from the septic tank. This design extends system life and provides a backup should one field clog. For system repairs, a new field and valve box may be added to the old system. The new field works while the old field rests and renews. Switch the fields annually in the summer.

Figure 9

5 Pressure Dosed Distribution

A pump or siphon doses a pressure distribution manifold that disperses the effluent evenly to each trench. Dosing prolongs system life by flooding a larger area and by forcing the exchange of air in the soil. Dosed systems are more common for larger flows. The pressure manifold can include valves or plugs that permit more control over trench loading or trench resting. Annual inspection is suggested.

Figure 10

6 Shallow Trench Low-Pressure Pipe Distribution

Small diameter pipe, located at a more shallow depth than a conventional system, receives pumped effluent. Effluent moves under pressure through small holes in the pipe and soaks the entire trench network area. Even dosing of more open and aerobic soil horizons improves treatment. Used in areas with high groundwater or shallow soils (because it places the treatment higher in the soil profile) or on steep slopes that require hand excavation. Professional maintenance is needed to flush the lines annually.

Figure 11

Appendix I

Options for Difficult Sites

7 Pretreatment & Soil Absorption

Pretreatment addresses the need to treat higher strength waste (such as from restaurants) and can help repair biologically overloaded systems where no additional absorption area is available. Aerobic treatment systems and filters can be used for this purpose. For aerobic treatment (called "package plants"), wastewater and air mix in a tank. Bacteria grow in the tank and break down the waste. For filters, septic tank effluent passes over porous media that trap the solids. Bacteria that grow in the media break down the waste. Professional maintenance by certified operators and a lot of energy are required for aerobic systems.

Figure 12

(USEPA, 1992)

Appendix I

Options for Difficult Sites

8 Septic Tank & Mound System

Pumps dose effluent (#6) into a gravel bed or trenches on top of a bed of sand. Sandy soil carefully placed above the plowed ground surface treats the effluent before it moves into the natural soil. The system extends onsite system use in areas with high groundwater, high bedrock, or tighter clay soils. Regular inspection of the pumps and controls and flushing of the distribution network are needed.

Figure 13

9 Evaporation & Absorption Bed

Effluent from a septic tank or aerobic tank flows into gravel trenches or chambers in a mound of sandy soil. Less permeable soil placed at the surface of the mound helps shed rain from the system. Trees that grow around the system and plants on top of the system pull liquid from the sand and transpire the water into the air. Some effluent may seep into the soil. This system requires a climate where evaporation consistently exceeds rainfall.

Figure 14

10 Septic Tank, Sand Filters, Disinfection & Discharge

Open or buried beds of sand may receive single or repeated applications of effluent. Effluent passes through the media and drains from the gravel and pipe network below the filter. Effluent may be discharged to the environment directly or into a soil absorption or land treatment system (#16). Disinfection often precedes discharge into a stream or land irrigation. Certain types of filters can significantly reduce nitrogen and may be used in areas where soil absorption is not possible. Requires inspection and periodic maintenance. Surface discharge requires management.

Figure 15

11 Constructed Wetlands

Effluent from a series of septic tanks passes through a bed of rocks planted with reeds. Liquid evaporates and drains into a soil absorption system or discharges. Used for additional treatment or where soils are not suitable for absorption. Discharge usually requires disinfection.

Figure 16

Appendix I

Options for Special Situations

12 Holding Tank

Sewage flows from low-flush toilets and water-saving fixtures into a large watertight storage tank. The alarm in the tank signals the owner to have the sewage hauled away. Only recreational housing utilizes holding tanks because of the high hauling cost. Public management is frequently required. Contracting for hauling helps to reduce costs.

Figure 17

13 Lagoon

A series of septic tanks or other pretreatment systems (#7, #10, #11) discharge into a lagoon. Sunlight and long storage times support the natural breakdown of the waste and die off of harmful organisms. Effluent evaporates, slowly seeps into the soil, or receives further treatment through land application (#16). Onsite lagoons require large lots and may be fenced.

Figure 18

Appendix I

Options for Special Situations

14 Waterless or Ultra Low-Flush Toilet System

Composting Toilets: No water

Serve commercial and single family units. Well-designed units produce a dry mixture that should be managed by professionals. Reduces discharge of nutrients into water resources. Electric vent, fan, and heating element common. Proper care is essential.

