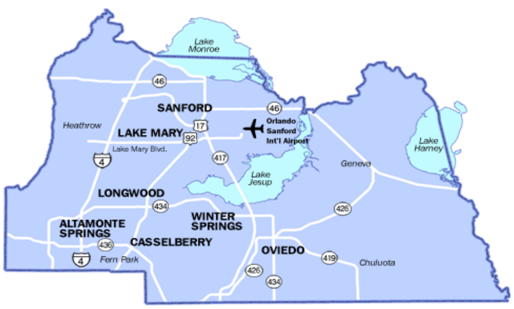
Final Report

Feasibility Study of Waste Tire Use in Pollution Control for Stormwater Management, Drainfields and Water Conservation in Florida

A Research Program of Seminole County, Florida Department of Environmental Protection and the Stormwater Management Academy



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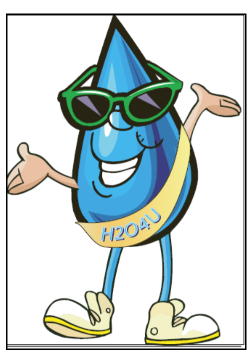

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EXECUTIVE SUMMARY

Seminole County and the Stormwater Management Academy at the University of Central Florida (UCF) benchmarked an innovative use for waste tires in stormwater management. The springboard for this work is based on documented use of processed waste tires as tire crumb for limited pollution control demonstrations when used under golf course and other playing fields. The purpose of this investigation is to perform pollution control effectiveness studies for the specific use of processed waste tires in stormwater treatment and septic tank drain field facilities.

The targeted materials/sectors for this project are Waste Tires requiring final disposal, per HB 851 modified Section 403.709(5), F.S. Furthermore, source reduction (reuse) of Waste Tires and pollution control are mutual benefits of the reuse projects.

Stormwater facilities using recycled tire crumb in the management of runoff from stormwater is documented by laboratory methods as well as full scale operations for the effluent from wet detention ponds, exfiltration trenches, and seepage from pervious concrete. The UCF Stormwater Management Academy provides the experimental facilities and manpower for the research using the processed waste tires as the media collection device. Issues such as toxicity, removal efficiencies, life expectancies, cost, and other pertinent factors are documented.

Laboratory acute toxicity studies to document safe environmental use of the processed tires are presented first. The results of the acute toxicity tests indicate no lethal concentrations at expected tire concentration use.

The remaining experiments demonstrated using laboratory and field testing the application of tire crumb mixes for pollution control. Laboratory studies are completed to demonstrate the use of tire crumb in septic tank drain fields. From these laboratory studies, mixtures of tire crumb show promise in reducing nutrients from septic tank drain fields.

The effluent from a wet detention pond is treated using an up-flow filter that has a mixture of tire crumb. The results indicate additional nutrient removal at low nutrient concentrations or a marginal removal not possible with a wet detention facility. The expected concentration of tire crumb used in the up-flow filter for discharges from a wet detention pond is much lower than the Lethal Concentration for 50% kill (LC50) or the acute toxicity.

Tire crumb is also demonstrated to remove pollution from beneath pervious concrete and within an exfiltration facility. The results provide an option for additional pollution removal before the effluent waters are discharged into ground waters.

Findings from this research provide guidance on the applicability of waste tires for use in stormwater facilities and septic tank drain fields for pollution control in Florida. Environmental benefits include water pollution control and water conservation. The use of waste tires for stormwater management and septic tank drain fields helps reduce pollutant mass necessary to meet Total Maximum Daily Load (TMDL) target levels.

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CHAPTER 1 – INTRODUCTION

Additional removal of pollutant mass may be needed to improve the quality of some of our State waters. To provide an alternative for removal, crumb rubber from waste tires is mixed with other media to provide for possible pollution control. The mixture is believed to offer a solution for the reduction of pollution mass.

To find solutions, students and faculty of the Stormwater Management Academy at the University of Central Florida provide the investigative laboratory and field skills under the direction of the Seminole County Publics Works Department. This partnership proved highly qualified to conduct, and evaluate research in the use of tire waste materials.

Processed waste tires for pollution control are not among the uses by the waste tire processing facilities cited in the "Waste Tires in Florida, State of the State, March 24, 2004" Report (FDEP, 2004). Finding new applications for used automobile tires is increasingly important with the amount of used tires generated per year. Annually, 16,000,000 automobile, light truck, and smaller tires plus 900,000 medium truck and larger tires were removed from vehicles in Florida in 2007. Adjusted for weight, this is an equivalent 20,500,000 passenger tire equivalents (FDEP, 2008).

Crumb rubber is made from the discarded tires and is a term used to describe recycled rubber in coffee grain size particles. Used tires can be typically ground into two different classes of tire crumb, 10 mesh and smaller and 20 mesh and larger. The 20 mesh size is the one used in this research.

1.1 Background Studies Related to Pollution Control

A potential use of tire crumb is as a filter in pollution control applications. Past studies have shown that tire crumb can be used as an effective filter medium achieving similar results compared to using a sand/anthracite filter to remove turbidity and suspended solids (Xie, 2007). It was also indicated that the head loss associated with running water through tire crumb as opposed to the standard sand/anthracite media is significantly less. The premise of this report is that tire crumb has the capacity to remove nutrients from waste streams. However, toxic effects on receiving waters must also be documented.

A potential use of tire crumb, though small in comparison to rubberized asphalt, is the use as a filter in stormwater applications. Studies have shown that tire crumb can be used as an effective filter medium achieving similar results when used as a pollution control media on green roofs and within other stormwater controls (Wanielista, 2008). It was also indicated that the head loss associated with running water through tire crumb as opposed to the standard sand/anthracite media is significantly less (Ryan, 2008). Using crumb rubber for wastewater filtration was also shown to be additionally beneficial by reducing capital and operational costs (Xie, 2007).

Tire crumb was also tested to document pollution control when used in the filtration of ballast water. It performed favorably in the removal of turbidity, particulates, phytoplankton, and zooplankton. The greatest removal efficiencies were experienced with the smallest media sizes, ranging from 0.5 to 1.2 mm though sizes up to 4 mm were still found to be effective. The study also found that the use of crumb rubber filters was additionally beneficial, requiring less backwash water than other filter media (Tang et al., 2006).

Tests were conducted on the feasibility of using tire crumb to replace pea gravel on putting green golf courses. In this study, traditional pea gravel was replaced with equally sized tire crumb in simulated putting green columns. It was observed that tire crumb helped to significantly reduce nitrate leaching. This led to the conclusion that using tire crumb as a distinct sub-layer beneath sand-based root zones can help reduce nitrogen contamination of water bodies by preventing nitrogen from migrating unrestricted. This study also made a very important observation for putting green applications in that tire crumb did not adversely affect the establishment, density, quality or color of the grass.

Research has shown that there is also potential to use granulated discarded tires to remove organic and inorganic contaminants from wastewater. One of the components of automobile tires is carbon black, which functions similar to activated carbon. Tire crumb generally contains 27 to 33 percent carbon black making it a good sorbent that can effectively remove dissolved organic substances (Gunasekara et al., 2000). It was found that ground, discarded tire rubber has great potential for absorbing organic compounds such as naphthalene and toluene, which are present in many contaminated sites and are considered threats to human health.

Another potential application utilizes recycled tires in erosion control. In California, several discarded tire erosion control applications have been designed and implemented. Tires have been used in applications such as reinforcing unstable highway shoulders or protecting channel slopes (Jan et al., 1998). In this application, whole tires are typically used as opposed to ground tires. To form a stable frame, the tires are generally banded together and then either partially or completely buried.

1.2 Objectives

Seminole County's recycling/waste reduction of 400 tons of waste tires in 2004 was significant. However, environmental challenges still facing the County are to find: 1) a cost effective alternative that can be used to reduce pollution from septic tanks and stormwater drainage. Waste tires may become valued for stormwater and septic tank pollution control; 2) an environmental use of waste tires that would encourage additional waste tire processing; and 3) a widespread use that is safe in terms of environmental impact and that would provide application for a variety of uses on public and private lands. Thus the objectives of this research are:

1. To observe potential adverse effects and consequences when using tire crumb in pollution control facilities. The measure of adverse effects is acute toxicity.
2. To document the pollution removal effectiveness of a laboratory pilot scale facility using septic tank effluent waters. A septic tank drain field is simulated in the pilot scale facility.
3. To document the pollution removal effectiveness of full scale stormwater management facilities augmented with waste tires. The facilities are:
    a. An upflow filter receiving detained water skimmed from a wet pond.
    b. A pervious concrete parking lot.
    c. An exfiltration tank.

The targeted materials/sectors for this project are WASTE TIRES requiring final disposal, per HB 851 modified Section 403.709(5), F.S. Furthermore, source reduction (reuse) of WASTE TIRES is the sole target of the proposed project.

1.3 Limitations

The results are constrained by the location and climate of Florida. The toxicity testing is limited to acute toxicity. Three field applications are presented. The drain field for septic tanks was not field tested under natural environmental conditions because of difficulties in securing a permit for a site and the time and monetary limitations of the grant.

1.4 Outline of Report

This report consists of six chapters. Provided in the first chapter is an introduction to the topic and also a description of the research objectives. Toxicity testing and the standards for the testing with various control parameters encountered are in chapter two (Baldassari, 2008). In the next four chapters applications with their pollution control results are presented. Chapter three includes the results of laboratory pilot studies for septic tank drain field use (Shah, 2007). In chapter four, the results of a field installation for the effluent from a wet detention pond are presented (Ryan, 2008). In chapter five, the results of tire crumb use under pervious pavement are shown (Wanielista, 2008a). In chapter six, the last field application and results for use in an exfiltration tank are demonstrated (Rivera, 2008).

All of the chapters but the first are arranged to have background, results, summary, conclusion, recommendations and reference sections. This is done for clarity in presentation and to make it more convenient as a complete reference for each of the investigations.

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CHAPTER 2 – TOXICITY TESTING

2.1 Introduction

Used tires in the form of tire crumb are proposed as pollution control media in stormwater applications including pervious pavement sub bases, green roof growth media, and in upflow filters. Wanielista et al. (2008) found the use of recycled tires as tire crumb can significantly decrease the concentration of ortho phosphorus and total phosphorus in water flowing through a tire crumb mixed with other soils. A decrease in nitrate, nitrite, and NH_3 was also observed. Using tire crumb to decrease limiting nutrients can minimize impacts on ecology while reducing the human footprint left by used tires.

2.2 Objective

The focus of the information in this chapter is to test the acute toxicity of tire crumb from used automobile tires in aquatic systems. A Lethal Concentration for 50% kill (LC50) is used. For the purpose of toxicity testing, an extreme tire crumb load is analyzed. This allows the determination of acute toxicity that is not ecosystem specific and that can be applied to different situations if the tire crumb loading is known.

2.3 Limitations

Toxicity testing is one method of assessing the potential ecological impact of tire crumb. A Lethal Concentration for 50% kill (LC50) measures the relative acute toxicity of a substance introduced to a natural environment over a short period (minutes to days) of time. Though considered an effective and acceptable measure of acute toxicity, there is one major limitation, namely insight into the long-term effect of tire crumb. However, Blrkholz and others (2003) found that no DNA and chromosome damaging chemicals are present in tire crumb.

Another limitation is how much exposure there is to tire crumb in the environment and exposure to test organisms. It is difficult to determine how much crumb rubber is deposited in the environment from its various uses over time.

2.4 Toxicity of Waste Tires

Tire crumb is composed of 85 percent carbon, 10 to 15 percent ferric material, and 0.9 to 1.25 percent sulfur. Though most steel, fiber, and other contaminants are removed from the used tires prior to recycling, they may be present in tire crumb in trace amounts (Global Tire Recycling, 1998). When tire crumb is allowed to equilibrate with water, there is potential for known toxic chemicals such as zinc, copper, chromium, and lead to leach into the water. Whether the levels of known toxins will be high enough to cause a toxic effect is unknown.

One study tested tires from different applications and life stages. These included both new and road-worn tires as well as tires previously used as a floating breakwater to protect marine structures from wind and waves. Whole tires were immersed in 300 L of water and samples were taken at 5, 10, 20 and 40 days to study their static lethality. It was found that the leachate created from the used tires was more lethal to rainbow trout than the leachate created from new tires. It was also found that the leachate was toxic to rainbow trout after the tires were removed from the water indicating that the toxicants degraded very slowly. Neither of these leachates was found to be toxic to fathead minnows. In this study, it was reported that leachate obtained from floating breakwater tires was not toxic to any species (Day et al., 1993). Due to the nature of breakwater applications, the lack of toxicity could be indicative of toxic substances leaching from the breakwater tires prior to the start of the experiment.

Another way tires can impact the environment is through the accumulation of tire dust, often called tire debris, which is formed by the degradation of tire tread while driving. Tire debris has a very complex chemical composition and a very large surface area. Some of its components are water-soluble and can be easily leached. A certain quantity of zinc is released by tire debris when it rains, which is particularly soluble at low pH values and may be carried in stormwater runoff. Many reports have identified zinc as the major toxicant in aquatic environments when automobile tires are utilized (Guiltier et al., 2005).

In one study reported was the effect of tire debris on living organisms in a laboratory setting under controlled conditions as well as under similar conditions to what would be found in the environment. The particles used in the laboratory had similar shape and dimension to those collected in ambient air. The leachates were tested on *Raphidocelis subcapitata, Daphnia magna,* and *Xenopus laevis* developing embryos (Guiltier et al., 2005). In this study, it was found that pH, dimension of the particles and particle aggregation all influenced the quality of the leachate. It is suggested that the toxicity is not only related to the amount of zinc that is leached out, but also the amount of organic chemical compounds (Guiltier et al., 2005).

To determine the particle size distribution that can be expected in the environment as a result of normal tire wear, wear tests were conducted on new vehicle tires and the resultant particles were analyzed. It was found that particles were produced in the range of 10 to 80 μm (Guiltier et al., 2005). Then, leachate was produced using the lab created tire particles at a pH of 3, which is the lowest pH value of acid rain caused by anthropogenic activities (Guiltier et al., 2005). In order to obtain a variety of leachates, 50 and 100 grams of tire debris were put in 1 L glass bottles containing water at pH ranging from 3 to 7. The bottles were put in a mechanical shaker where they were shaken for 24 hours at a speed of 50 rpm. In addition, different concentrations of the leachate at a pH of 3 were prepared (Guiltier et al., 2005).

This allowed for the quantification of zinc leached from tire debris at different pHs. The quantity of zinc was measured in the undiluted samples. Each leachate was tested for toxicity on living organisms at concentrations of 1, 10, 50, and 100 percent (Guiltier et al., 2005). As would be expected, the zinc values for lower pH were found to be higher than those associated with higher pH.

Both the quantity of zinc and the toxicity were found to be higher in solutions made with 50 grams of tire debris per liter of water than with 100 g/L. It was noted that there is a non-linear relationship between the quantity of tire debris and the concentration of zinc in the leachate. It was found that with a higher concentration of tire debris, the tire debris tends to form an aggregate that exposes a lower surface area and inhibits leaching (Guiltier et al., 2005).

Leachates created using tire wear were tested on *Daphnia magna*, commonly called water fleas, to determine the potential toxicity. In order to test if toxic compounds leach from tires, rubber was allowed to equilibrate with dilution water for 72 hours at 44°C, which was considered the worst case scenario as leaching is known to occur more rapidly at higher temperatures and would represent the temperature of a road on a hot summer day. In the filtered samples, it was determined that most of the toxicity resulted from non-polar organic compounds. It was also found that the toxicity of all leachates increased with exposure time (Wik et al., 2006).

Other studies using *D. magna* as test organisms have found that leachate derived from whole tires, about 33 grams rubber/liter, was non lethal while tire pieces leached at 200 grams per liter were found to have a 72 hour LC50 of 12.5%, or 25 grams per liter. One of the reasons for this difference in toxicity between the different forms of rubber is that metals are often leached out of cut or shredded tires, but not out of whole tires (Wik et al., 2006).

In the same study, it was found that when the water containing the daphnids was placed underneath a UV light for 2 hours, several of the leachates showed a significant increase in toxicity (Wik et al., 2006). It is suggested that the photo-enhanced toxicity of the unfiltered samples is caused by PAHs, which are known to be photo toxic. Though, it was found that the ratios of photo-enhanced toxicity did not vary significantly from the controls.

There is high variability between the toxicity found in this study and in others, which could be due to differing methods and materials. Variability has been found to be the result of the salinity of the test water, the age of the tested tires, as well as the different rubber formula used by different tire manufacturers. When reviewing the content of 29 different brands and sizes of tires, significant variation was found in the amount of cobalt, aluminum, and lead (Wik et al., 2006).

The methods of which leachate is made can vary the potency greatly. The pH used to make the leachate can determine the concentration of metals and PAHs that leaches out of the tires. In terms of making leachate, it was also pointed out that leachate prepared at lower loading rates gives higher toxicity. This puts even more importance on the procedure for preparing the leachate because it is apparent that allowing different amounts of tire pieces to equilibrate with water will lead to different leachate concentrations (Wik et al., 2006). The zinc concentration for the different tire leachates ranged from 110 to 590 μg/l (Wik et al., 2006).

Acute Chemical Sensitivity of Freshwater Organisms

Martins, et al (2004), found that acute toxicity assays with *D. magna* and *D. rerio* can give important and relevant information concerning the possible human oral chronic intoxication and could be used as an initial screening of toxicity.

In a study, it was found that some substances were markedly more toxic to one of the test species than the other. For the majority of such instances, substances are more toxic to *D. magna* than to *D. rerio*. Very rarely was it found that a substance was more toxic to *D. rerio* than to *D. magna*. For the chemicals that are more toxic to *D. magna*, crustaceans could be used to predict acute toxicity to fish. In the instance where *D. magna* is used to predict toxicity in fish, it is beneficial that tests involving *D. magna* have a 48-hour exposure time compared to a 96-hour exposure time in *D. rerio*. This could be extremely beneficial when faster answers are needed when facing potential environmental contamination (Martins et al., 2004).

Chronic Chemical Sensitivity of Freshwater Organisms

Currently, when studying the toxicology of a pollutant, the main focus is on the mortality of the test specimens. However, environmental pollutants can negatively impact aquatic ecosystems at much lower concentrations than necessary to kill a specimen. Many pollutants can have an impact on the physiology of animals, which may impair their ability to survive in the long term. Pollutants could alter basic life functional ability, such as impairing the ability to either hunt prey or hide from predatory animals.

Traditionally, regulatory guidelines are based on lethality tests, such as the 96-hour LC50. These tests fail to examine what could happen to an aquatic system if lower concentrations of the pollutant are allowed to enter the system. Even if the test specimens are not killed by the contaminant, their normal behavior may be altered, preventing them from being able to function in an ecological context (Scott et al., 2004).

There is much known about the physiology of fish and these normal behaviors can be observed and quantified in controlled environments. For this reason, fish behavioral indicators may be used to monitor levels of environmental contamination. Toxicants may disrupt or initiate specific physiological sequences, causing inappropriate behavioral responses, which could result in detrimental behavioral alterations and have severe implications for survival (Scott et al., 2004).

The majority of research has discussed direct behavioral responses of fish. Only recently has research turned to the impact on the more complex behaviors, such as social hierarchies and reproduction. These less obvious behavioral alterations can pose a much larger threat to the overall health of the ecosystem. Behavioral indicators are likely to be ideal for assessing sub-lethal impacts of pollutants (Scott et al., 2004).

Predator-prey interactions can be altered by sub-lethal doses of a pollutant by altering the ability of prey to avoid a predator by altering their response to a potential predation risk, such as altering the schooling abilities of a group. This increase in the likelihood of a predator catching a prey increases the contamination level as you move up the food chain (Scott et al., 2004). This could essentially disrupt an entire aquatic ecosystem.

Pollutants can also alter reproduction procedures. Spawning of fish involves many interrelated steps. For instance, if two connected life functions were to include the defense of spawning site and nest building and one of these steps were to either fail to occur in a timely manner or fail to occur all together, the following steps, such as courtship and spawning, could also fail to occur, altering the reproductive success of a species. Though most studies have shown that nest building, spawning, and courtship behaviors are frequently interrupted by pollutants such as trace metals and organic pollutants, behaviors such as spawning site selection and natal homing have been altered by pollutants (Scott et al., 2004).

Scott et al. (2004) has shown that environmental pollutants can also effect the social interactions associated with territory and dominance of fish. At different concentrations, fish would either show greater or lesser levels of agonistic interactions thus disrupting the social hierarchy of fish populations. The hierarchy of fish populations is established to allow the top fish optimal feeding and larger growth rate. This hierarchy has been shown to promote population stability.

Choice of Species

Model species are chosen so that information obtained from examining them can be used to generalize about other groups of species. For this reason, the species chosen to be model species are typically non-specialized. The behaviors necessary for fish survival are dependent on many physiological systems including sensory, hormonal, neurological and metabolic. The impact of pollutants on each of the systems should be considered.