Incinerating: No water

Electricity, gas, or oil burns solids and evaporates the liquid, which is vented to the roof. Small amounts of ash are removed weekly. Proper care is essential. Limited to less frequent use sites, such as recreational cabins.

Water Conservation Toilets: Low water

Low-flush toilets use 1.6 gallons or less per flush. They generally cost slightly more than conventional units, but pay for themselves by lowering the water bill. They perform well. Many work as well as 4 gallons per flush models.

Recycling Water: Low water

Treated wastewater or graywater recycles to flush toilets. Treatment systems use electricity and require professional maintenance.

15 Dual Systems

Two systems treat the waste. Composting toilets or low-flush (1.6 gallons or less) toilets coupled with a holding tank (#14, #12) exclude nutrient rich toilet wastes (blackwater) from the wastewater disposal system. All other household wastewater (graywater) must be treated in an approved septic tank and absorption system, which is usually smaller.

(A) Blackwater (Toilet Wastes)

(B) Graywater (Other Household Wastewater)

Figure 19

Figure 20

Appendix I

Options for Special Situations

16 Land Application

Effluent from a septic tank is further treated (#7, #10, #11, #13) and stored. Timed sprinklers apply the effluent at night or below the soil surface to plants and trees in a large treatment area. Protects high groundwater in more permeable soils as plants take up nutrients and water. Disinfection and fencing may be required for individual home use. More common in warm climates, but not widely permitted by health authorities.

Treated effluent from a lagoon (#13) or wetland (#11) is sprayed on the surface of a gentle, grass covered slope. Effluent flows over the clay soil through the grass and collects at the base where it is disinfected before being discharged. Best for tight soils where absorption systems are not possible. A professional operator usually cares for the grass and disinfection system.

Figure 21

Appendix II

Design Variations for Vegetative Submerged Beds*

Reference	Water Depth cm(in.)	Width m(ft.)	Length m(ft.)	HRT days
Sievers, 1993	31 (12)	0.14 (24)	11.4 (43.5)	6.5
Cooper, 1990	62 (24)	0.59 (5.6)	12.1 (40)	5.6
Reed 1993	11.8 (30)	0.49 (1.6)	36.0 (118)	4.7
Reed 1993	62 (24)	0.61 (2.0)	36.0 (118)	4.7
Reed 1993	31 (12)	1.7 (4.0)	36.0 (118)	4.7
TVA 1993	7.1 (18)	2.0 (6.7)	14.3 (47)	3.6
TVA 1993	31 (12)	3.0 (10)	14.3 (47)	3.6
Kadlec & Knight, 1996	7.1 (18)	0.91 (3.0)	11.6 (38)	1.3
Wolverton et al. 1983 and Amberg, 1992	7.1(18)	0.61(2.0)	32.0 (105)	2.4
Reference	Flow lpd(gpd)	Media [saturated hydraulic conductivity m/day(ft/day)		
Sievers, 1993	1363 (360)	2.5 cm (1") rock		
Cooper, 1990	901 (238)	.64 - 1.3 cm (0.25-0.5") gravel	85 [280]	
Reed 1993	1136 (300)	3.2cm(1.25") gravel	3048 [10,000]	
Reed 1993	1136 (300)	"		
Reed 1993	1136 (300)	"		
TVA 1993	1363 (360)	1.27 cm(0.5") river gravel	259 [850]	
TVA 1993	1363 (360)	"		
Kadlec & Knight, 1996	1136 (300)	not specified		
Wolverton et al. 1983 and Amberg, 1992	1514(<400)	2.5-7.6 cm (1-3") rock [not specified]		

*(For a 5 person 3 bedroom household with a mean temperature of 4°C)
(Mankin and Powell 1998, 229)

Appendix III

Information from Observations

Number
L x W
Actual square feet of bed
Plants used
% cover
Weeds
Additional bed
planned
unplanned
Size of gravel
System's condition
landscape timbers: linear rotten
berms
erosion
pooling
backflow
pooling
odor
clogged
discharge from system
water draining into system
Soil
Wetland vegetation
Crayfish mounds
Placement in yard
Chlorine: none correct incorrect kind of chlorine
Notes

Appendix III

Information from Files

[illegible]