It is important to test a variety of suitably representative organisms to test of the toxicity of chemicals to understand their potential effects on both humans and the health of the environment (Teather et al., 2006).

A variety of fish is used to test the toxicity of chemicals, including fathead minnows and rainbow trout. However, the sensitivity each individual specimen varies according to the type and concentration of toxicant. Comparing the sensitivity of each specimen to different toxicants is expected to be useful for predicting the responses of different species to untested chemicals. Some species may react to chemicals in a way that is specific to the particular species or some may react to a different degree than others. For instance, certain species absorb, metabolize, or excrete chemicals more than others. Generalizing the impact a pollutant may have on an ecosystem based on the results of one species may have negative implications.

According to Teather and Parrott (2006), it remains unclear whether the difference in species sensitivity remains consistent across an array of chemicals. After reviewing all studies that tested the LC50 of a chemical, it was found that the three most common test specimens were fathead minnows, rainbow trout, and bluegill sunfish. After analyzing all of the previous studies that contained both fathead minnows and rainbow trout, Teather and Parrott (2006) determined that fathead minnows are only about forty-two percent as sensitive as rainbow trout, making the rainbow trout quite a bit more sensitive to most chemicals than the fathead minnows. If studies were available that contained rainbow trout and bluegill sunfish, guppies or goldfish, the results were also analyzed. It was found that rainbow trout were significantly more sensitive to the acute effects of the chemicals tested.

Once it was determined that rainbow trout do, overall, exhibit increased sensitivity to chemicals, the studies were analyzed to determine if the rainbow trout and fathead minnow exhibit differential sensitivity to different classes of chemicals. Teather and Parrott (2006) found that trout were almost 10 times as sensitive to metals, fathead minnows were significantly more sensitive to hydrocarbons, and the two species showed equal sensitivity to CH-chains and phthalates. Though the information obtained from the various studies shows the rainbow trout is dramatically more sensitive to metals, there is very little information concerning the age of the test specimens. Generally, juveniles exhibit greater sensitivity to toxicants.

An interesting example of the varying sensitivity of different species is the relative toxicity of waste tires to rainbow trout compared to *D. magna*. Previous literature found that leachate obtained by leaving scrap tire in water for 60 days caused 100 percent mortality to rainbow trout within 24 hours. However, this same leachate was found to be nonlethal to *D. magna* (Guiltier et al., 2005).

Bioassays and Toxicity Testing

Toxicity tests are vital to examining questionable compounds and their potential to harm life in aquatic systems. For this reason, the Environmental Protection Agency recognizes several different exposure assessment models, including the LC50, to examine aquatic sensitivity and the impact a pollutant may have on a natural body of water. Exposure assessment models can help reduce the reliance on uncertainty factors in ecological risk assessment ("LC50," 2007).

A toxicity test exposes carefully chosen indicator organisms to different concentrations of a questionable pollutant to observe the pollutants effect on the organisms ("Bioassay," 2007). A toxicity test can measure either acute or chronic effects. Acute toxicity tests measure how well an organism can survive and chronic tests measure sub-lethal effects, including the effect on an organism's ability to grow and reproduce ("Toxicity Testing," 2007). Both acute and chronic toxicity tests are important to protect the overall health of an ecosystem.

Acute tests can run for twenty-four, forty-eight, or ninety-six hours. LC50 is an acute toxicity test that specifically measures the concentration of a pollutant in an aquatic system that is lethal to fifty percent of the test animals in a given amount of time, generally 96 hours.

Short-term chronic tests can run from seven to nine days, depending on the test organism. The most common test organisms for both acute and chronic testing include water fleas, fathead minnows, bannerfin shiners, mysid shrimp, and tidewater silversides ("Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms," 2006).

As with many tests, the number and concentration of dilutions and replicates directly affects the quality of the data. To obtain quality data, the maximum feasible number of dilutions, test organisms, and test replicates are necessary. However, with a bioassay, there are far more factors involved in quality assurance. For instance, the initial condition of the test organisms can greatly impact the test results. For best results, it is important to be consistent with the groups tested, but also to have test samples with organisms of various ages and sizes ("Toxicity Testing," 2006).

In addition to maintaining healthy organisms at the start of a bioassay, it is important to maintain healthy organisms throughout the duration. The test organisms must be handled very carefully at the beginning of the test to not injure them before exposing them to the test concentrations. The organisms must be handled carefully during the test while the test chamber is cleaned and chemical adjustments are made if necessary. They must also be fed regularly ("Toxicity Testing," 2006).

Though a high level of quality may be maintained by the source of test organisms, there are many different areas in which toxicity test variability may be introduced and minimized with proper attention. For instance, shipping and handling samples in a consistent manner can reduce response variations and consistency in measurement methods will help to reduce variability.

Toxicity Test Guidelines

The U.S. Environmental Protection Agency (EPA) developed a manual for measuring acute toxicity of effluents and receiving waters to freshwater organisms. Standard Methods also developed guidelines for the testing of toxicity on freshwater species. Section 8910 Fish and Section 8020 Quality Assurance and Quality Control in Laboratory Toxicity Tests were both referenced (American Public Health Association, 2005). The main difference in the two guidelines is the EPA manual is meant for use in the NPDES Permits Program and is significantly more detailed while Standard Methods provides more general toxicity test guidelines. It should be noted that much of the Standard Methods procedure comes from the EPA's Methods of Measuring the Acute Toxicity of Effluents and Receiving Waters of Freshwater and Marine Organisms.

After detailed review of both guidelines, it is apparent that certain components be included in any toxicity test. Of all the guidelines, two components appear to be the most substantial. The first component of interest is the age and species of the test specimens. It is important that the test species be closely related to a species found in the relevant aquatic systems. It is also important that the species be easily cultured in the laboratory and sensitive to a variety of pollutants. In this instance, fathead minnows have been selected. The age of the specimens is also important as organisms are more sensitive to toxicants in the early life.

The second component of interest is the overall setup of the experiment. Both guidelines recommend that each test should include a control group and five different concentrations of the toxicant. For each concentration, it is further recommended that a minimum of 20 specimens be tested within a minimum of 2 test chambers made of tempered glass. All testing shall be performed based on these two main components. Table 2.1 presents a summary of the required and recommended test conditions from EPA's Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organisms.

Table 2.1: Summary of Test Conditions

Summary of Test Conditions and Test Acceptability Criteria for Fathead Minnow, *Pimephales Promelas*, Acute Toxicity Tests with Effluents and Receiving Waters	
Test type	Static non-renewal, static renewal, or flow-through
Test duration	24, 48, or 96 h
Temperature	20°C ± 1°C; or 25°C ± 1°C (recommended). Test temperatures must not deviate by more than 3°C during the test (required)
Light quality	Ambient laboratory illumination (recommended)
Light intensity	10-20 μE/m2/s (50-100 ft-c) (ambient laboratory levels) (recommended)
Photoperiod	16 h light, 8 h darkness (recommended)
Test chamber size	250 mL (recommended minimum)
Test solution volume	200 mL (recommended minimum)

Renewal of test solutions	After 48 hours (required minimum)
Age of test organisms	1-14 days; less than or equal to 24-h range in age (required)
No. organisms per test chamber	10 for effluent and receiving water tests (required minimum)
No. replicate chambers per concentrations	2 for effluent tests (required minimum) 4 for receiving water tests (required minimum)
Feeding regime	*Artemia* nauplii are made available while holding prior to the test
Test chamber cleaning	Cleaning not required
Test solution aeration	None, unless DO concentration falls below 4.0 mg/L
Dilution water	Moderately hard synthetic water, receiving water, ground water, or synthetic water, modified to reflect receiving water hardness (available options)
Test concentrations	Effluents: 5 and a control (required minimum)
Dilution series	Effluents: ≥0.5 dilution series (recommended)
Endpoint	Mortality (required)
Sampling and sampling holding requirements	Receiving Waters: Grab or composite sample first used within 36 h of completion of the sampling period (recommended)
Sample volume required	2 L for effluents and receiving waters (recommended)
Test acceptability criterion	90% or greater survival in controls (required)

1 Adapted from US EPA (2002)

2.5 Toxicity Testing Approach

One of the problems faced in determining the toxicity of crumb rubber is finding the best method for exposing the test specimens, in this case fathead minnows, to the rubber. One method is to expose fathead minnows to tire crumb by allowing the tire crumb to equilibrate with water for 72 hours with the aid of an air pump assuming any toxic substances should leach from the tire crumb within this period of time. At the end of 72 hours, the tire crumb will be removed from the water creating a filtrate that can then be easily tested for toxicity at varying concentrations.

One limitation in this approach is the length of time chosen for equilibration. It is necessary that the equilibration time be sufficient to allow toxic substances to leach out. However, it is also important that the equilibration period not be unnecessarily long such that testing cannot be completed within a reasonable amount of time. An equilibration time of 90 days, for instance, would require years for testing. Researchers have found 72 hours a sufficient amount of time to allow a substance to equilibrate with water (Wik et al., 2006). To examine the difference in equilibration durations, leachates were allowed to equilibrate for 72 hours and 30 days and their composition analyzed. In Table 2.2, shown is the breakdown of the different filtrates. It should be noted that allowing the tire crumb to equilibrate for 30 days does not significantly change the composition of the filtrate.

For each of the different experiments, 25 grams of crumb rubber per liter of water was used to make the filtrate. In order to determine the magnitude of loading that can be expected, a typical stormwater application of tire crumb was analyzed (Ryan, 2008). Ryan used an upflow filter using 12 ft^3 of media with 45 percent tire crumb in a detention pond with a permanent pool volume of 12 acre-ft, the whole pond will only be exposed to 0.004 grams of tire crumb per liter of pond water. Though it remains unclear whether the average detention pond will be exposed to more or less than 0.004 g/L tire crumb, 25 g/L tire crumb is still considered an extreme load.

Table 2.2: Comparison of Equilibration Times for Tire Crumb Filtrate

	Tire Crumb Filtrate Equilibration Time: 72 hours	Tire Crumb Filtrate Equilibration Time: 30 days
Date	10/22/07	10/22/07
pH S.U.	6.57	6.60
Alkalinity mg/l	14.0	18.0
Copper µg/l	17	19

Lead µg/l	9	9
Barium µg/l	<2	6
Chromium µg/l	2	<2
Zinc µg/l	2878	2714
Iron µg/l	126	146
NOX-N µg/l	18	35
SRP µg/l	1	6
Mercury µg/l	0.11 U	0.11 U
Silver µg/l	0.77 U	0.77 U
Phenol mg/L	0.025 U	0.16
VOC	X	X

For each experiment, the filtrate was tested using four different concentrations and one control. For quality assurance purposes, the tests should be conducted in triplicate, using one aquarium for each of the different test chambers. As a general rule, fish should be allowed a gallon of water per inch of fish. The approximate size of 6 day-old fathead minnows is a quarter of an inch. With EPA's specification of 10 fish per chamber, 2.5 gallon aquariums are sufficient.

To reduce the margin of error due to stress of the organisms, test organisms should be received at 4 days old and tested when the organisms are 6 days old, allowing 2 days for acclimation to testing conditions. This was noted after the first experiments experienced significant loss in all scenarios when using fish without a two-day acclimation period. When the fish are allowed to acclimate for 48 hours, the weaker specimens expire leaving only the healthy specimens to be tested. Due to the age of the organisms, fresh brine shrimp were hatched and fed every day beginning the day of receipt of the test organisms until the end of the test.

Two different sets of data are desired. The first set of data sought after is the raw toxicity of crumb rubber with as little interference as possible. To achieve this, distilled water and tap water are both used, with and without an aquarium buffer and dechlorinator. The second set of data is the effect of tire crumb on natural pond water. In this experiment, water is collected from the Pegasus Pond on the University of Central Florida campus for two different scenarios. The first scenario is regular pond water and the second scenario is pond water after a rainfall event. In this instance, one day and eleven days after a 2.83-inch rain occurred April 6, 2008. For pond water, the total amount is collected within an hour to reduce variability in the sample.

During the course of the experiment, the dissolved oxygen, pH, temperature, and the number of fish alive were observed and recorded. Testing at the beginning and every 24 hours until the completion of the test should be sufficient to determine if loss of life results from high pH or low dissolved oxygen.

2.6 Experimental Design for Toxicity

The tire crumb is allowed to equilibrate with water for 72 hours in 10-gallon aquariums prior to each experiment. An air pump was used to aid in the mixing of the tire crumb. With a capacity of 35 liters, 875 grams of tire crumb is needed for each filtrate aquarium to obtain a concentration of 25 grams per liter. Once the equilibration period finishes, the tire crumb was removed from each aquarium and discarded. Because research has shown that the toxicity of tire crumb may be reduced by exposure to water, tire crumb should not be reused in toxicity testing (Day et al., 1993). It is important that the filtrate aquariums not be in close proximity to the testing aquariums.

It was arranged that 4-day old fathead minnows arrive 48 hours prior to each experiment. Upon arrival, minnows were transferred to a holding chamber in the same water they arrived in. For the next 48 hours, dead and weak minnows are to be culled.

It was also arranged that fresh brine shrimp hatch the day new fish arrive and each day subsequent to their arrival. Young minnows were fed freshly hatched brine shrimp until they are old enough to eat commercial fry food, generally occurring around three weeks of age.

The testing chambers consisted of 2.5-gallon glass aquariums. To accommodate one control group and five different concentrations of filtrate, 18 testing chambers are necessary. The breakdown of the different concentrations is shown in Table 2.3:

Table 2.3: Filtrate Concentration Breakdown

Percent Tire Crumb Filtrate	Filtrate Volume (L)	Water Volume (L)	Total Volume (L)
100	8	0	8
50	4	4	8
25	2	6	8
12.5	1	7	8
6.25	.5	7.5	8

Filters and air pumps are not required. When the filtrate is ready, it is transferred to the testing chambers in the required concentrations with the base of the filtrate used as dilution water. For instance, if tap water is used as the base for the tire crumb filtrate, tap water is used as the dilution water. If it is necessary to use multiple aquariums for the preparation of filtrate, equal volumes are pulled from each of the aquariums when the filtrate is harvested for each of the concentrations.

Once the test chambers were prepared, minnows were added one at a time to each of the chambers until each chamber has 10 minnows. This ensures that the weaker specimens are not caught first and all added to the first chamber. Minnows should be handled using a brine shrimp net to avoid damage during transport. Each minnow should be observed upon transport to ensure they are not harmed during the transport process.

The pH, dissolved oxygen, and temperature should be measured and recorded at zero hours and every 24 hours for a total of 96 hours. The minnows should be observed every 24 hours and expired specimens are culled. Specimens are considered expired when immobile and fail to respond to a stimulus. In this case, creating a gentle movement in the water near the specimen in question creates enough of a stimulus to determine if the specimen has expired.

At the end of each toxicity experiment, all remaining minnows are transferred to a 10-gallon aquarium where they are fed. Testing chambers are all emptied and cleaned.

2.7 Results and Discussion

Distilled Water-Based Filtrates

In Figure 2.1 is illustrated the percent survival of fathead minnows exposed to filtrate prepared using distilled water as a base. For 100 percent tire crumb filtrate, no distilled water is used to dilute the filtrate. However, for 0 percent tire crumb filtrate, minnows are exposed to 100 percent distilled water. The detailed data bases are found in Baldassari (2008).

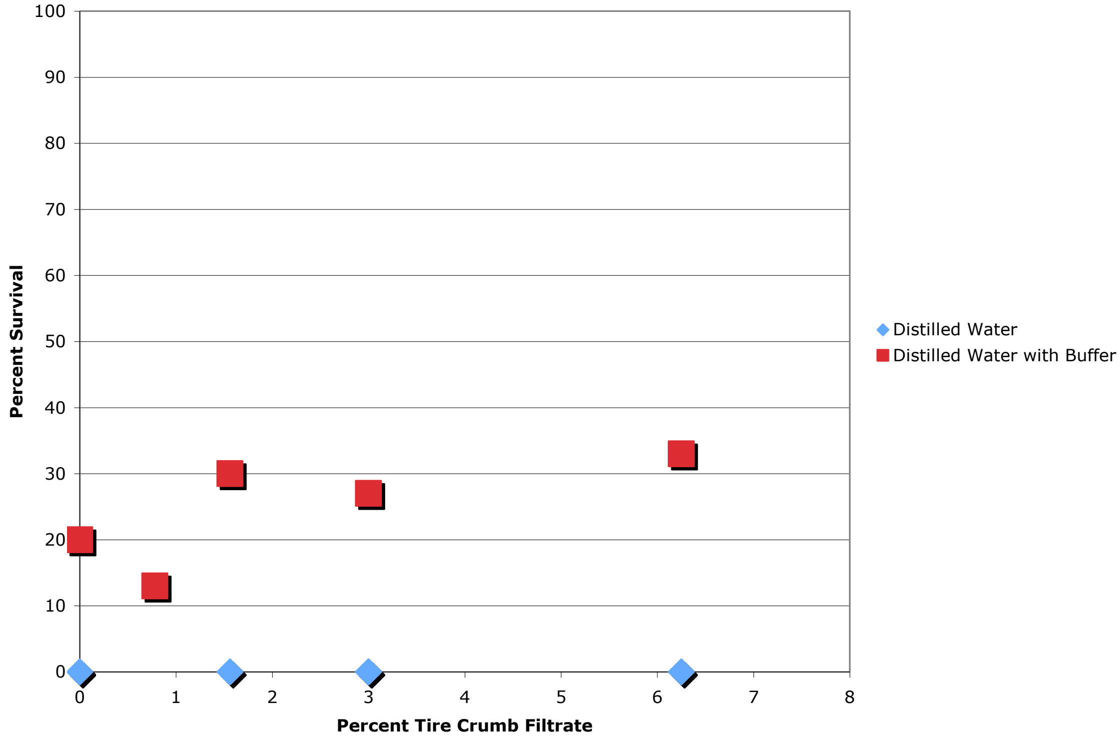

Figure 2.1: Percent Survival for Distilled Water-Based Filtrates

As shown, all concentrations of tire crumb filtrate prepared using distilled water were 100% lethal to fathead minnows, including the control. This is likely due to the lack of essential minerals and buffering capacity that a natural system would contain.

The second data set illustrates the percent survival when exposed to filtrate prepared using distilled water with a buffer as a base. As shown, the survival rates tend to increase with increasing percent of tire crumb filtrate, though the overall survival is still relatively low.

Using distilled water is proven to not be an acceptable method for acute toxicity and thus an LC50 cannot be determined. There is a low level of survival in the control group as well as the experimental groups.

Tap Water-Based Filtrates

In Figure 2.2 are illustrated the two data sets for the survival of fathead minnows exposed to filtrate prepared using tap water as a base. The same method of preparing the different dilutions for percent tire crumb filtrate was used with 100 percent tire crumb filtrate consisting of an undiluted sample. For both the tap water with and without buffer, survival rates tended to increase with increasing tire crumb filtrate concentration.

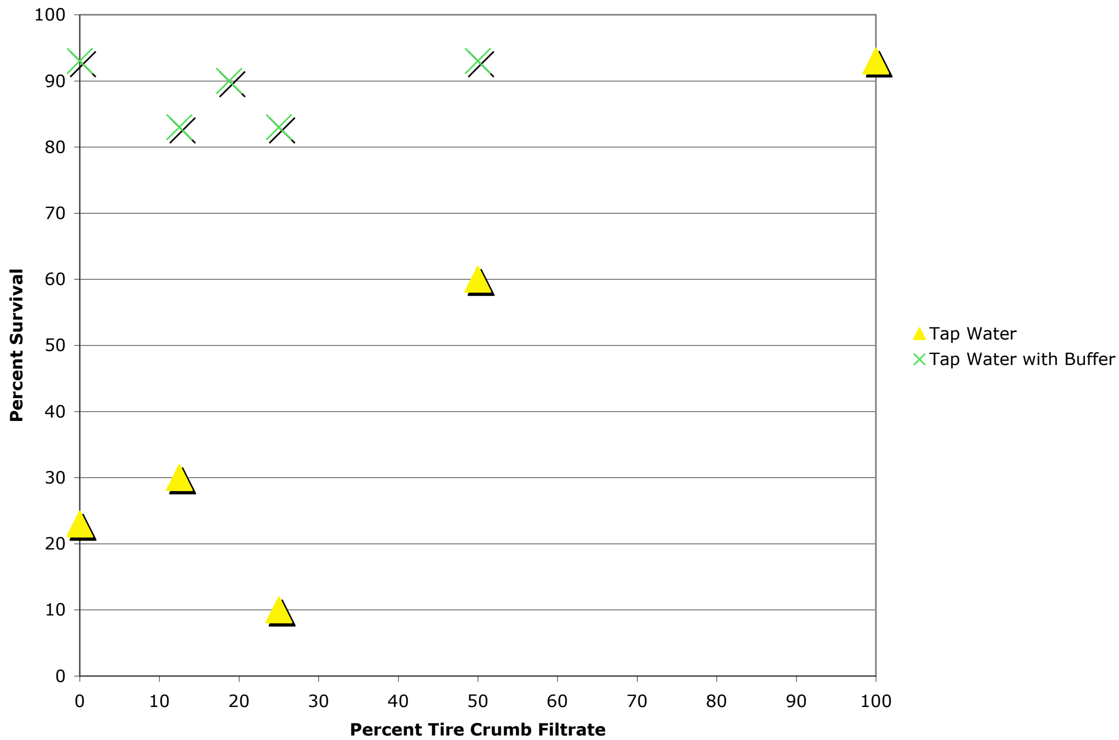

Figure 2.2: Percent Survival for "Tap" Water-Based Filtrates

The use of "Tap" water is not recommended for testing as demonstrated in Figure 2.2. Again, essential nutrients for survival may not be present. Though the tap water without buffer experienced survival rates near fifty percent, an LC50 cannot be determined due to the low survival rate of the control group.

Pond Water-Based Filtrates

In figure 2.3 is illustrated the percent survival of fathead minnows exposed to filtrate prepared using pond water as a base. For lower concentrations of tire crumb filtrate, the pond water collected immediately after the storm exhibits higher percent survival than the pond water collected 11 days after the storm. However, for 100 percent tire crumb filtrate, the pond water immediately after the storm shows a lower percent survival.

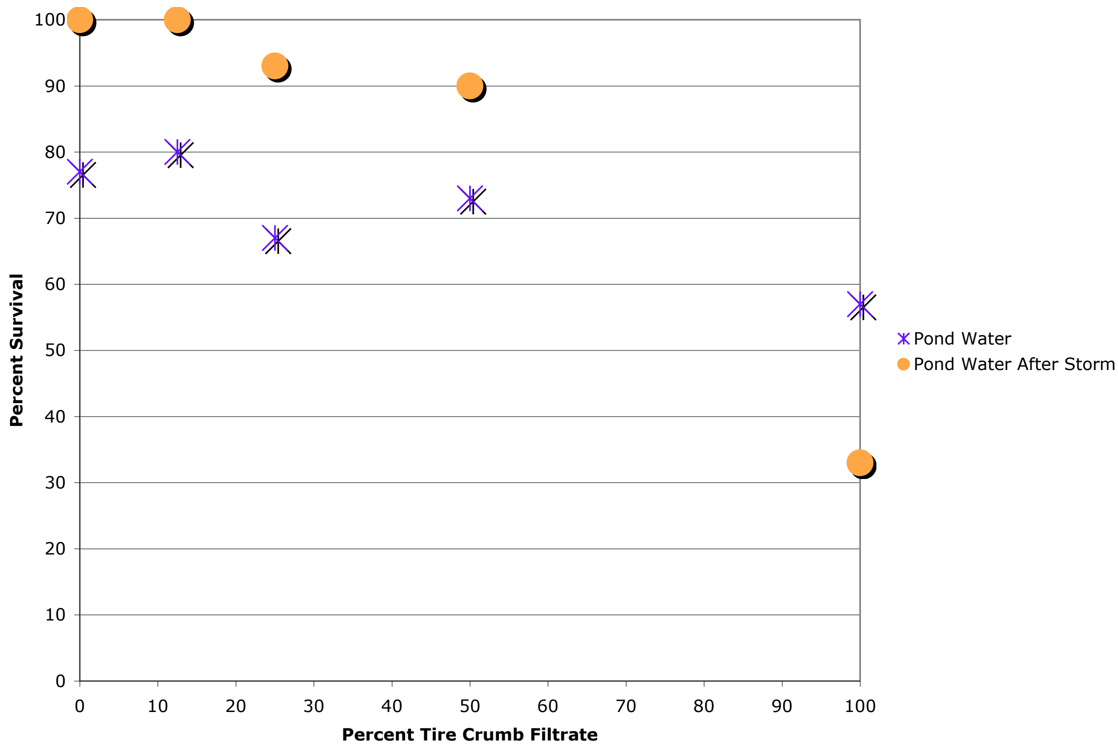

Figure 2.3: Percent Survival for Pond Water-Based Filtrates

An LC50 for typical pond water was not found because the survival rate was consistently greater than fifty. However, an LC50 of 100 percent tire crumb filtrate prepared with 25 grams per liter pond water immediately after a storm was found.

2.8 Summary

With a growing number of pollution control applications for tire crumb, it has become increasingly important to test for toxicity of tire crumb to aquatic life. Both EPA and Standard Methods provide guidelines for toxicity testing using freshwater organisms.

Because fathead minnows are commonly found in Central Florida ponds, fathead minnows are the selected test species. The fathead minnows are exposed to filtrates created with tire crumb and several types of water as a base. The different types of water include distilled water, distilled water with an aquarium buffer, tap water, tap water with an aquarium buffer, detention pond water and, detention pond water immediately affected by stormwater runoff. Exposing specimens to filtrate with distilled water and tap water as a base intends to find the toxicity of crumb rubber with as little interference as possible. Exposing specimens to filtrate with pond water as a base intends to find the toxicity of crumb rubber in a setting similar to that which the crumb rubber will be applied.

Tire crumb filtrate was prepared by allowing tire crumb to equilibrate with water for 72 hours. The tire crumb was then filtered out. Specimens were exposed to tire crumb filtrate in 2.5-gallon aquariums using three test chambers per concentration. A total of 30 specimens were exposed to each concentration. Every 24 hours during the 96-hour duration, the pH, dissolved oxygen, temperature, and number of live specimens were recorded.

2.9 Conclusions

Tire crumb is not found to be toxic when testing with tap water and distilled water. In tap water and distilled water instances, tire crumb filtrate increased the survival of fathead minnows to greater rates than that experienced in the control chambers. In the case of distilled and tap water, the tire crumb could either offer a constituent necessary for survival, or help to removal a substance that could prevent the survival of fathead minnows.

In detention pond water not effected immediately by stormwater runoff, tire crumb is found to lower the survival rate of fathead minnows, though not low enough to determine the LC50 of tire crumb leachate made with 25 grams per liter of pond water. An LC50 is found when 100 percent tire crumb filtrate is prepared with 25 grams per liter of detention pond water that is collected directly after a storm. It is important to note that a natural body of water will never experience this level of tire crumb loading. In most applications to date, up to .5 grams of tire crumb are used per liter of water. As an example, Ryan (2008) found and in Chapter 4 his findings are repeated in that tire crumb is used in a 12 ft^3 filter with 45 percent tire crumb and a detention pond with pool permanent volume of 12 acre-ft, even if only 1 percent of the detention pond is initially exposed to the tire crumb, it will still only be exposed to 0.43 g/L of tire crumb. It is also important to note that the lower percentages of tire crumb filtrate did not show a significant toxic effect, and the overall load is still greater the exposure that an average detention pond will have.

2.10 Recommendations

Based on the results of this acute toxicity testing with fathead minnows, the use of tire crumb in stormwater management pond applications is an acceptable means of recycling tires and implementing green engineering practices. The other stormwater management in this report discharges to the ground (pervious concrete and exfiltration) so the impact will be further reduced before researching a surface water body. Though an LC50 of 100 percent tire crumb filtrate prepared with 25 grams per liter pond water immediately after a storm was found, tire crumb is considered safe to use with detention pond water. The LC50 found is significantly higher than what can be expected in the environment and is therefore considered non-threatening to aquatic fish.

2.11 Future Research

Testing to determine chronic or long term toxicity may be beneficial. It is not however reasonable based on the high LC50 for acute. Nevertheless, additional research should be conducted to determine how much crumb size rubber actually makes its way into local bodies of water in a long time period. Lacking this knowledge, it is difficult to determine the toxic impact or concentration and mass that may be experienced. If more is known in this regard, a more precise toxicity test may be performed compared to a worst-case scenario. However, it is highly impossible that the leachate from 25 grams per litter can reach a water body and retain the relative concentration. Also, in order to get a representative impact on different species for the toxicity of tire crumb, additional testing may be necessary.

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CHAPTER 3 – LABORATORY SEPTIC TANK DRAIN FIELD

3.1 Introduction

It is generally understood that conventional septic tank and drain field systems may discharge high levels of nitrogen into the ground waters. A family of four will discharge 25 pounds of nitrogen (measured in the form of nitrates) per year into the drain field of a conventional onsite sewage treatment and disposal system (Florida Department of Health, 2004).

Nitrates and phosphorus are the primary pollutants of concern in this research. Nitrates have been detected in some ground and surface water supplies in concentrations greater than public health drinking water limitations. In cases where the concentration of nitrate-nitrogen exceeds the Maximum Contaminant Level (MCL) of 10 mg/L (USDHEW, 1962), as set forth by the U.S. Environmental Protection Agency, water suppliers are required to issue a nitrate alert to users. The use of tire crumb in the drain field may help in reducing nutrient discharges.

For the past twenty years in central Florida, there has been a rise in nitrates in ground waters as measured at some wells (O'Reilly, 2006). Groundwater has the greatest potential for pollution if onsite wastewater disposal systems occur in high density, or are placed in soils with high water tables and/or coarse textures. Since 55-85% of the nitrogen that enters the septic tank is available to ground water (Stoltz and Reneau, 1998) mainly in the form of nitrates, the concentration of nitrogen in the effluent becomes very important in determining how much nitrates reach the groundwater. This can lead to localized levels of nitrate exceeding the MCL of

10 mg/L. In addition, there is a potential impact to receiving water quality in the form of algal growth.

3.2 Objectives

Since parts of Seminole County are in the Wekiva Basin and affect surface water bodies, and there are significant numbers of septic tank systems in the County, the main objective is to study the removal of nitrogen and phosphorus compounds by a tire crumb mix, called Black and Gold Nugget Mix™. This is done in a laboratory column study simulating the drain field with anaerobic conditions and one day hydraulic retention time.

The other objectives include recommending a design for future drain fields and also to determine an estimated cost of the media used in the designed drain field.

3.3 Limitations

The laboratory column research has some limitations which are as follows:

- Daily flow variations and peak flow didn't affect the columns as the columns were dosed once a day.
- The temperature remained constant at about 21°C or 70°F. In case of real world septic tank drain field the temperature is variable and frequently as high as 28°C or 82.4°F. Higher temperatures produce higher denitrification rates (Stanford, 1975). Thus the column resulting nitrogen removal may be lower than actual values.

3.4 Background Drain Field Work

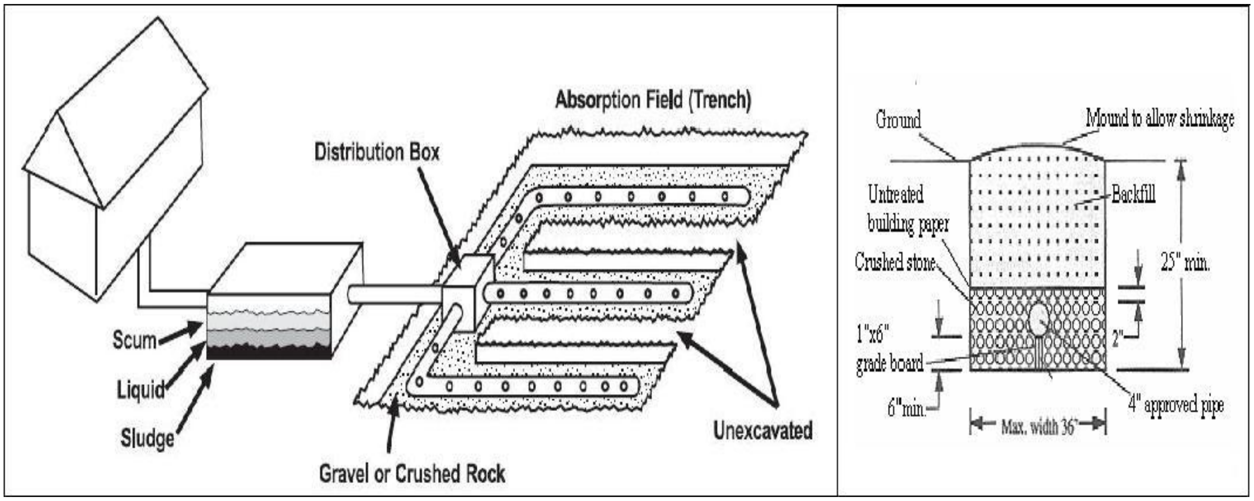
It is anticipated that additional constraints will be placed on a septic tank with drain field as to the removal of nitrogen and phosphorus. Thus it is important to review all options for the ones that will produce cost effective solutions. The use of tire crumb in the drain field is one option. Thus it is important to understand the components of a septic tank and drain field.

The Septic Tank System

Raw wastewater flows into the septic tank where the solids separate from the liquid. Light solids, such as soap suds and fat, float to the top and form a scum layer. This layer remains on top and gradually thickens until you have the tank cleaned. The liquid waste goes into the drain field, while the heavier solids settle to the bottom of the tank where they are gradually decomposed by bacteria. But some non-decomposed solids remain, forming a sludge layer that eventually must be pumped out.

Septic tanks may have one or two compartments. Two-compartment tanks are more efficient in settling solids and are required in some areas for new installations. Tees or baffles at the tank's inlet pipe slow the incoming wastes and reduce disturbance of the settled sludge. A tee or baffle at the outlet keeps the solids or scum in the tank. All tanks should have accessible covers for checking the condition of the baffles and for pumping both compartments.

Further treatment of wastewater occurs in drain field and soil beneath the drain field. The drain field consists of long underground perforated pipes or tiles connected to the septic tank (Figure 3.1.1). The entire septic system can operate by gravity alone, or where topographic considerations require, with inclusion of a lift pump.



(a) (b)

Figure 3.1: Schematics of Drain fields (a) Plan View (b) Cross Section View

Source: (a) USEPA, 2002
(b) http://www.fcs.uga.edu/pubs/gfx/ack2a.gif

The network of pipes is usually laid in gravel-filled trenches (2–3 feet wide), or beds (over 3 feet wide) in the soil. Liquid waste or effluent flows out of the tank and is evenly distributed into the drain field through the piping system. Chemical and biological processes take place in the drain field enhancing the removals of nutrients such as phosphorus and nitrogen, BOD, suspended solids, Coliform etc. The soil below the drain field provides the final treatment and disposal of the septic tank effluent. After the effluent has passed into the soil, most of it percolates downward and outward, eventually entering the groundwater. A small percentage is taken up by plants through their roots, or evaporates from the soil.

The commonly required hydraulic retention time (HRT) for a septic tank is around 6 to 24 hours whereas the commonly required hydraulic retention time (HRT) for the drain field is 24 to 36 hours (USEPA, 2002). Usually, longer hydraulic retention times result in higher efficiency of both septic tank and drain field.

Approximately 25% of the U.S. population relies on septic tanks, mostly in rural communities and small towns (http://en.wikipedia.org/wiki/Septic_tank). In the Wekiva springshed, it is estimated that some 55,000 homes are on septic tanks. To slow the pollution, building moratoriums and limits on the size of property are often imposed. Within the Wekiva basin, new lot sizes are limited on 55,000 acres (Florida Department of Health, 2004). However, once groundwater is polluted, it is very slow to improve the quality, so urgent action is appropriate.

Media Selection

To remove nitrogen in the form of Nitrates, it is generally believed that an anaerobic condition is necessary and that there is a source of carbon or other means to encourage nitrate removal. Peat, paper, Sulfur and sawdust have been used before. In the past, researchers tried several alternative carbon sources to facilitate efficient denitrification. The peat system utilized a layer of sphagnum peat moss below the weeping tile bed (Brooks et al., 1984). The "Ruuk" system (Laak, 1981) mixed gray water with treated black water to provide an external carbon source. The recirculation sand filter system (Piluk and Hao, 1989) returned a portion of the treated wastewater to the soil adsorption system. These methods achieved partial total nitrogen removal (40-90%), however there was a much lower removal of nitrates.

With respect to solid organic carbon substrates, a variety of cellulose based waste materials have been studied and applied in the field to enhance denitrification for treating various types of nitrate-contaminated water, including tree bark, wood chips, and leaf compost (Blowes et al., 1994) as well as sawdust (Robertson and Cherry, 1995: Schipper and Vojvodi6-Vukovi6, 1998, 2000). Furthermore, Soares and Abeliovich (1998) and Volokita et al. (1996a, 1996b) studied microbial denitrification of drinking water in laboratory columns packed with various types of cellulose-based materials (newspaper, cotton, and wheat straw).

In a Nebraska study (Zhang and Shan, 1999), the feasibility of coupling a conventional drain field with a sulfur/limestone layer was investigated to treat nitrate in septic tank effluent using laboratory column reactors to simulate the septic tank soil adsorption system. The denitrifiers can use inorganic carbon compounds (i.e., CO_2, HCO^{3-}) as their carbon source, nitrate as the electron acceptor, and elemental sulfur as the electron donor. The stoichiometric equation of sulfur-based material is as follows (Batchelor and Lawrence, 1978a, 1978b):

$$55\ S + 20CO_2 + 50\ NO^{3-} + 38\ H_2\ O + 4\ NH^{4+} \rightarrow 25\ N_2 + 4\ C_5\ H_7\ NO_2 + 55\ SO_4^{2\ -} + 64\ H^+$$

Since pH is lowered in this reaction limestone is needed. The removal is shown in Figure 3.2.

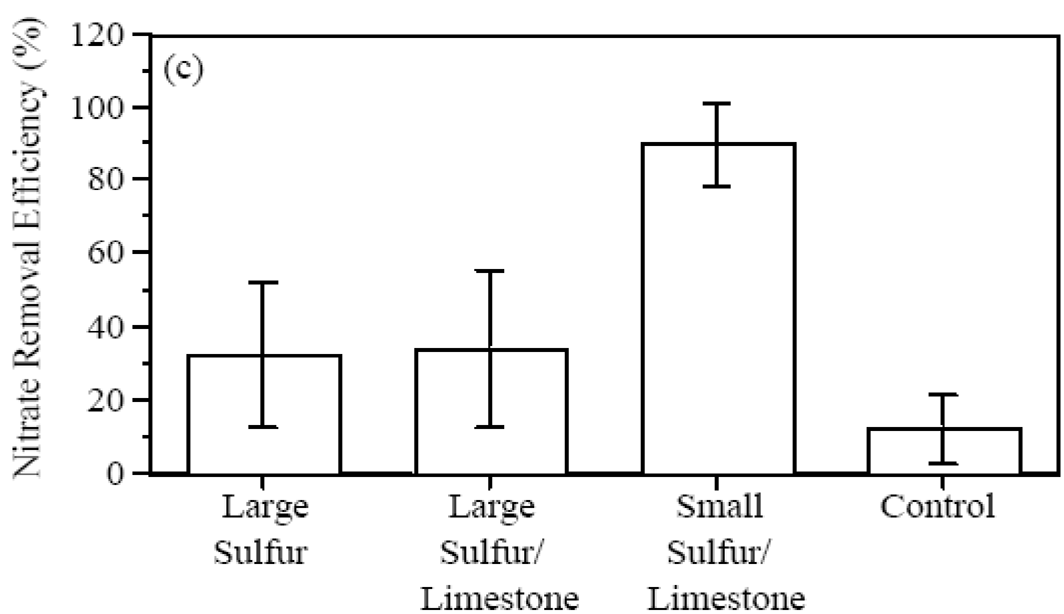


Figure 3.2: Nitrate Removal Efficiency with respect to Sulphur/Limestone Mix

Source: Davis et al., 2003.

When alfalfa, mulch and newspaper were used, 100% nitrate removal was observed, while that in the control of leaf mulch was approximately 60% as shown in Figure 3.3

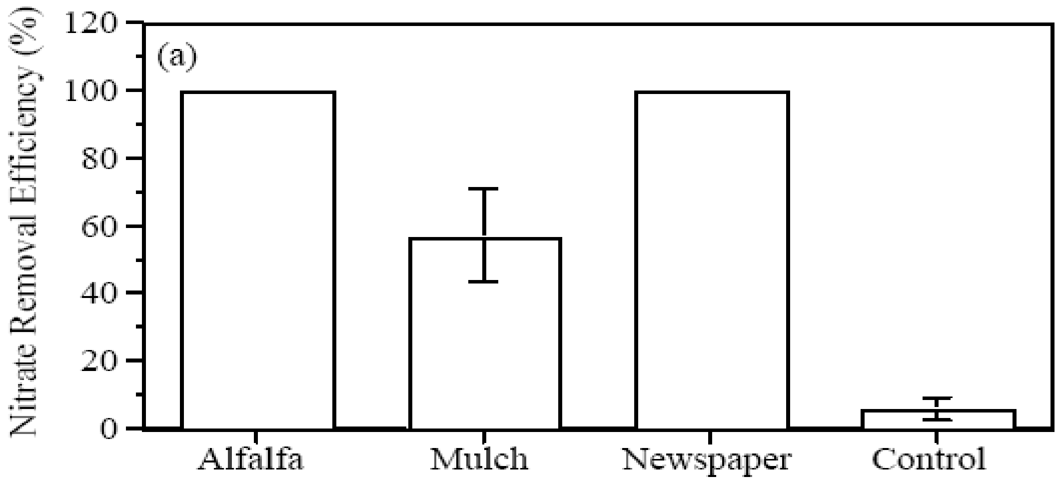


Figure 3.3: Nitrate Removal Efficiency with respect to Alfalfa, Mulch and Newspaper
Source: Davis et al., 2003.