Appendix IV
Table 10: Wastewater Tests

	pH	TCR g/ml	BOD-5 g/ml	TSS g/ml	P g/ml	TKN g/ml	Fecal Coliform colonies/100ml 200 - 400
Site #							
USEPA guidelines							
1			30	30	10	10	
2	7.13	ND	7	8	8.30	26.3	2,600
3	6.53	ND	72	146	7.56	22.4	14,000
4	7.15	ND	45	280	9.08	34.4	123,000
5							
6	6.75	ND	9	13	2.43	8.4	2,900
7	6.61	ND	6	15	1.75	3.0	9,400
8							
9	6.78	ND	25	192	12.94	17.4	620
10							
11	6.49	ND	34	518	3.80	18.8	35,000
12	7.1	0.02	64	64	4.44	7.8	ND
13	7.03	ND	40	730	9.81	139.7	35,000
14	6.79	ND	15	ND	5.42	24.4	20,000
15	6.28	ND	23	33	5.76	10.9	700
16	6.77	ND	15	4	4.88	17.9	21,000
17							
18	6.74	ND	10	19	6.15	49.6	29,000
19	7.31	ND	30	4	6.05	26.1	84,000
20							
21	7.54	ND	32	48	4.98	8.7	ND
22	7.03	ND	21	2	6.78	1.4	60
23	6.79	ND	39	105	10.6	22.1	166,000

Appendix IV
Table 11: Description of Property and Bed

Site #	Age Yrs	Lot Size Hectares	Dimensions				Required				Actual	
			Width		Length		Length		Square		Square	
			Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
1	11	3.8	1.5	5	27.4	90	122	400	137	450		
2	11	1.9	0.9	3	30.5	100	91	300	91	300		
3	9	0.6	1.9	6	14.6	48	91	300	91	300		
4	4	2.0	3.0	10	9.1	30	91	300	91	300		
5	7	1.6	1.2	4	9.1	30	37	120	37	120		
6	8	1.2	1.5	5	18.3	60	91	300	91	300		
7	8	1.4	1.8	6	13.1	43	91	300	79	258		
8	8	1.3	1.5	5	18.3	60	122	400	91	300		
9	9	0.4	1.8	6	13.1	43	91	300	92	301		
10	8	0.4	2.1	7	13.1	43	91	300	92	301		
11	9	0.4	1.8	6	15.2	50	91	300	91	300		
12	11	1.2	2.1	7	15.2	50	91	300	107	350		
13	8	2.0	1.5	5	12.5	41	91	300	62	205		
14	8	4.0	3.0	10	9.1	30	91	300	91	300		
15	9	1.3	1.7	6	17.1	56	91	300	94	308		
16	8	1.2	1.8	6	18.6	61	122	400	91	300		
17	5	2.8	1.5	5	18.3	60	91	300	91	300		
18	8	1.8	3.0	10	9.1	30	91	300	91	300		
19	8	1.2	1.5	5	15.2	50	91	300	91	300		
20	9	0.6	1.8	6	15.2	50	91	300	91	300		
21	9	0.6	3.0	10	8.8	29	122	400	91	300		
22	9	2.0	3.7	12	10.7	35	91	300	128	420		
23	10	2.0	2.1	7	17.1	56	122	400	122	399		

Appendix IV
Table 12: Condition of System

Site #	System's Condition		Landscape Timbers	Berms	Odor	Clogged	Pooling	Discharge
	Linear	Erosion						
1	yes	no	ok	level with lawn				
2	yes	yes	somewhat eroded	level with lawn	little	yes @1-2 yrs	yes	yes
3	yes	no	replaced by brick	no berms	no	no	no	yes
4	yes	no	ok	level with lawn	no	no	yes	yes
5	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	yes
6	yes	yes	ok	< 0.5 m (1.5ft.)	no	no	no	yes
7	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	yes
8	yes	no	ok	level with lawn	no	no	yes	no
9	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
10	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
11	yes	no	ok	level with lawn	no	no	yes/backflow	yes
12	yes	no	rotten	< 0.5 m (1.5ft.)	no	no	yes	yes
13	no	yes	rotten	< 0.5 m (1.5ft.)	no	no	no	no
14	yes	yes	a little rot	< 0.5 m (1.5ft.)	no	little	no	yes
15	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
16	mostly	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
17	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
18	yes	some	rotten	< 0.5 m (1.5ft.)	no	no	no	no
19	no	yes	a little rot	< 0.5 m (1.5ft.)	no	no	yes/backflow	yes
20	no	no	ok	< 0.5 m (1.5ft.)	no	no	no	no
21	no	no	ok	< 0.5 m (1.5ft.)	no	no	no	yes
22	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	yes
23	yes	no	ok	< 0.5 m (1.5ft.)	no	no	no	yes