However, the alfalfa column had elevated effluent total nitrogen and turbidity, making this material less attractive for practical use. Amongst saw dust, wheat straw, and wood chips, 95% and greater nitrate removal was observed as shown in Figure .

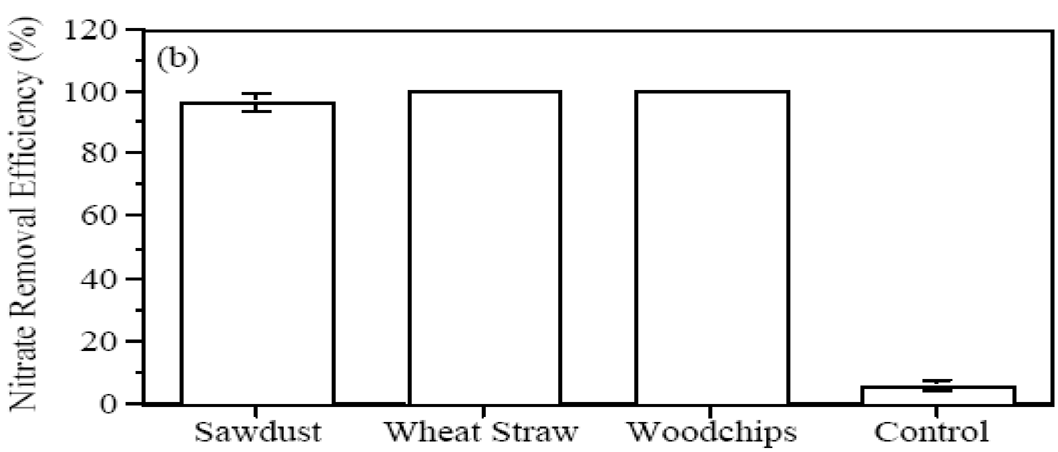


Figure 3.4: Nitrate Removal Efficiency with Sawdust, Wheat straw and Woodchips
Source: Davis et al., 2003.

Nitrate reduction demonstrated by using select media with stormwater bioretention proved newspaper as the best solid-phase electron-donor substrate for denitrification out of the set studied (alfalfa, leaf mulch compost, newspaper, sawdust, wheat straw, wood chips, and elemental sulfur) based on superior nitrate removal and effluent water quality (Davis et al., 2003).

Sawdust is also used to remove the nitrates from groundwater and is very efficient. It is used as a wall and is placed within the groundwater so that the water passes through it and gets treated within the wall (about 1.5 meters in width) and discharges with a reduction in its nitrates concentration. In Table 3.1 the efficiency in terms of nitrate removal is shown.

The results of Table 3.1 were the major reasons behind choosing paper (newspaper) and sawdust as electron donors for the columns. Furthermore, low cost and ready availability are useful from the economic perspective Also they are environmental friendly while disposing which adds to its selection.

Table 3.1: Rates of Nitrate Removal from a Number of Denitrification Walls

Carbon Source (vol %)	Residence time (day)	Average nitrate input (mg/L)	Nitrate removal (mg/L/day)	Reference
Sawdust wall (30% sawdust)	1-10	5.9	0.014-0.43	Schipper and Vojvodic-Vukovic (2001)
Sawdust wall (20% sawdust)	1-10	30	0.16-0.29	Schipper et al. (2004)
Sawdust wall (20% sawdust)	10-13	34	2.4	Robertson et al. (2000)
Sawdust layer (15% sawdust)	17-40	57	2.6	Robertson et al. (2000)
Sawdust layer (15% sawdust)	15-30	12	0.7	Robertson et al. (2000)

Tire Crumb as a Drain Field Media

Tire Crumb has not been used before in a septic tank drain field, but it is believed to be a likely candidate because of its infiltration capacity and good sorption properties (Lisi, 2004). Also it has about 85% carbon by weight. Because of the very high carbon content it is considered a good carbon source for denitrification of nitrates. Past research has proved that tire crumb is capable of sorption of nitrates and other chemicals, where it is used a layer beneath the turf grass in a golf course and it has shown removal capacity of about 58% of nitrates (Lisi, 2004). Some properties related to practical use in drain fields are shown in Table 3.2.

Table 3.4: Properties of Tire Crumb

Vulcanized Rubber Compound (Wt %)	99%
Talc, (Hydrous Magnesium Silicate) (Wt %) (14807-96-6) Restorable dust	Less than 4 %
Solubility in water	Insoluble
Specific gravity	1.04 – 1.16
Density	27 lbs/ft^3 or 729 lbs/yard^3
Flash point	Temperature of dust cloud 320^{0}C (608 F)
Hazardous Polymerization	Will not occur
Health Hazards (Acute and chronic)	The product can contain fine fibers that may cause itching. Otherwise not known. This material is generally thought to be a nuisance dust.
Carcinogenicity	Tire Crumb is not listed as a carcinogen
Waste disposal Method	Product not defined as hazardous waste. Dispose of in accordance with federal, state and local regulations

Source: Global Tire Recycling (GTR, 2007)

3.5 Designing a Septic Tank and Drain Field

In this section, a brief discussion of septic tanks and drain field design are presented to establish important parameters for the experimental design. The major parameters that affect the design and operational conditions of septic tanks are:

- **Configuration:** The shape of the tank must be designed to maximize the hydraulic retention time of the wastewater. Surface area is more critical for particle settling than depth, so a shallow, wide tank is preferable to a deep, narrow tank.
- **Materials**: Typically, septic tanks are made of concrete, polyethylene or fiberglass
- **Structural integrity:** The long-term performance of the septic tank will depend on its structural integrity. For concrete septic tanks, structural integrity is dependent on the method of construction, the placement of the reinforcing steel, and the composition of the concrete mix.
- **Water-tightness**: Watertight tanks are a necessity for the protection of the environment and for the operation of the system.
- **Size:** Household water usage determine the hydraulic retention time of the tank. The recommended hydraulic retention time ranges from 6 to 24 hours (USEPA, 2002)
- **Appurtenances**: Influent baffles restrict and redirect the flow of the influent to help prevent short-circuiting. Effluent baffles prevent floatables, scum, or suspended solids from flowing into the drain field.
- **Drain field Size**: Once the percolation rate is known, the drain field trench bottom area is specified using information similar to that in Table 3,2 for residential areas.

Table 3,2: Residential Drain field Area per Bedroom in House

		Length of trench in feet		
Average percolation rate at tile depth (min/in)	Trench bottom/bedroom (sq ft)	18" wide	24" wide	36" wide
5+	125	84	63	42
10	165	110	83	55
15	190	127	95	64
20	215	144	108	72
30	250	167	125	84
45	300	200	150	100
50	315	210	158	105
60	340	227	170	113
70	360	240	180	120
80	380	254	190	127
90*	400	267	200	134
+ Fastest rate allowed, * Slowest rate allowed				

Source: http://www.fcs.uga.edu/pubs/current/C819-2.htm

- **Location and Dimensions:** Drain field should be at least 100 feet from the closest water well (http://www.fcs.uga.edu/pubs/current/C819-2.html). The aggregate should be a minimum of six inches deep under the drain tile.
- **Selecting a Site:**
    1. Slope drain fields away from houses, buildings and the water supply.
    2. The soils types are important (see Table 3.3).

Table 3.3: Drain field Area Depending on the Type of Soil

Soil Class	Soil Type: take a soil sample 3 to 4 feet below grade in the drain field area	2 Bedroom House	3 Bedroom House	4 Bedroom House
# 1	Coarse Sand	200 sq ft gravel or 10 six ft vaults or 16 four ft vaults	300 sq ft gravel or 14 six ft vaults or 22 four ft vaults	400 sq ft gravel or 18 six ft vaults or 28 four ft vaults

# 2	Medium Sand	240 sq ft gravel or 12 six ft vaults or 20 four ft vaults	360 sq ft gravel or 16 six ft vaults or 25 four ft vaults	480 sq ft gravel or 21 six ft vaults or 33 four ft vaults
# 3	Fine Sand – Loamy Coarse Sand - Loamy Med Sand	300 sq ft gravel or 10 six ft vaults or 16 four ft vaults	450 sq ft gravel or 15 six ft vaults or 24 four ft vaults	600 sq ft gravel or 20 six ft vaults or 32 four ft vaults
# 4	Very Fine Sand - Loamy Fine Sand - All Loams	400 sq ft gravel or 14 six ft vaults or 22 four ft vaults	600 sq ft gravel or 20 six ft vaults or 32 four ft vaults	800 sq ft gravel or 26 six ft vaults or 42 four ft vaults
# 5	All Silt Loams of Good Structure	540 sq ft gravel or 18 six ft vaults or 28 four ft vaults	800 sq ft gravel or 26 six ft vaults or 42 four ft vaults	1070 sq ft gravel or 35 six ft vaults or 55 four ft vaults
# 6	Other Silt Loams - All Clay Loams - All Clays	1200 sq ft gravel or 39 six ft vaults or 62 four ft vaults	1800 sq ft gravel or 60 six ft vaults or 94 four ft vaults	2400 sq ft gravel or 78 six ft vaults or 122 four ft vaults

Source: http://www.eco-nomic.com/septic.htm

Possible Drain Field Design

Based on the above mentioned design and operational parameters, a drain field design is completed as shown in Figure 4. Septic tank effluent flows into the Multi-Pipe System (MPS) which has a downward slope of 1%, so that water flows to the edge of the drain field. The patented Multi-Pipe units as shown in Figure 3.5 function as a trickling filter, dispersing effluent into the voids in and around the specially-banded ADS pipe. This pipe is engineered with holes and slots, allowing it to collect and disperse the effluent as it passes over the corrugations in the pipe. Effluent leaves the D (Distribution) pipe and is distributed throughout the other V (Void) pipes. Once the effluent is distributed throughout the V pipe, it trickles down to the drain field. Each V pipe allows for partial biological breakdown before reaching the drain field.

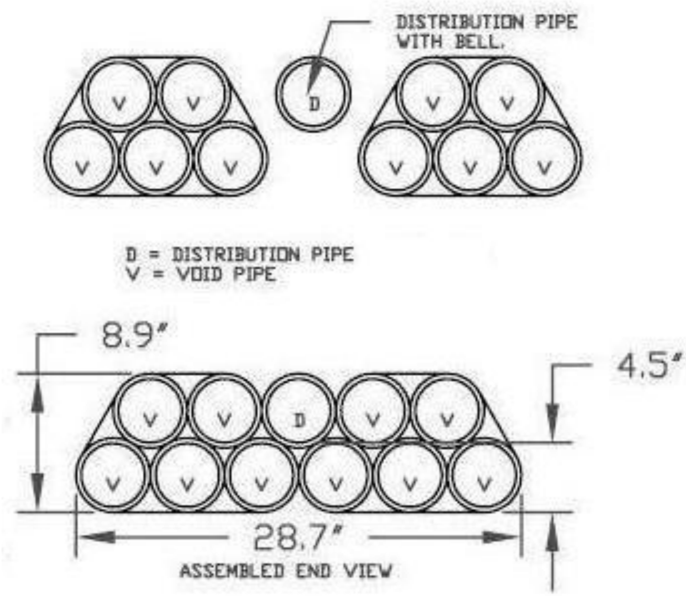


Figure 3.5: MPS – 11

The wastewater is retained in the Black and Gold Nugget Mix™ Treatment Zone for a hydraulic retention time of 24 hrs so as to provide the desired denitrification to get the wastewater under required MCL of 10mg/L of NO_3-N. The wastewater is retained in the treatment zone with the help of pre-fabricated riser. After 24 hrs the wastewater flows out of the treatment zone and drains through a seepage zone and into the Redundancy pipes. At the end of the redundancy pipes, a Sampling well is built to collect the samples for analysis so as to regular check the consistency in the nutrient removal of the system.

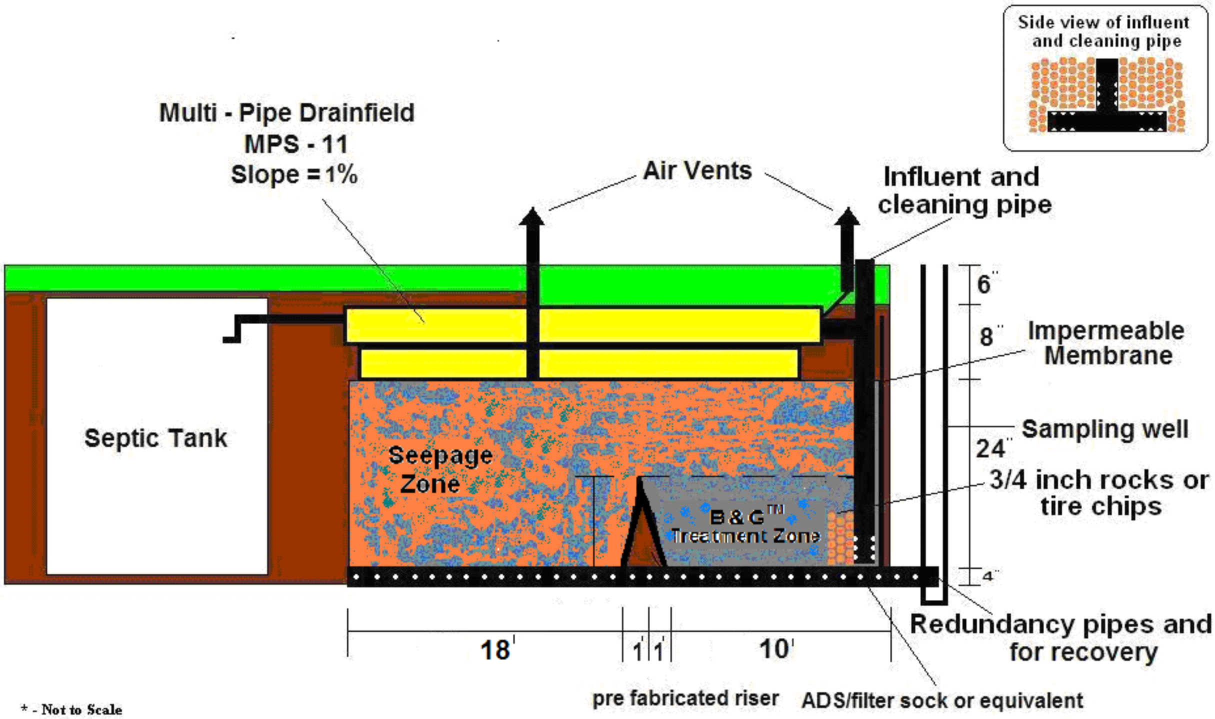


Figure 4: Drain field Design

3.6 Experimental Design

Column studies are completed to determine the removal effectiveness of the media. If good removal effectiveness is obtained, then batch studies are completed to determine the life expectancy of the media. For additional detail, go to Shah, 2007.

Experimental Procedure for Column Study

The fate of nitrogen and phosphorus species in a septic tank drain field is found using a simulated column study following the factors for design presented earlier. Experimental setup consisted of 3 columns:

- Control column (C) consisting only of sand
- Second column consisting Sand, Tire crumb and Paper (STP) and
- Third column consisting Sand, Tire crumb and Sawdust (STS)

The columns were setup in one of the environmental engineering research labs at the University of Central Florida.

Three Plexiglas packed-bed columns, 11.5 inch inner diameter and 5 ft tall are built to stimulate septic tank drain field. The columns are drilled with holes for sampling at 0.75 ft, 1.25 ft, 1.75 ft, 2.25 ft, 3.25 ft and 4.75 ft from top keeping a free on board space of 3 inch at the top. The sampling ports are sealed with ball valves. The media are filled in the columns keeping a distance of 3 inch from top and are 4.75 feet deep as shown in Figure . The bottom most sampling port has 4.5 ft of media above it and hence the name C – 4.5, STP – 4.5 and STS – 4.5 for the Control and the STS and STP columns respectively. Knowing the volume of the column and hence the media to be placed in it and also knowing real world volume of drain field and the real world density of different components of the media in the drain field, the mass of different components to be filled in the different mixes of columns was thus determined. The composition of all the columns in terms of weight and volume were thus determined as shown in Table .

The feed solution (raw septic tank effluent) from a functioning septic tank in Central Florida is used in the study. The effluent is pumped into the top of the columns at an average proportional rate as in the real world septic tank drain field. To prevent air from penetrating into the column from the top and through the end of discharge ports, the columns is covered with a lid from top and the discharge ports are air tight keeping the columns anoxic in condition.

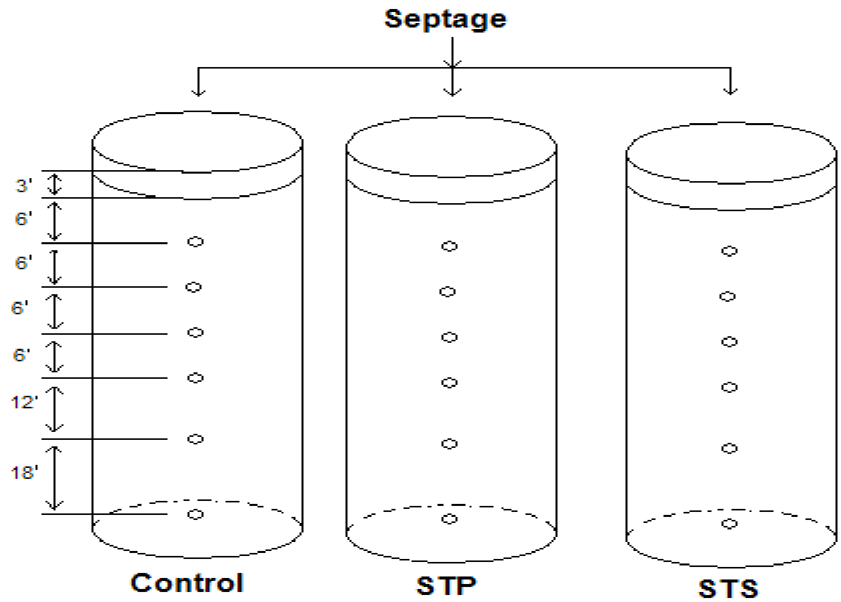


Figure 3.7: Experimental Design of Columns

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Table 3.4: Composition of Columns in Terms of Weight and Volume

	Column 1 (Control C – 4.5)				Column 2 (STP – 4.5)				Column 3 (STS – 4.5)			
	Wt	wt %	vol	vol%	Wt	wt %	vol	vol%	Wt	wt %	vol	vol%
Tire crumb	0.00	0.00	0.000	0.00	21.84	10.73	0.811	25.00	21.84	10.85	0.811	25.00
Paper	0.00	0.00	0.000	0.00	8.15	4.00	0.201	6.19	0.00	0.00	0.000	0.00
Sawdust	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00	8.05	4.00	0.230	7.09
Sand	252.31	100.00	3.244	100.00	173.62	85.27	2.232	68.81	171.34	85.15	2.203	67.91
Total	252.31	100.00	3.244	100.00	203.60	14.73	3.244	100.00	201.23	100.00	3.244	100.00
Lbs/CF	77.78				62.76				62.03			

Experimental Approach for Batch Study

For batch studies the volume percentage and the mass percentage of the STS – 4.5 column used in the column studies (Table) are replicated to have a total mass of media as 100g for nitrates isotherm study and 200g for ortho-phosphorus isotherm study. The residence time for the batch studies is also 24 hrs. The reason for replication of the mass and volume percentage replication is to study the life expectancy of the same media with respect to adsorption of nitrates and ortho-phosphorus.

The nitrate is made using 1.3707 grams of sodium nitrate dried at 105^{o}C diluted in a liter of deionized water. The deionized water is autoclaved to minimize the influence of biological activities. The resulting solution concentration is 1000 mg/L NO_3 – N. This solution is used to make the influent which had a concentration of 9.56, 8.37, 7.17, 5.98, 4.78 mg/L NO_3 – N.

The phosphate is made using 1.4330 grams of potassium hydrogen phosphate dried at 105^{o}C diluted in a liter using deionized water. The deionized water is autoclaved to minimize the influence of biological activities. The resulting solution concentration is 1000 mg/L PO_4 – P. This solution is diluted to make the influent concentration of 4.12 mg/L PO_4 – P.

3.7 Results and Discussion

Results from Column Study

The Results from the Column study are from a 6 month testing period and are reflected in the data shown in Tables 3.5 -3.8 for the nitrogen species and Tables 3.9-3.10 for the phosphorus species. Corresponding graphical presentations are shown in Figures 3.8 – 3.13. BOD data are also presented in Table 3.11 and Figure 3.14.

Table 3.5: Nitrate Data

Nitrates			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	0.266	0.035	0.030
26-Oct	0.311	0.055	0.056
10-Nov	3.021	0.079	0.110
17-Nov	3.490	0.021	0.077
30-Nov	3.102	0.145	0.860
2-Feb	0.157	0.011	0.078
26-Feb	0.214	0.006	0.005
7-Mar	1.949	0.020	0.028
Average Conc. (mg/L)	1.564	0.047	0.156
% Removal		97.03	90.06

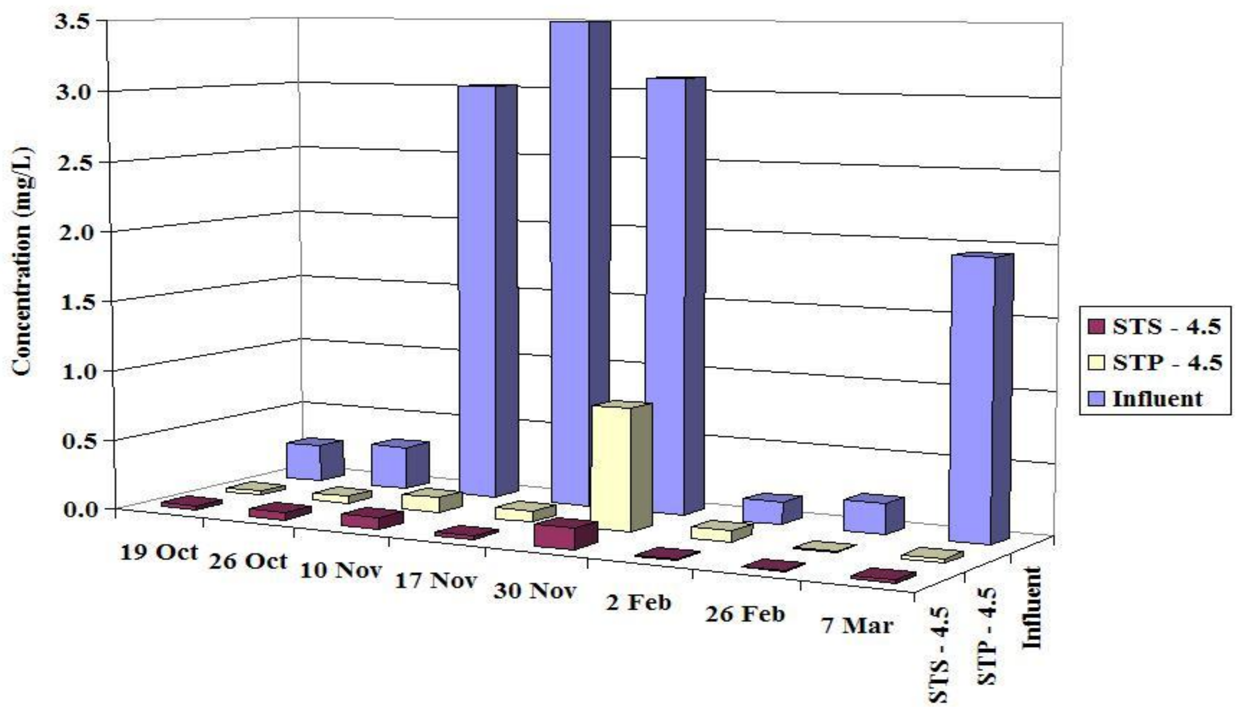

Figure 3.8: Nitrates Concentration Plot

Table 3.6: Organic–N Data

Organic- Nitrogen			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	90.642	5.952	4.969
26-Oct	6.941	2.675	6.728
10-Nov	1132.737	4.533	6.451
17-Nov	369.103	0.031	5.601
30-Nov	576.294	0.847	4.642
2-Feb	667.032	0.272	0.184
26-Feb	52.511	1.325	4.876
7-Mar	10.726	0.358	0.207
Average Conc. (mg/L)	363.248	1.999	4.207
% Removal		99.45	98.84

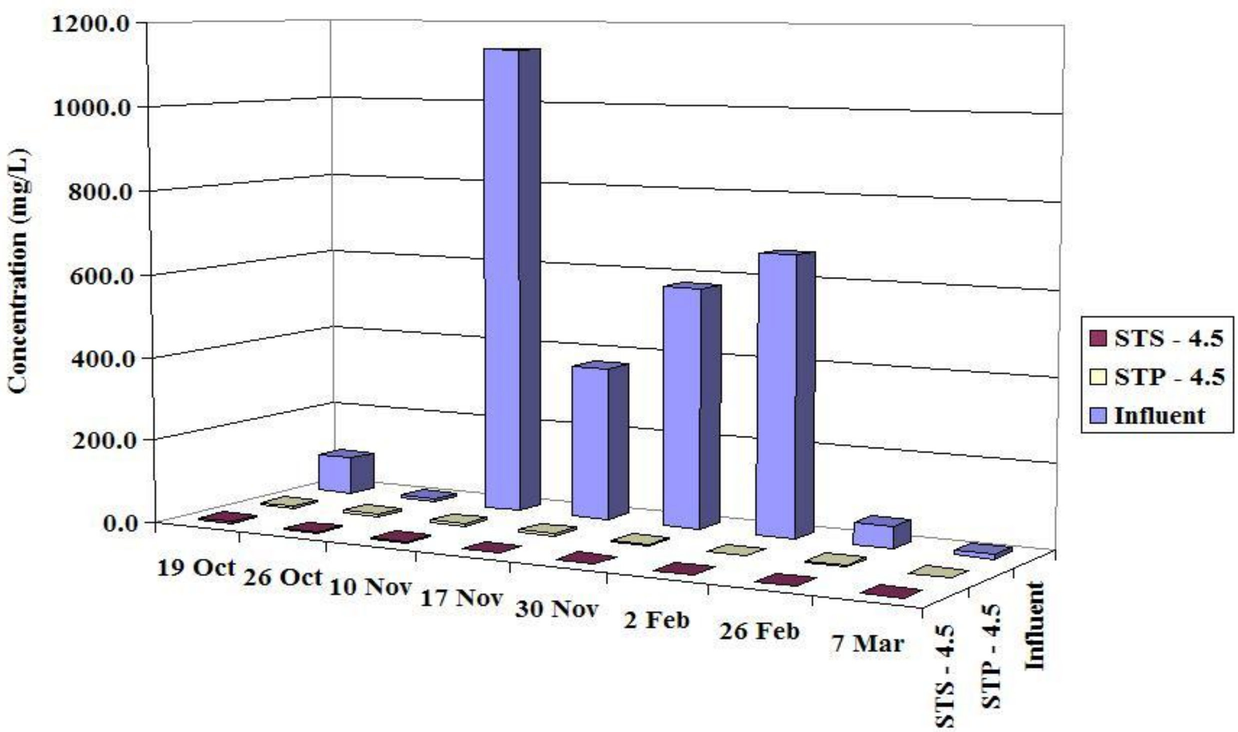

Figure 3.9: Organic-N Concentration Plot

Table 3.7: Ammonia Data

Ammonia			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	4.89	0.28	0.13
26-Oct	27.75	3.68	0.22
10-Nov	1.51	0.71	0.03
17-Nov	118.52	4.14	0.09
30-Nov	111.79	4.38	0.79
2-Feb	10.743	6.658	0.862
26-Feb	72.938	10.78	10.99
7-Mar			
Average Conc. (mg/L)	49.73	4.37	1.87
% Removal		91.21	96.23

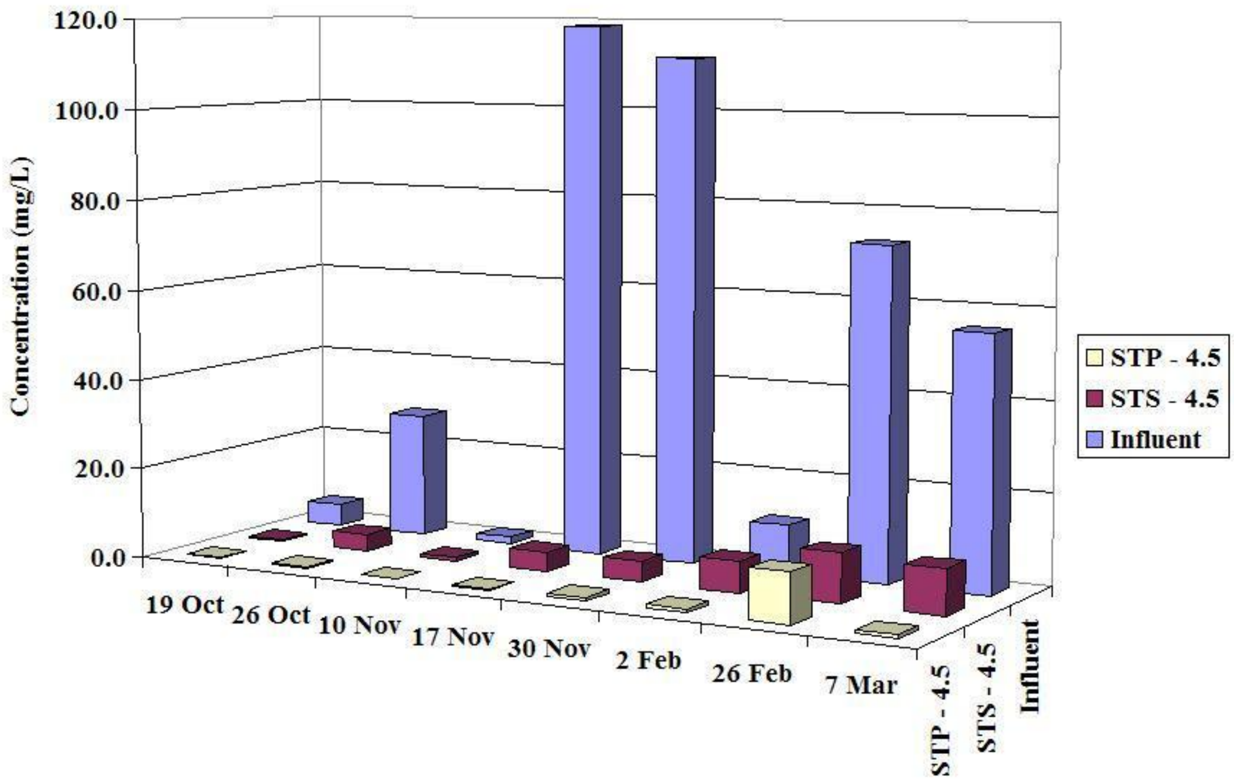

Figure 3.10: Ammonia Concentration Plot

Table 3.8: Total Nitrogen Data

Total Nitrogen			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	96.39	6.24	5.12
26-Oct	35.60	6.36	6.96
10-Nov	1135.06	5.26	6.50
17-Nov	488.25	4.21	5.71
30-Nov	688.82	5.22	5.44
2-Feb	678	6.93	1.058
26-Feb	126.16	12.106	15.917
7-Mar	67.493	10.289	0.948
Average Conc. (mg/L)	414.47	7.08	5.96
% Removal		98.29	98.56

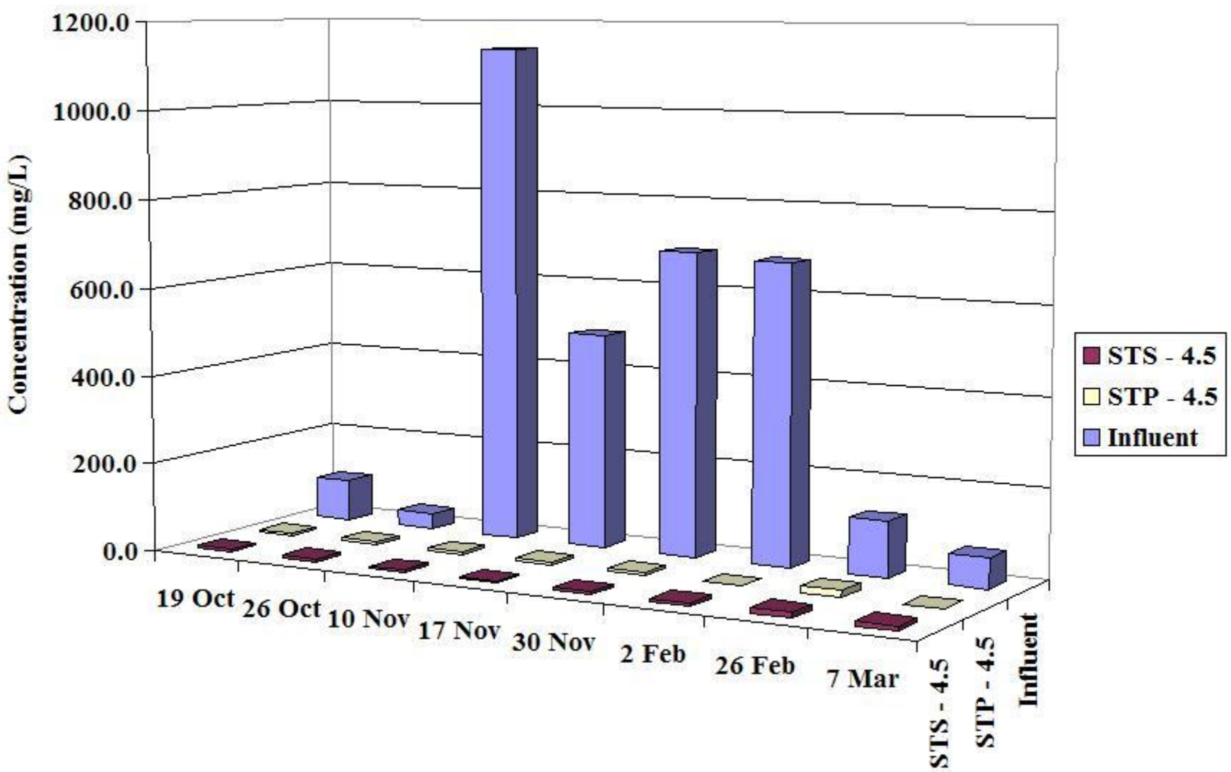

Figure 3.11: Total Nitrogen Concentration Plot

Table 3.9: Ortho-phosphorus Data

Ortho Phosphorus			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	0.862	0.006	0.020
26-Oct	0.909	0.003	0.009
10-Nov	0.812	0.022	0.015
17-Nov	0.631	0.041	0.020
30-Nov	0.731	0.001	0.005
2-Feb	0.225	0.000	0.012
26-Feb	0.711	0.001	0.051
7-Mar	1.257	0.001	0.001
Average Conc. (mg/L)	0.767	0.009	0.017
% Removal		98.79	97.83

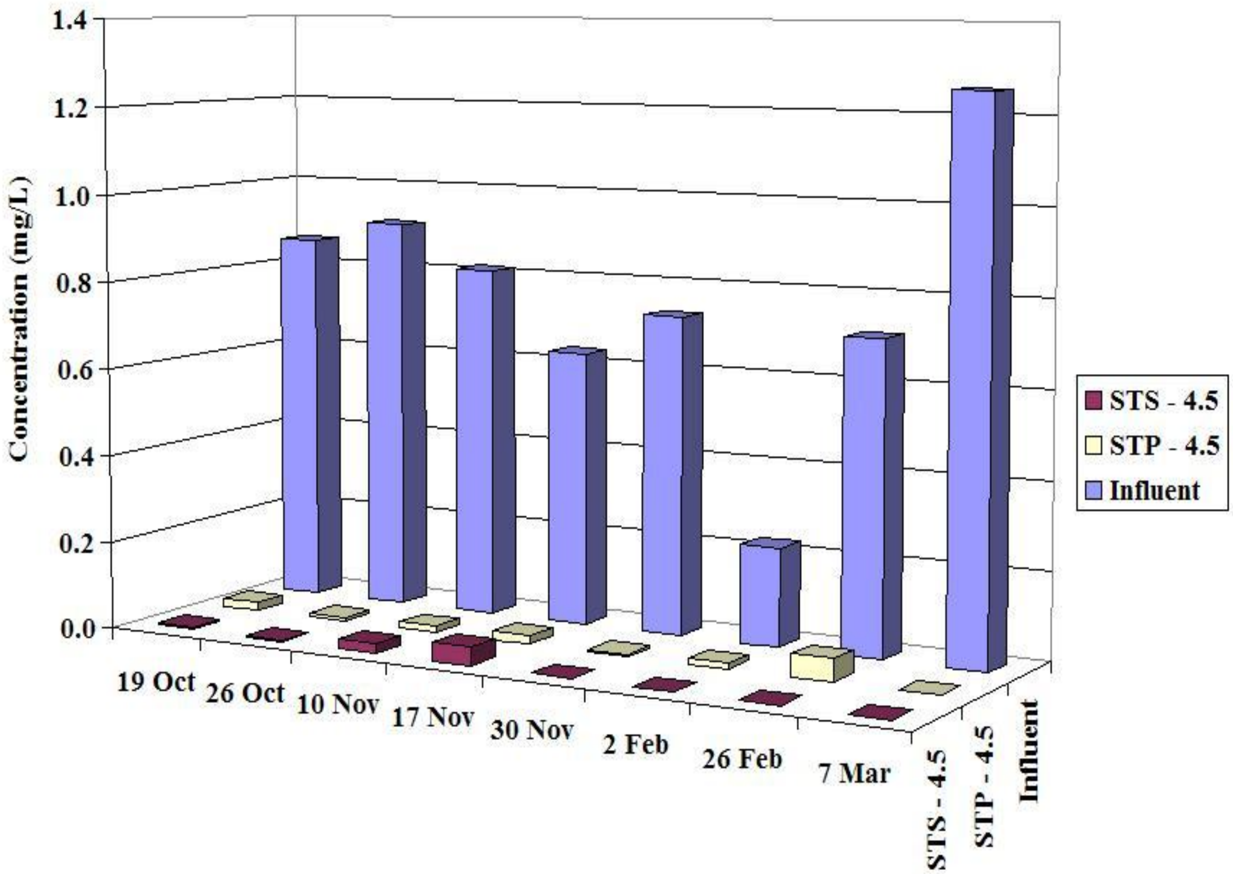

Figure 3.12: Ortho-phosphorus Concentration Plot

Table 3.10: Total Phosphorus Data

Total Phosphorus			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
19-Oct	6.79	0.15	0.21
26-Oct	4.15	0.06	0.08
10-Nov	704.54	0.23	0.19
17-Nov	194.81	0.09	0.15
30-Nov	550.45	0.18	0.21
2-Feb	36.09	0.09	0.19
26-Feb	3.19	0.08	0.07
7-Mar	2.13	0.14	0.07
Average Conc. (mg/L)	187.77	0.13	0.15
% Removal		99.93	99.92

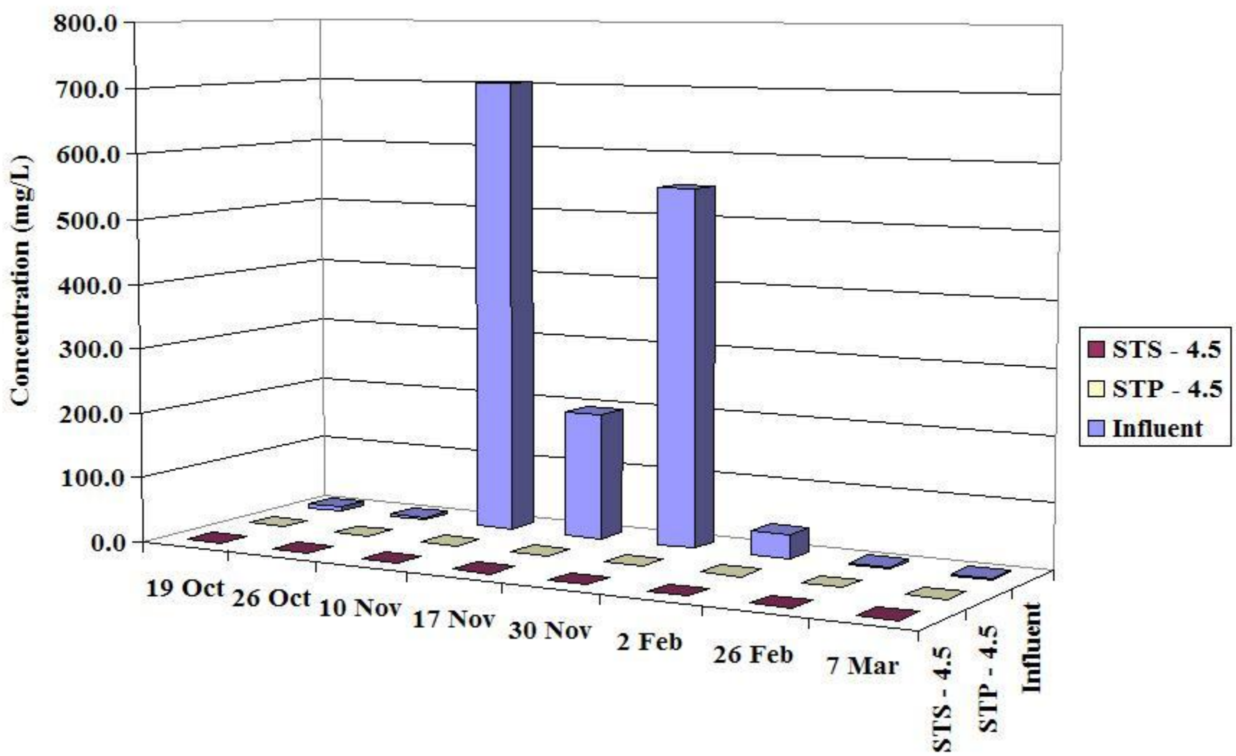

Figure 3.13: Total Phosphorus Concentration Plot

Table 3.11: BOD Data

BOD$_5$			
Date	Influent (mg/L)	STS - 4.5 (mg/L)	STP - 4.5 (mg/L)
10-Nov	2,180	240	751
17-Nov	1,475	45	750
30-Nov	7,200	405	833
2-Feb	606	85	342
26-Feb	173	36.9	2
7-Mar	198	52	48
Average Conc. (mg/L)	1972.00	143.98	454.33
% Removal		92.70	76.96