Appendix IV
Table 13: Additional Treatment, Plants and Soil Conditions

Site #	Additional Treatment	Plants	% cover	Soil	Crayfish Mounds
1	no	C, E, cat	33%	ok	no
2	no	C	25% sporadic	clay pan, wet	yes
3	yes - underground rock	C	10%	back of property soggy	yes
4	overgrown ditch	pine tree, whatever grows	100% no vsb	soggy, pitcher plants	yes
5	no	E,C, weeds	30%	ok	no
6	no	C, removed E	60%	elevated house & vsb	yes
7	yes, additional bed	C, E, weeds	95%	lower area soggy	yes
8	no	E, surrounded by weeds	60%	soggy	yes
9	no	C	5%	soggy	yes
10	no	bannanna tree	2%	soggy	yes
11	no, drains into ditch	C, Acacia	100%	ok for reg.septic	no
12	vsb plants in drainage	C, weeds	95%	soggy	yes
13	second bed	poplar tree only	1%	u, soggy	no
14	second bed	C	90%	u	yes
15	second bed	C, E	98%	u	yes
16	second bed	C, E	100% (33% vsb)	swamp/doesn't drain	no
17	no	G	98%	ok	no
18	vsb plants in drainage	G,E	98%	ok	yes
19	vsb plants in drainage	G,E,Iris	80%	soggy	yes
20	no - vsb before bed	Bamboo, poplar trees	100%	soggy, house elevated	yes
21	no	G, E	70%	wet & soggy	no
22	no	100% no vsb	100% no vsb	u	no
23	second bed	C, E, G	100%	elevated house & first bed	no
			C = canna lily		
			E = elephant ears	u = unsuitable	
			G = ginger		
			Cat = cattail

Figure 22. Site 1 View a (scale = 1 decameter between lines)

Figure 23. Site 1 View b (scale = 1 decameter between lines)

Figure 24. Site 2 View a

(scale = 1 decameter between lines)

Figure 25. Site 2 View b

(scale = 1 decameter between lines)

Figure 26. Site 3

(scale = 1 decameter between lines)

Figure 27. Site 4

(scale = 1 decameter between lines)

Figure 28. Site 5

(scale = 1 decameter between lines)

Figure 29. Site 6

(scale = 1 decameter between lines)

Figure 30. Site 7 View a

(scale = 1 decameter between lines)

Figure 31. Site 7 View b

(scale = 1 decameter between lines)

Figure 32. Site 8

(scale = 1 decameter between lines)

Figure 33. Site 9

(scale = 1 decameter between lines)

Figure 34. Site 10

(scale = 1 decameter between lines)

Figure 35. Site 11

(scale = 1 decameter between lines)

Figure 36. Site 12 View a

(scale = 1 decameter between lines)

Figure 37. Site 12 View b

(scale = 1 decameter between lines)

Figure 38. Site 13 View a

(scale = 1 decameter between lines)

Figure 39. Site 13 View b

(scale = 1 decameter between lines)

Figure 40. Site 14 View a (scale = 1 decameter between lines)

Figure 41. Site 14 View b (scale = 1 decameter between lines)

Figure 42. Site 15 View a

(scale = 1 decameter between lines)

Figure 43. Site 15 View b

(scale = 1 decameter between lines)

Figure 44. Site 16 View a (scale = 1 decameter between lines)

Figure 45. Site 16 View b (scale = 1 decameter between lines)

Figure 46. Site 17

(scale = 1 decameter between lines)

Figure 47. Site 18

(scale = 1 decameter between lines)

Figure 48. Site 19

(scale = 1 decameter between lines)

Figure 49. Site 20

(scale = 1 decameter between lines)

Figure 50. Site 21

(scale = 1 decameter between lines)

Figure 51. Site 22

(scale = 1 decameter between lines)

Figure 52. Site 23 View a

(scale = 1 decameter between lines)

Figure 53. Site 23 View b

(scale = 1 decameter between lines)