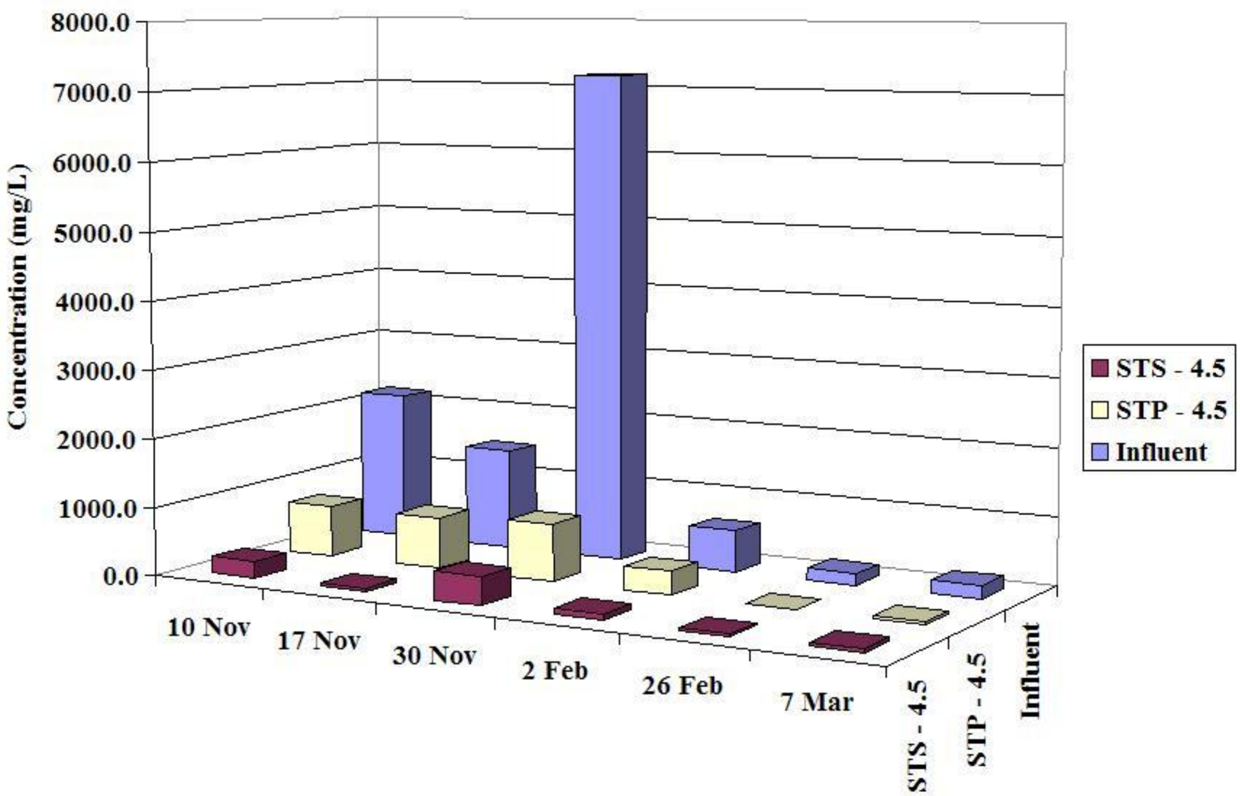

Figure 3.14: BOD Concentration Plot

Results from Batch Study

Batch studies are useful for estimation of life expectancy for the removal of nitrogen and phosphorus species. The results for the nitrate isotherm are presented in Table 3.12.

Table 3.12: Nitrate Isotherm Results

Sample	Mass Loading [mg]	Mass Removed [mg]
1	0.48	0.11
2	0.42	0.00
3	0.36	0.08
4	0.30	0.01
5	0.24	0.00

The results for the phosphate isotherm are presented in Table 3.13. It can be seen that there is higher phosphate removal for the initial days and it goes on gradually decreasing. Langmuir isotherm and Freundlich isotherms were plotted for ortho-phosphorus.

Table 3.13: Phosphate Isotherm Results

Sample	Mass Loading [mg]	Mass Removed [mg]
1	0.41	0.35
2	0.41	0.27
3	0.41	0.23
4	0.41	0.21
5	0.41	0.17
6	0.41	0.12

The Freundlich isotherm equation has the following form as presented by Sawyer et al. (2003) and Snoeyink & Summers (1999):

$$q_e = KC_e^{(1/n)}$$

where:

q_e = Sorbed concentration [mass adsorbate/mass adsorbent]

K = Capacity adsorbent [mass adsorbate/mass adsorbent]

C_e = Aqueous concentration of adsorbate [mass/volume]

n = Measure of how affinity for the adsorbate changes with changes in adsorption density

The linear form of this equation is as follows and is as shown in Figure :

$$\log q_e = \log K + (1/n)\log C_e$$

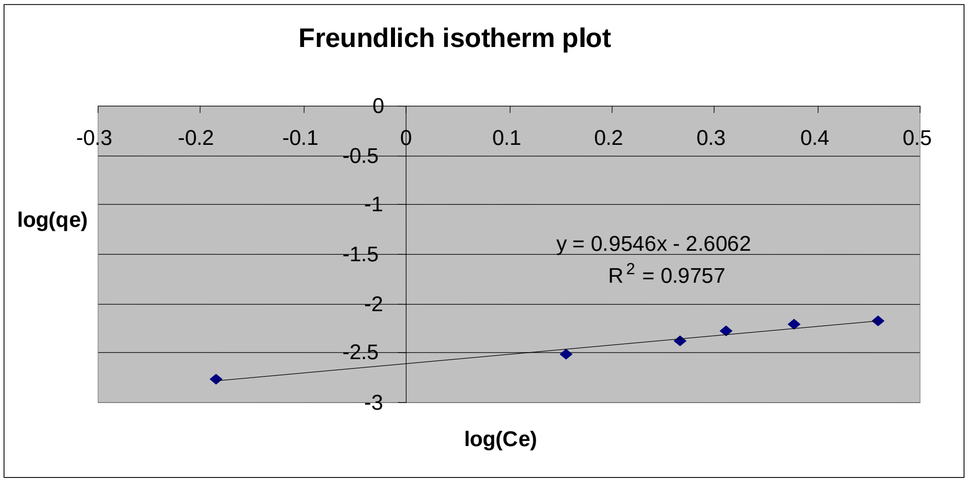

Figure 3.15: Freundlich Isotherm Plot for Ortho-phosphorus

The Langmuir isotherm equation has the following form as presented by Sawyer et al. (2003) and Snoeyink & Summers (1999):

$$Q_e = Q_{max}(bC_e) / (1 + bC_e)$$

where:

Q_e = Sorbed concentration [mass adsorbate/mass adsorbent]

Q_{max} = Maximum capacity of adsorbent for adsorbate [mass adsorbate/mass adsorbent]

b = Measure of affinity of adsorbate for adsorbent

C_e = Aqueous concentration of adsorbate [mass/volume]

This equation can be linearized as follows and its plot is shown in Figure .

$(1/Q_e) = (1/(Q_{max}b)) \times (1/C_e) + (1/Q_{max})$

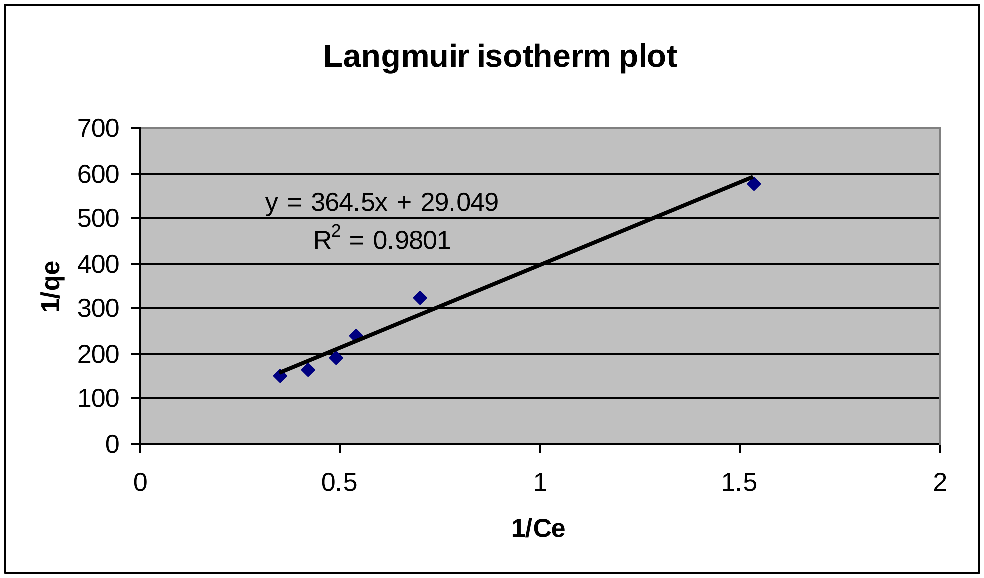

Figure 3.16: Langmuir Isotherm Plot for Ortho-phosphorus

Discussion of Drain Field Batch Study Results

It can be seen from Table 3.12 that there is very little removal of nitrates. It should be noted that the nitrates was not sorbed by tire crumb and biological activity could not initiate as the batch studies were performed in 24 hrs. However, Lisi et al. (2004) achieved a significant reduction in the concentration of nitrates which were not achieved using the batch studies of this work. The required anoxic conditions for the batch studies in this research were not simulated and may be the difference in results.

It can be seen from Table 3.13 that the media mix showed significant removal in terms of ortho-phosphorus. The phosphorus removal results are in contradiction to Lisi et al. (2004) who concluded that tire crumb does not have potential for the removal of phosphate. Tire crumb showed significant reduction in ortho-phosphorus removal with a retention time of as small as 15 minutes (Hardin, M., 2006).

From the Langmuir and Freundlich plots it can be seen that Langmuir isotherm plot fit the data set better. The Langmuir model was fitted to the change in phosphorus concentration detected at each sampling period and the related surface loading of phosphorus on the *Black and Gold Nugget Mix™*.

Using the linear equation of the Langmuir graph as shown in Figure , the resulting parameter values are: $1/Q_{max} = 29.049$ and $1/bQ_{max} = 364.5$. So the equilibrium constant, b, is determined to be 79.7×10^{-3} with a maximum surface loading capacity, Q_{max}, of 34.38×10^{-3} mg phosphorus/mg media, assuming monolayer coverage of phosphorus adsorbed to the media surface as shown in Figure .

Estimated life time for Black and Gold Nugget Mix™ for Adsorption of Phosphorus

For the designed drain field as shown in Figure 4, the volume Black and Gold Nugget Mix™ Treatment Zone is 256.5 ft^3 (Appendix 3.A) and the density of the total media is 62.05 lbs/ft^3 so the total media used is 15.92×10^3 lbs (sand of 13.55×10^3 lbs, tire crumb of 1.72×10^3 lbs, saw dust of 0.65×10^3 lbs). The maximum surface loading capacity Q_{max} of the media is 34.38×10^{-3} mg phosphorus/mg media. So the total maximum mass of phosphorus adsorbed by the media is $34.38 \times 10^{-3} \times 15.92 \times 10^3 = 547.19$ lbs of phosphorus. For most domestic waste using septic tanks, the average concentration of phosphorus coming into the drain field is around 14 mg/L (http://pubs.usgs.gov/sir/2004/5299: USEPA, 2002) and with an average flow of 480 gallons per day coming to the drain field the total phosphorus coming to the drain field is about 20.42 lbs/yr. Thus, the number of years before media exhaustion is equal to 547.19/20.42 = 27 years. Based on the phosphorus effluent concentration from the septic tank of 14 mg/L, the media lifetime for high efficiency phosphorus removal is of about **27 years**. The lifetime of the media would be about **38 years and 32 years** respectively if the effluent phosphorus concentration were about 10 mg/L (http://jeq.scijournals.org/cgi/content/abstract/34/4/1243) and 12mg/L (http://www.ecomax.com.au/tech.html). Thus, the average life of the media for phosphorus removal ranges from **27 to 38 years.**

Discussion of Drain Field Column Study Results

From the results it can be seen that there is significant removal of total phosphorus, ortho-phosphorus, total nitrogen, ammonia, nitrates and BOD. During the experimental period the columns did not show any signs of saturation with nutrients although the columns were loaded with high concentrations of nutrients with average total phosphorus concentration of 188 mg/L which is approximately thirteen fold than the average concentration of 14 mg/L for total phosphorus (USEPA, 2002) and average total nitrogen concentration of 415 mg/L which is approximately eight fold than the average concentration of 50 mg/L for total nitrogen (USEPA, 2002).

For the designed drain field as shown in Figure 4 and 24 hours detention, the volume of the Black and Gold Nugget Mix™ Treatment Zone is 256.5 ft^3 (Appendix 3.A) and the density of the total media is 62.05 lbs/ft^3 so the total media used is 15.92×10^3 lbs. The mass of total nitrogen adsorbed by the media during the experimental period of six months is 1.39 lbs and the mass of media in the columns was 203.6 lbs. So the total mass of total nitrogen adsorbed per mass of media is $1.39/203.6 = 6.8 \times 10^{-3}$ lbs of total nitrogen/lb of media. Therefore, the total mass of nitrogen that would have been adsorbed by the media would have been $(6.8 \times 10^{-3}) \times$

(15.92×10^3) = 108.22 lbs of total nitrogen. The average concentration of total nitrogen coming into the drain field is around 50 mg/L (USEPA, 2002) and with the average of 480 gallons per day coming to the drain field the total nitrogen coming to the drain field is about 72.95 lbs/yr. So the number of equivalent long term performance time using average loadings = (108.22 / 72.95) = **1.5 years.**

For the designed drain field as shown in Figure 4 and 24 hours detention, the volume of the Black and Gold Nugget Mix™ Treatment Zone is 256.5 ft^3 (Appendix 3.A) and the density of the total media is 62.05 lbs/ft^3 so the total media used is 15.92×10^3 lbs. The mass of total phosphorus adsorbed by the media during the experimental period of six months is 0.42 lbs and the mass of media in the columns was 203.6 lbs. So the total mass of total phosphorus adsorbed per mass of media is 0.42/203.6 = 2.06×10^{-3} lbs of total phosphorus/lb of media. Therefore, the total mass of phosphorus that would have been adsorbed by the media would have been $(2.06 \times 10^{-3}) \times (15.92 \times 10^3)$ = 33 lbs of total phosphorus. The average concentration of total phosphorus coming into the drain field is around 14 mg/L (http://pubs.usgs.gov/sir/2004/5299: USEPA, 2002) and with the average of 480 gallons per day coming to the drain field the total phosphorus coming to the drain field is about 20.43 lbs/yr. So the number of equivalent long term performance time using average loadings = (33/20.43) = **1.62 years.**

In the suggested drain field design, the Black and Gold Nugget Mix™ Treatment Zone provides the required hydraulic retention time is 24 hrs (calculations and assumptions are shown in Appendix 3.A). The Seepage Zone (1148 ft^3) with a volume almost equal to the treatment zone (256.5 ft^3), provides additional nutrient removal and improves the removal of other parameters. The cost of the media for the total drain field (calculated in Appendix 3.A) is equal to $1,980 and the cost per cubic yard is $37.17.

In the previous study by Davis et al. (2003), paper and sawdust proved effective in terms of nitrate removal and were accepted as one of the best electron donors. In this research, paper and sawdust did showed similar results and were just not limited to nitrates but also to total nitrogen, total phosphorus, ammonia, ortho-phosphorus and BOD.

At the end of the experimental period, the newspaper in the columns was still visible and most of the newspaper in the media mix remained similar in appearance to the original material. These observations are consistent with other studies that indicate that newspaper is somewhat resistant to bacterial degradation under anoxic conditions (Cummings and Stewart. 1994: Volokita et al, 1996: Davis et al, 2003). This resistance seems to be the chemical composition of newspaper, in particular the relatively high lignin content.

3.8 Summary

Due to increasing worldwide and Florida problems related to an increase in the concentration of nitrogen (mainly in the form of nitrates) and phosphorus in the groundwater, a septic tank drain field media mix (Black and Gold Nugget Mix^{TM}) was examined to determine the removal effectiveness, life expectancy and cost of treatment.

Past research was used to determine probable electron donor media that can be used in a drain field. It was decided that sawdust and paper may be the best electron donor amongst the ones reviewed. Tire crumb was used as a carbon source in the mix. Tire crumb has never been used before in a septic tank drain field but its sorption properties with respect to nitrates and other chemicals has been tested in other applications with success in the removal of nitrates.

Batch study (bench scale study) was then performed to determine the expected life of the media mix in terms of sorption of ortho-phosphorus and nitrates. The required anoxic conditions were not developed in the batch study so nitrate removal was not seen. However, with respect to ortho-phosphorus the life of the media mix was determined to be between 27-40 years.

Columns (pilot scale study) were built to further investigate media mixes with tire crumb. Tire crumb has carbon content of 85%. and has no metal content. The tire crumb was mixed with sand, paper and sawdust. A common name of the fine sand used was Astatula or groove sand, and is commonly found in central Florida.

The media mixes that were tested were:

- Sand, Tire crumb and Sawdust (STS column)
- Sand, Tire crumb and Paper (STP column)

During the experimental period of six months the drain field columns were loaded with as high as thirteen fold over the normal average total phosphorus concentration and eight fold over the normal average total nitrogen concentration. Throughout the experimental period, both the columns with tire crumb showed almost equal and consistent removal of more than 90% for all the water quality parameters (ortho-phosphorus, total phosphorus, nitrates, total nitrogen, ammonia, BOD).

3.9 Conclusions

The desired hydraulic retention time of 24 hrs is achieved in the Black and Gold Nugget Mix™ Treatment Zone. The drain field column simulations showed removal rates consistently higher than 90%. The required hydraulic retention time for a drain field is between 24 hrs to 36 hrs; still a 24hr retention time is considered because lower the retention time results in a lower cost. The calculated cost of drain field media for both the Seepage and Treatment Zone is \$1,980 when using the Black and Gold Nugget Mix^{TM}. If the retention time increased to 36 hrs in the Treatment Zone, the total cost of the drain field media would be \$2,200. Also if just fine sand were used as a media for similar sized drain field the cost would have been \$1,680 but the drain field would not have provided the treatment level provided with using the Black and Gold Nugget Mix^{TM}.

During the experimental period the columns did not show any signs of saturation and continue to give significant and consistent results. Within the six months of experimental period the columns are loaded with a total mass of phosphorus equivalent to 1.62 years in a normal regular septic tank drain field with an average daily flow of 480 gpd and with a total mass of nitrogen equivalent to 1.5 years in a normal septic tank drain field with the same average daily flow.

Batch study (bench scale) is performed to determine the expected life of the media mix in terms of sorption of ortho-phosphorus and nitrates. The required anoxic conditions are not developed in the batch study so nitrate removal was not seen. However, with respect to ortho-phosphorus the life of the media mix was determined to be between 27-40 years.

Overall, this research demonstrates the effectiveness of sawdust and paper as a drain field media. This is most likely because the sawdust and paper function as electron donors and tire crumb as a carbon source. Also the Black and Gold Nugget Mix^{TM} have significant potential of pollutant removal in a septic tank drain field.

3.10 Recommendations

Black and Gold Nugget Mix^{TM} showed potentially high performance in a pilot study in terms of removal of BOD, total phosphorus, and nitrogen. The investigated media mix (Black and Gold Nugget Mix^{TM}) is likely to be useful in a septic tank drain field in full scale operations. It is recommended that the media mix of this research should be used in full scale septic tank drain field.

A drain field design that includes a treatment zone and a seepage zone is recommended. Additional design features are also included to facilitate redundancy or operation and sampling in an experimental situation.

3.11 Future Research

The laboratory performance is proven, now the use of Black and Gold Nugget Mix^{TM} in a field study (full scale operation) and with normal septic tank effluent is recommended. The field study would be more appropriate to examine the long-term performance and determine the expected life of the media mix in terms of removal of nutrients.

Exhaustion time of the media is determined based on bench scale laboratory phosphorus removal isotherms. Exhaustion time should now be determined based on full scale operation and nitrogen species. At the time of this report, plans were underway at the University of Central Florida to conduct these full scale tests.

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APPENDIX 3.A – SEPTIC TANK AND DRAIN FIELD CALCULATIONS

Size of Septic Tank					
Volume	1350	1200	1350	1500	gallons

Actual Drain field Size					
Flow rate	480	400	500	600	gpd
For "Fine sand" bed Maximum Sewage Loading rate to bed adsorption surface	0.7	0.7	0.7	0.7	gal/sq ft/day
Drain field size	686	571	714	857	sq ft
Length	30	30	30	30	ft
Nos of MPS 11	10	9	11	13	
Width	24	21	26	31	ft
Actual Drain field size	720	630	780	930	sq ft
Depth	2	2	2	2	ft
Unobstructed area	1440	1260	1560	1860	sq ft
Volume	1440	1260	1560	1860	ft^3

Black and Gold Nugget Mix™ Treatment Zone					
Length	10	10	10	10	ft
Width	24	21	26	31	ft
Height	1	1	1	1	ft
Volume	256.5	234.75	284.75	334.75	ft^3

Seepage Zone					
Volume	1147.5	993.75	1236.25	1478.75	ft^3

Hydraulic Retention Time, t					
HRT	1.00	1.10	1.07	1.04	days

Mass of Media Calculation in Black and Gold™ Treatment Zone					
Total mass of media	15911	14562	17663	20765	lbs
Mass of Tire crumb	1726	1580	1916	2253	lbs
Mass of Sawdust	636	582	707	831	lbs
Mass of Sand	13548	12399	15040	17681	Lbs

Mass of Media Calculation in Seepage Zone

Mass of Sand	89253	77294	96156	115017	Lbs

Total Cost of Media in the Black and Gold Nugget Mix™ Treatment Zone

Cost of Tire crumb	345	316	383	451	$
Cost of Sawdust	25	23	28	33	$
Cost of Sand	271	248	301	354	$
Total Cost of media	642	587	712	837	$

Total Cost of Media in the Seepage Zone

Cost of Sand	1,339	1,159	1,442	1,725	$

Total Cost of Media in the Drain field

Cost of Media	1,980	1,747	2,155	2,563	$
Cost of Media / CY	37.17	37.47	37.33	37.24	$

Mass of Media (Sand alone)

Mass of Sand	112003	98003	121337	144671	Lbs

Total Cost of Media in the Drain field (Sand alone)

Cost of Media	1,680	1,470	1,820	2,170	$
Cost of Media / CY	31.53	31.53	31.53	31.53	$

Sample Calculation for the drain field sizing for a flow of 480 gpd

From the flow rate (480 gpd), the size of Septic tank is obtained from **Error! Reference source not found.**.

For "Fine sand" bed Maximum Sewage Loading rate to bed adsorption surface = 0.7 gal/sf/day.

Drain field Area = 480/0.7 = 686 sq ft.

Taking length of drain field = 30 ft

Width = Area / Length = 686 / 30 = 23 ft.

Each MPS – 11 = 28 inch.

To adjust 10 MPS – 11, 23 ft of width is modified to 24 ft.

And depth of the drain field cannot be more than 2 ft, Depth = 2 ft.

New drain field area = 24 * 30 = 720 sq ft.

And unobstructed area (safety factor of 2) = 2 * 720 = 1440 sq ft.

Volume of drain field = 24 * 30 * 2 = 1440 ft^3.

For Black and Gold Nugget Mix™ Treatment Zone;

Length = 10 ft.

Width = 24 ft (same as drain field).

Height = 1 ft.

Volume of Black and Gold Nugget Mix™ Treatment Zone = 240 ft^3 + ½ (1) (1) (24)

(for Pre-fabricated riser). = 256.5 ft^3.

For Seepage Zone;

Volume = Total drain field volume – Black and Gold Nugget MixTM Treatment Zone –

Remaining Pre fabricated riser

= 1440 – 256.5 – 36

= 1147.5 ft^3.

Hydraulic Retention time = Volume of Black and Gold Nugget Mix™ Treatment Zone/Flow rate*porosity

= 1.0 days ≈ 24 hrs.

Mass and Cost of media in Black and Gold Nugget Mix™ Treatment Zone;

Mass = Total Volume * Density (of 62.05 lbs/ft^3) = 256.5 * 62.05 = 15911 lbs

Tire crumb = 10.85% of total mass = 1726 lbs

Sawdust = 4% of total mass = 636 lbs

Sand = 85.15% of total mass = 13548 lbs

Cost of tire crumb = 0.20 $/lb * 1726 lbs = $ 345

Cost of sawdust = 0.04 $/lb * 636 lbs = $ 25

Cost of sand = 0.015 $/lb * 13548 lbs = $ 271

Total Cost of media in the Black and Gold Nugget Mix™ Treatment Zone = $ 642

Mass and Cost of media in Seepage Zone;

Mass of Sand = Total Volume * Density (of 62.05 lbs/ft^3) = 1147.5 * 77.78 = 89253 lbs

Cost of sand = 0.015 $/lb * 89253 lbs = $ 1,339

Total Cost of media in the Drain field = $ 1,980

Cost of media/CY = 1980/1440/0.037 = $ 37.17/CY.

Mass and Cost of Drain field (Sand alone);

Mass = 1440 ft^3 * 77.78 lbs/cf^3 = 112003 lbs

Cost of Sand = 112003 lbs * 0.015 $/lb = $ 1,680

Cost of media/CY = 1680/1440/0.037 = $ 31.53/CY.

CHAPTER 4 – CHAMBER UPFLOW FILTER AND SKIMMER (CUFS)

4.1 Introduction

Stormwater runoff has become an increasing concern due to the pollution it contributes to receiving surface water bodies. The classification of "surface water" includes all water open to the atmosphere, such as rivers, lakes, and reservoirs (USEPA, 2008). Surface waters provide a source of drinking water, recreational activities and food for human consumption due to the diversity of plants and animals within the water.

To understand what factors influence stormwater runoff, a water budget should be analyzed. A water budget shows how much water is contained in all possible locations, represented as a mass balance (Wanielista et al., 1997). Precipitation transfers water from the atmosphere to the ground, where it can infiltrate, transpire from plants, evaporate from water surfaces, runoff, or go into storage. Runoff occurs when precipitation falls on an area too quickly for infiltration or storage, or when it falls on a surface that restricts infiltration and storage. This runoff water mixes with pollutants as it travels over land, carrying them to its final destination. Nutrients, sediments, and metals, all capable of mixing with stormwater runoff, are among the leading causes of impairment in the rivers, lakes, and estuaries assessed by the Environmental Protection Agency's 2002 National Water Quality Inventory Report (USEPA, 2007).

Although growing cities and continuous development create more impervious surfaces, the stormwater runoff can be managed with a reduction in pollution. Stormwater detention ponds minimize pollution effects of stormwater runoff on a receiving water body. Considered as one of the most efficient Best Management Practices (BMPs), a wet detention pond removes contaminants through physical, biological, and chemical processes (USEPA, 1999). Physically, particulates, organic matter, and metals settle out of the stormwater and into the pond, allowing cleaner water to discharge from the pond. Biological processes use dissolved nutrients as food, eliminating them from the runoff (USEPA, 1999). Chemical reactions occur between some pollutants and the pond's soil, resulting in adsorption of the particles to the soil. However, the pond only removes a certain percentage of a contaminant, and the discharged pollution, although significantly less than in stormwater runoff, may still damage a fragile receiving water body. For example, the target concentrations for total phosphorus and total nitrogen in Lake Jesup in central Florida are 0.044 and 0.61mg/L, respectively (Gao, 2005). Also the wet detention ponds may not remove enough nutrients to meet TMDL regulation standards. This research provides a possible addition to a detention pond in Seminole County, Florida using a Chamber Upflow Filter and Skimmer (CUFS), which can increase the removal of phosphorus and nitrogen by the system

4.2 Objectives

One option to increase the pollutant removal efficiency of a detention pond is to install a CUFS. This research aims to evaluate the performance of a CUFS in terms of water quality, water quantity, and overall operation and maintenance. Specifically, the objectives are:

1. estimate the head loss through an upflow filter with a chosen media mix
2. test the applicability of a surface skimmer

3. assess nitrogen and phosphorus concentrations leaving a detention pond using a CUFS setup with Black and Gold Pond Media ™ .

4.3 Limitations

The results of this section of research are limited to the Central Florida climate, and a well functioning detention pond designed to the current standards. The pond does produce significant phosphorus removal efficiencies. Also, the media used for pollutant removal is limited to one media mix, namely Black and Gold Pond Media ™.

4.4 Background Treatment Information

Wet detention ponds, also referred to as wet ponds or stormwater ponds, are the most frequently used water quality and quantity treatment option for stormwater runoff. A wet detention pond (hereinafter called simply "detention pond") receives a large volume of water over a short period of time and releases that water over a long period of time. The St. Johns River Water Management District defines a wet detention system as, "The collection and temporary storage of stormwater in a permanently wet impoundment in such a manner as to provide for treatment through physical, chemical, and biological processes with subsequent gradual release of the stormwater" (SJRWMD, 2006). Local and state governments set regulations on required dimensions and features of newly constructed detention ponds. Some typical dimension regulations for Central Florida include the following: side slopes of at least 6:1

to provide a littoral zone (to encourage rooted aquatic plant growth), length to width ratio of 2:1 to increase settling, and an average hydraulic residence time (length of time that the runoff stays in the pond) of 14 days from June through October (SJRWMD, 2006).

Detention ponds vary in regards to pollutant removal efficiency due to location and loading from influent stormwater runoff. Environmental factors such as temperature of the detention pond may affect the biological uptake of pollutants (USEPA, 1999). Kantrowitz and Woodham (1995) studied a detention pond in Pinellas County, Florida to investigate the removal efficiency of certain pollutants. The reported removal efficiencies for nitrate/nitrite, organic nitrogen, phosphorus, ortho-phosphate, and total suspended solids are 23%, 2%, 40%, 52%, and 7%, respectively. They attribute the variable removal efficiencies of nitrogen species to the complex chemistry of nitrogen and its occurrence in various oxidation states. They suggest that the detention pond reduced phosphorus and ortho-phosphate loads via chemical precipitation, dilution, and biological uptake (Kantrowitz and Woodham, 1995). Harper (2006) shows comparative removal efficiencies for total phosphorus and total nitrogen by wet detention ponds and indicates removals of nearly 65% and 30% for total phosphorus and total nitrogen, respectively (Harper, 2006). Other selected research studies compiled by Harper and Baker (2007) show detention pond removal efficiencies of total nitrogen, ortho-phosphorus, total phosphorus, and total suspended solids of 37%, 79%, 69%, and 77%, respectively.

The nutrient loading into a receiving surface water body depends on the removal efficiency of a detention pond. The Department of Environmental Protection defines a total maximum daily load (TMDL) as "the maximum amount of a given pollutant that a water body can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses" (Gao, 2005a). In a TMDL report proposed by the Florida Department of Environmental Protection, Gao (2005b) compares target nutrient concentrations from studies performed by the St. Johns River Water Management District (SJRWMD) to those concentrations predicted by models from the Florida Department of Environmental Protection (FDEP) for Lake Jesup in Florida.

The SJRWMD examined several approaches to find a target nutrient concentration for Lake Jesup, which ranged from 0.04 to 0.076 mg/L for total phosphorus and 0.61 to 2.4 mg/L for total nitrogen. Gao (2005b) suggests taking an average of the total phosphorus concentrations above 0.70 mg/L and the total nitrogen concentrations above 1.0 mg/L, which results in a target total phosphorus concentration of 0.073 mg/L and total nitrogen concentration of 1.30 mg/L. The FDEP then performed an analysis using watershed and water quality models and found that the target concentrations should be adjusted to 0.094 mg/L and 1.32 mg/L for total phosphorus and total nitrogen, respectively (Gao, 2005b). Water clarity was also used to develop standard concentrations for Lake Jesup. The SJRWMD found concentrations of total nitrogen and total phosphorus that provide sufficient water clarity for growth of submerged aquatic vegetation (SAV) over 25% of Lake Jesup. SAV growth should enhance fisheries and provide wildlife habitat, as well as reduce the resuspension of flocculent organic sediments. The total nitrogen and total phosphorus target concentrations that allow the 25% SAV criteria are 0.61 mg/L and 0.044 mg/L, respectively (Gao, 2005b). These concentrations will be used as the standards for Lake Jesup in regards to the CUFS research project.

The TMDL report for Lake Jesup shows a current annual load entering the lake of 559,500 kg/year of total nitrogen and 36,000 kg/year of total phosphorus. Surface runoff accounts for 42% and 48% of the total nitrogen and total phosphorus loadings into the lake, respectively. The results from the studies performed by the FDEP show the loading into Lake Jesup should be reduced to target loads of 252,600 kg/year and 21,400 kg/year of total nitrogen and total phosphorus, respectively. To meet the TMDL standards, the loading into the lake should decrease 52% for total nitrogen and 37% for total phosphorus (Gao, 2005c). Since no point sources discharge into the lake, these goals must result mainly from reduced nutrient concentrations in stormwater runoff.

Contaminated stormwater runoff, although treated by a detention pond, may exceed these concentrations and cause harm to Lake Jesup. According to Chapter 62-40 of the Florida Administration Code, a stormwater pond shall achieve an 80% average annual load reduction of pollutants from the influent stormwater. The current law refers to the removal of solids only. The data compiled by Harper and Baker (2007a) from previous research studies suggest that detention ponds do not achieve this 80% goal for the nutrient pollutants of concern. The averages of the removal efficiencies from these studies show a 37% removal of total nitrogen, 79% for ortho-phosphorus, and 69% for total phosphorus (Harper and Baker, 2007a).

Upflow filtration for stormwater treatment is a relatively new idea to remove pollutants from contaminated stormwater runoff. The common method for any type of filtration processes utilize traditional down-flow filters, where water enters at the top of the filter and flows by gravity through the filter media and out at the bottom. Granular activated carbon filters, sand filters, trickling filters, among others, are used for drinking water or wastewater treatment and function in this manner. While these down-flow filters achieve water treatment, they require periodical backwashing to unclog the filters at the end of a run.

Upflow filters have the advantage of longer run times and less maintenance due to the design of the filter. Khambhammettu et al. (2006a) used an upflow filter to treat runoff from highly contaminated critical source areas (large paved areas, heavy equipment storage lots, etc.) before it mixed with runoff from less contaminated areas. Upflow filtration was the chosen treatment option for the work due to the fast clogging of traditional downflow filters, reducing the flow rate potential and treatment capacity. Clogging of the filter requires more maintenance or pretreatment of the stormwater runoff for solids removal (Khambhammettu et al., 2006a). Khambhammettu et al. (2006a) pointed out that the upflow filter requires less maintenance than traditional filtration because heavier particles settle into the sump below the filter, which reduces filter clogging. They studied a field application of the upflow filter inserted into a catch basin that achieved reductions of 70% for suspended solids, 65% for turbidity, and 18% for phosphorus (Khambhammettu et al., 2006a). Khambhammettu et al. (2006c) also looked at flow rates through the upflow filter for different media types under test conditions and reported maximum flow rates of about 30 gallons per minute for a filter area of 1.5 ft^2.

Khambhammettu et al. (2006b) states that upflow filters remove pollutants via multiple treatment processes. The Upflow Filter ™ removes pollutants via sedimentation, gross solids and floatables screening, moderate to fine solids capture, and sorption/ion exchange of targeted pollutants Khambhammettu et al. (2006b). Khambhammettu et al. (2006b) also suggests that using a sedimentation and sorption/ion exchange treatment train can reduce the stormwater effluent concentrations of particulate solids to a range of less than 5 mg/l to 10 mg/L and phosphorus to a range of 0.02 mg/L to 0.1 mg/L.

Clark (2001) investigated the effect of anaerobic conditions on the pollutant retention of filtration media. Since only the top of an upflow filter is exposed to air between storms, anaerobic conditions are highly likely. Clark (2001) examined four media types (sand, activated carbon, peat moss, and compost) and found that carbon, peat, and sand retained phosphorus during anaerobic conditions, but pollution retention was equal to or greater under aerobic exposure conditions than under anaerobic exposure conditions for ammonia, nitrate, and total nitrogen. Clark (2001) suggests that upflow filtration with these types of media may not be a suitable stormwater treatment option for locations where nutrient reduction is necessary.

The previous studies performed on upflow filtration collect water directly from stormwater runoff inside a catch basin. In these studies, the inlet grate on the catch basin removes large debris from the stormwater. However, an upflow filter for a detention pond requires a different form of large debris removal. This concept uses a floating surface skimmer to prevent large debris from entering the upflow filter. The surface skimmer, manufactured by J.W. Faircloth & Son, was originally intended to drain sediment basins and regulate outflow slowly at a constant rate to maximize settling within the basin. The skimmer floats at the water surface, so it drains the water at the top of the basin first, allowing settling to occur in the water column below the skimmer (Faircloth, 2005).

Two companies, Hydro International and USI, currently market upflow filters for runoff treatment in stormwater inlets. Of all the literature reviewed, there is currently no research or manufacturers that use an upflow filter fed by a detention pond and surface skimmer to treat stormwater runoff. Furthermore, the upflow filter in this research uses a modification of the

Black and Gold Green Roof Pollution Control™ media investigated by Hardin (2005) to remove phosphorus from irrigation water in green roof applications.

4.5 Site Characteristics

Watershed Site Location for Full Scale Testing

The wet detention pond used for the field demonstration is located in the Lake Jesup Watershed in Central Florida and discharges to Howell Creek that flows into Lake Jesup (Figure 4.5). Lake Jesup is located within the Middle St. Johns River Basin (Gao, 2005). Its watershed extends into Seminole and Orange counties and covers more than 87,000 acres, and the lake itself has a surface area of about 10,660 acres (Gao, 2005). Lake Jesup, much like the surrounding lakes and the St. Johns River, is a popular lake for outdoor activities such as fishing and boating.

Figure 4.5: Pond Outflow into Howell Creek and Lake Jesup

However, decades of discharges, including stormwater runoff, have taken a toll on the Lake. Lake Jesup has been identified as one of the most hypereutrophic lakes in central Florida, as displayed by often fish kills and pea-green colored water (FDEP, 1997). The Middle St. Johns River Basin, including Lake Jesup, was named a Surface Water Improvement and Management (SWIM) priority water body. The Florida Legislature developed the SWIM program in 1987 to identify polluted water bodies (FDEP, 2007). More recently, Lake Jesup was defined as an impaired water body for nutrients using the Identification of Impaired Surface Waters Rule (IWR) from assessments performed between January 1, 1996 and June 30, 2003 (Gao, 2005). Section 303 (d) of the Clean Water Act requires states to identify impaired water bodies (those that do not meet applicable water quality standards) and establish Total Maximum Daily Loads

(TMDLs) for those water bodies (FDEP, 2008). The TMDL for nutrients and unionized ammonia for Lake Jesup was prepared in 2005.

Several small waterbodies feed into the south end of Lake Jesup, including Howell Creek, Gee Creek, Sweetwater Creek and Soldier Creek. These creeks receive rain and stormwater runoff from cities in the watershed, some of which include Winter Springs, Longwood, and Oviedo. The Florida Department of Environmental Protection divided the watershed into the following five sub-basins: Gee Creek, Howell Creek, Lake Jesup, Little Lake Howell, and Soldier Creek (Gao, 2005).

Wet Detention Pond Site for Full Scale Testing

The site for the upflow filtration project is located in Seminole County, Florida. The CUFS receives water from Red Bug Stormwater Pond B (which will be referred to as red bug pond), which is located on the south side of Red Bug Road, east of the intersection of Red Bug Road and Tuskawilla Road, as shown in Figure 4.6.

This stormwater pond is contained within the Howell Creek sub-basin of Lake Jesup. Howell Creek, the primary waterway in the basin, originates from Lake Maitland in Orange County and ends at Lake Jesup in Seminole County. It flows in a northeasterly direction and connects with Bear Gully Canal near S.R. 419 (“Final Engineering Report”, 1990). The Howell Creek sub-basin encompasses many highly urbanized areas and accounts for 35% of the total surface runoff in the Lake Jesup watershed.

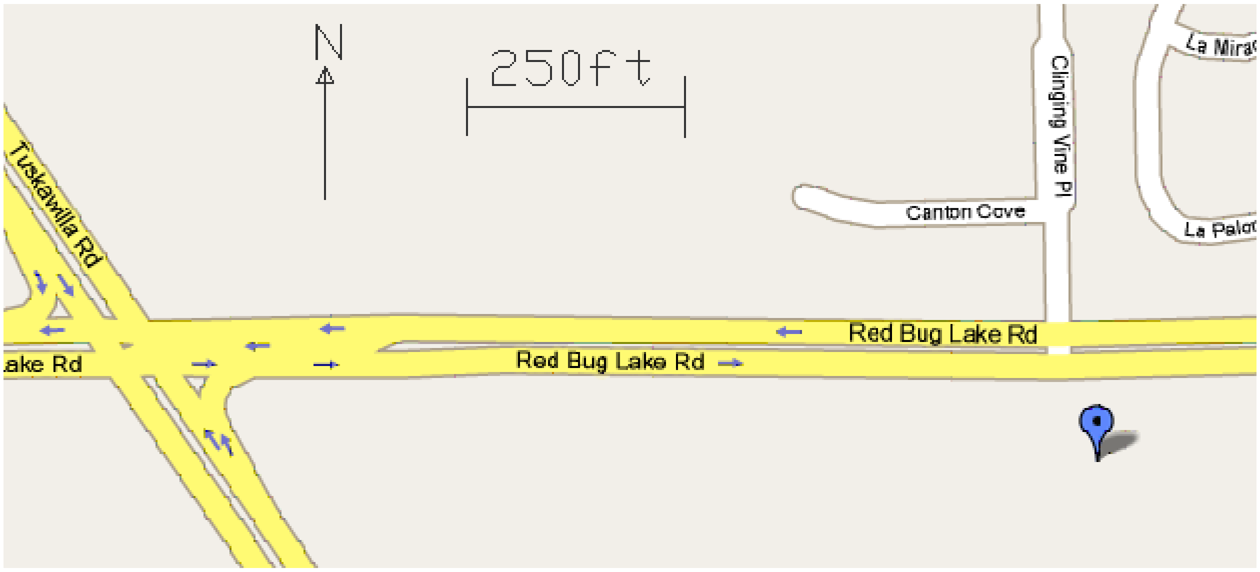


Figure 4.6: Location of Red Bug Stormwater Pond B in Seminole County

In terms of water quality, the Howell Creek sub-basin contributes 34% of the annual total nitrogen loading and 36% of the annual total phosphorus loading into Lake Jesup from data collected by the FDEP from 1995 to 2002 (Gao, 2005). These values show significant importance because the red bug pond discharges directly into Howell Creek.

This pond was constructed in 1990 as an improvement to stormwater control systems for the Lake Jesup Watershed in Seminole County. Before construction of the pond, stormwater runoff, created by Red Bug Lake Road and the Sunrise Unit One development, traveled through roadside ditches and culverts into Howell Creek. The Sunrise Unit One residential development contributed to the runoff via a small storm sewer system that discharged directly into the ditches along Red Bug Lake Road and Rising Sun Boulevard. This system provided no treatment to the runoff before entering Howell Creek. The stormwater pond (red bug pond B) was constructed to enhance the water quality of the stormwater runoff created by the widening of Red Bug Lake

Road and the surrounding residential developments, including Sunrise Unit One. Prior to construction, the 46.89 acres of drainage area consisted of the following: 4.28 acres of roadway and miscellaneous impervious areas, 7.56 acres of open spaced grassed areas, 3.9 acres of mixed brush and woods, and 31.15 acres of residential development. Following construction in 1990, the cover description changed to 9.02 acres of impervious surfaces, 6.72 acres of open spaced grassed areas, and 31.15 acres of residential development ("Drainage Report/Calculations", 1990). The drainage area for red bug pond B is shown below in Figure 4.7. The Soil Conservation Service (SCS) Soil Survey of Seminole County determined the soils in the drainage area as type "D" and type "C". These soils consist of poor hydraulic conductivity with poor drainage, resulting in moderately high runoff potential (Wanielista et al., 1997).

Figure 4.7: Red Bug Pond B Drainage Area

Red bug pond B treats stormwater runoff from the following sources: offsite drainage from the Sunrise Unit One Development, the portions of Red Bug Lake Road included within the drainage area, and 2.51 acres of adjacent development not accounted for in the corresponding stormwater pond. A circular orifice and inlet grate control the design high water elevation and peak discharge rate ("Drainage Report/Calculations", 1990).

Red Bug Wet Detention Pond Characteristics

Red bug pond B adheres to the design regulations set by St. Johns River Water Management District and Seminole County for wet detention ponds at the time of construction in 1990. These regulations require the pond to store the first one inch of runoff over the entire basin or 2.5 inches of rainfall times the impervious area, whichever is greater. The pond cannot discharge more than half of the pollution abatement volume within the first sixty hours following a storm event, and the permanent pool volume must provide a minimum residence time of 14 days as measured in the wet season. In addition, the post-development rate of discharge cannot exceed the pre-development rate for a 25-year frequency, 24-hour duration storm event ("Drainage Report/Calculations", 1990). Specific details on the pond geometry and performance are shown below in Table 4.5. The methodologies shown in SCS Technical Release 55: *Urban Hydrology for Small Watersheds* were used to determine the pre- and post-development curve number (CN) and pre-development time of concentration (Tc).

Table 4.5: Red Bug Pond B details ("Drainage Report/Calculations", 1990)

Pond Category (Units)	Value
Rainfall distribution used for calculations	SCS FL Type II Modified
Drainage area (ac)	46.89
Pre-development Curve Number (CN)	81
Post-development Curve Number (CN)	84
Allowable Discharge (cfs)	159.02
Proposed Discharge (cfs)	131.5
Pre-dev. Time of Concentration (hr)	0.73
Normal Water Surface Elevation (ft)	38.4
25 yr, 24 hr peak pond elevation (ft)	42.52
Tailwater condition (ft)	40.46
Littoral zone slope (H:V)	6:1
Pond area at N.W.S.E. (ac)	2.24
Length to Width Dimensions (ft:ft)	629:155
Permanent Pool Volume (ac-ft)	12.0
Max. depth at N.W.S.E. (ft)	9.0
Average Depth (ft)	5.4

4.6 Experimental Setup

The application of an upflow filter appears to be a viable treatment option to reduce the nutrient loadings from the effluent of a wet detention pond. The studies performed on upflow filtration mentioned in the previous background section indicate acceptable nutrient removals and minimal maintenance. These studies make the application of the CUFS a viable option to reduce nutrients discharged from a detention pond.

The setup of the CUFS consists of a floating pond skimmer connected by a pipe to the bottom of a precast concrete chamber. The chamber houses the filtering media which serves as the main nutrient removal mechanism in the setup. The concrete has a thickness of 6 inches on all sides which prevent the structure from collapsing during construction activities and normal underground forces. The floating pond skimmer is the inlet that directs water from the surface of the pond through the filter. The inlet at the surface allows heavier particles to settle in the pond, and the water has fewer particles that will travel to the filter. The skimmer also prevents floating trash (soda bottles, plastic bags, etc) from entering the inlet pipe and clogging the filter

The skimmer helps provide the power required to push the pond water through the filtering media and out to the pond effluent. This happens as a result of the difference in water elevations between the pond and upflow filter. At a time when no inflow to the pond is encountered (no stormwater runoff), the water level in the stormwater pond will equal that of the upflow filter (the actual water surface elevation in the filter will be lower than that of the pond due to the head loss of the filtering media). Since the skimmer floats at the water surface of the pond, the skimmer inlet elevation will equal that of the water elevation in the upflow filter, and the Black and Gold Pond Media ™ will not treat any water. When water enters the pond (during and after a storm event), the pond water surface elevation rises, along with the floating skimmer. The rise in the skimmer provides a difference in water surface elevation between the pond and the surface of the upflow filter because the outlet pipe in the filter prevents the water surface from rising to the elevation of that of the pond. The elevation head differential supplies the power required to push the pond water through the upflow filter and out, to the pond effluent pipe. Flow through the filter occurs until the pond water surface elevation decreases to an elevation higher than the bottom of the filter outlet pipe (equal to the head loss of the filter). With the head loss accounted for, the filter will begin and stop discharging water when the pond begins or stops discharging water.

Experimental Setup for Head Loss

For flow conditions, the upflow filter must pass a certain amount of water to be feasible as a pollution control option. An ordinary filtration velocity range between 2 to 5 gpm/ft^2 (Cleasby and Logsdon, 1999) is considered for the design of the filter. Because the water is flowing through filtering media, it will experience a certain amount of head loss during these conditions. Determination of the head loss allows the elevation of the filter outlet pipe to be set lower than the pond outlet pipe to account for the head loss. The minor losses due to friction and fittings are assumed to be negligible.

The head loss of twenty-four inches of Black and Gold Pond Media ™ is determined in the laboratory through the use of clear HDPE pipe in the shape of a "U", as shown in Figure 4.8.4. The procedures for the experiment are located in Appendix A. Examined are different flow rates of water, which enters and flows down one side of the "U". It travels across the bottom and up through the filter media, which is located on the other side. Permeable plastic rings and black fabric mat enclose the filter media inside the clear pipe to hold the media in place during flow conditions (as it will in the actual application). The difference in water levels during this experiment show the amount of head loss encountered through the filter media. Also, the amount of outflow from the filter compared to the inflow rate shows the flow differences at a specified head loss. This provides an estimate of the head loss where the inflow would equal the outflow.

Water is added to the device at desired surface loading rates (SLR), or filtering velocities, of 1, 2, 3, 4, and 5 gpm/ft^2. The head losses produced at these velocities are shown below in Figure 4.9. The head loss for 5 gpm/ft^2 resulted in a value larger than the maximum for this experiment (7 inches). To get a full range of values, the head loss was determined for 18 inches of Black and Gold Pond Media ™. This head loss was then multiplied by 4/3 (or 24 in / 18 in), to scale up the value for 5 gpm/ft^2 for 24 inches of media. With the scale-up, the maximum head loss for 24 inches of Black and Gold Pond Media ™ is 8.8 inches. Therefore, the bench study concludes that a head loss of nine inches would allow a surface loading rate between the desired range of 1-5 gpm/ft^2.

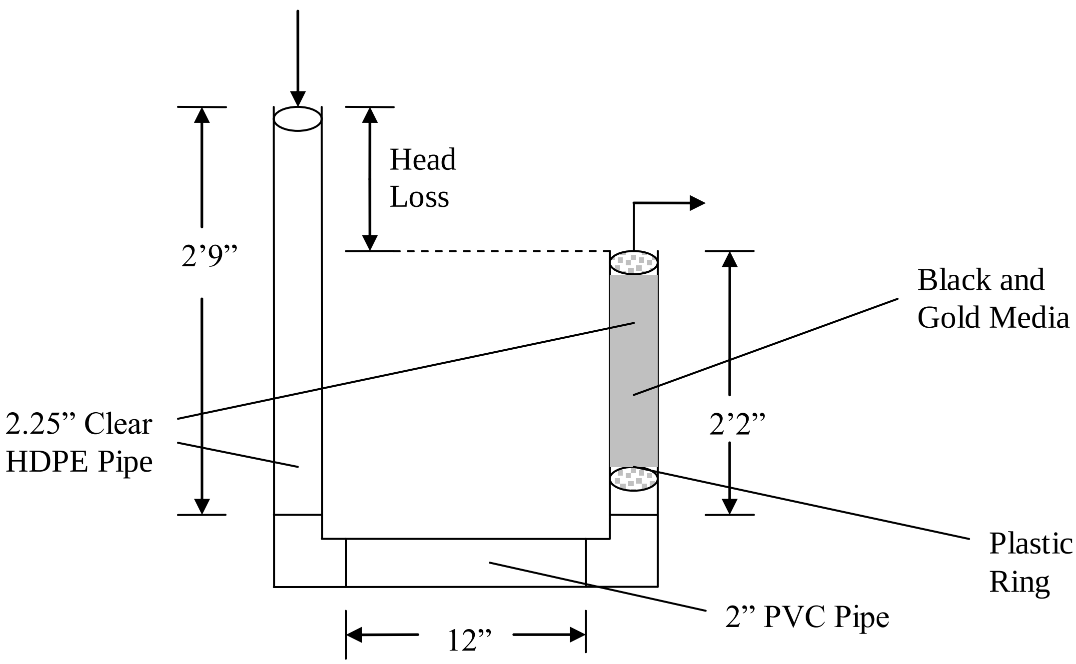


Figure 4.8: Bench Scale Setup for Head Loss Determination (N.T.S.)

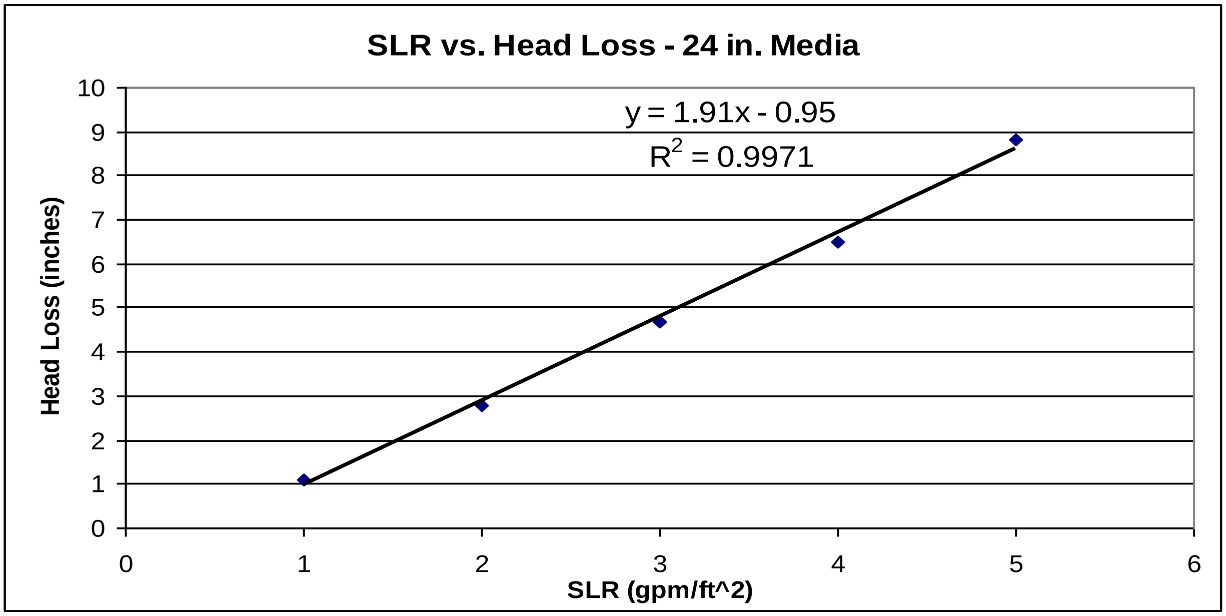


Figure 4.9: Results from Bench Study head loss experiment

Pilot Study

Another experiment confirmed the functionality of the upflow filter on a larger scale than the bench study but a smaller scale than the actual field application. This study required the development of procedures for installing a CUFS, from the original surveying to the final installation. It also incorporated the floating pond skimmer to provide a flow through the bottom of the filter.

The pilot study filter is located on a small pond on the campus at the University of Central Florida (UCF). This pond simply slows down runoff water upstream of a wetland, and the dimensions do not conform to typical design standards. The pond has dimensions of 100' by 40' during normal flows, with a rectangular weir outlet and average depth of 3 feet. The stormwater collection system for the university consists of typical grates, curb and gutters, and underground concrete pipes. This system drains more than 20% of the campus during a storm event. Downstream of the weir, the water travels underneath Gemini Boulevard into a wetland on campus. From there, the water flows into Bonneville Creek and into the St. Johns River.

The pilot chamber structure consists of a DOT Type C inlet, which measures 2' X 3' of surface area. The inlet holds two feet of Black and Gold Pond Media ™ inside. The CUFS is installed adjacent to the rectangular weir outflow on the southern end of the pond. The skimmer connects to the piping into the bottom of the chamber, and the filter effluent flows into the pond effluent downstream of the weir. This network allows the CUFS to function in parallel with the pond effluent structure to directly compare the water quantity and quality data for storm events.

Red Bug Road Wet Detention Pond Full Scale Field Application

The first full scale field application of the CUFS occurred on site at Red Bug Stormwater Pond B, located off of Red Bug Road in Seminole County. Out of the numerous possible wet detention facilities in the Central Florida area, this site provided some advantages, such as:

1. The banks of the pond were large enough to allow easy access for machinery and materials to work in the construction of the CUFS.
2. The drainage area contained a mixed land use of impervious areas, some grassed areas, and residential development typical of a common stormwater pond in Central Florida.
3. The pond is a fully functional wet detention facility with year-round water.
4. The pond is significantly larger than the experiment conducted in the pilot study.
5. The pond has a reasonable design, with the inlet far enough away from the outlet.
6. It has close proximity to the research facility (university) for laboratory testing and reduced cost of travel.
7. Seminole County supported the project, so a pond location within the County is prudent.

The field application wet detention pond drains a significantly larger area than the pilot study pond, which requires a scale-up of some dimensions in the design of the upflow filter. The larger stormwater pond requires an increase in the flow discharged through the surface skimmer and therefore, an increase in surface area of the upflow filter. To house the larger filter, a DOT Type D inlet was chosen because it contains twelve square feet of surface area. At the maximum possible flow from the four inch skimmer (based on Faircloth (2005)), this size inlet will provide a surface loading rate within the acceptable range of 2 to 5 gpm/ft^2. The CUFS is installed in parallel with the detention pond outlet, as shown in Figure 4.6. Stormwater from the detention pond flows down the inlet pipe, up through the filtering media, and out the filter outlet pipe. The outlet from the filter connects to the concrete outlet pipe of the pond, and the filtered water and effluent pond water mix and travel to Howell Creek.

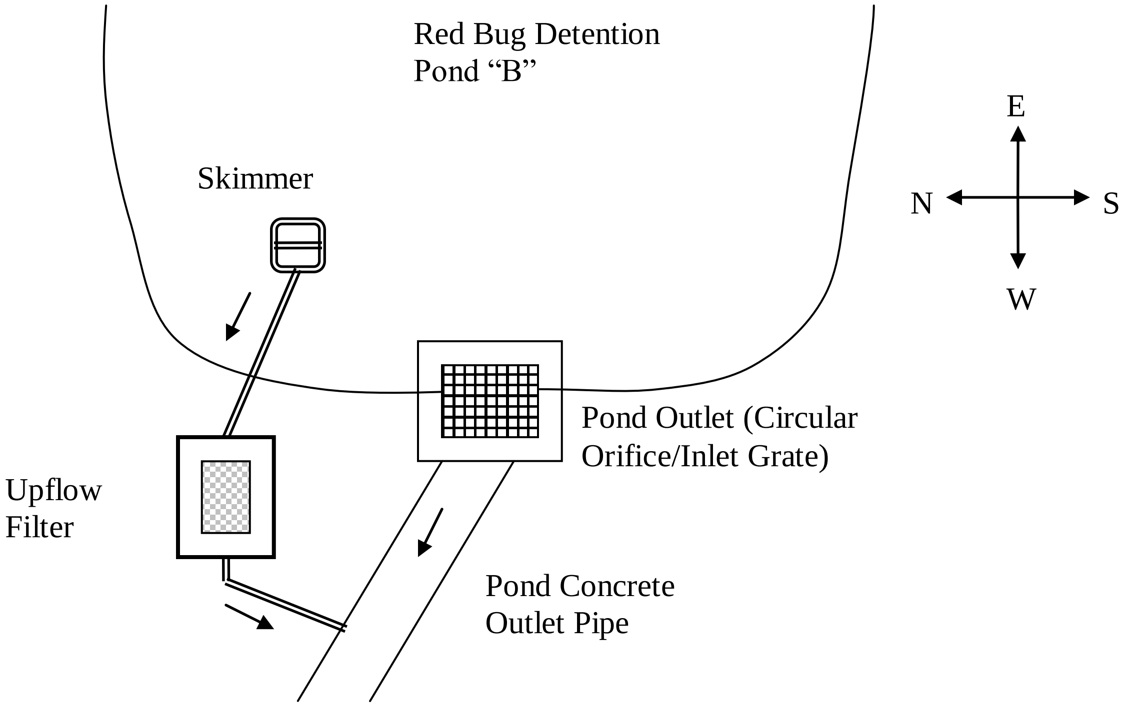


Figure 4.6: Plan View of Red Bug Pond B in Seminole County (N.T.S.)

Construction and Installation of the Full Scale Field Demonstration

Prior to ordering any materials, the site is surveyed to determine the necessary height of the type D inlet and the depth of the hole required to place the filter at the correct elevation. The results of the survey show the depth below the ground surface at which the filter outlet should be placed. The following surveying procedures are used at the red bug pond B:

1. Perform a calibration check (peg test) on the surveying equipment to determine the possible error.
2. Assume an elevation of 100 feet for a benchmark. The concrete overflow weir on the existing pond outlet is used as a benchmark.

3. Find the elevation of the bottom of the existing pond outlet pipe. This shows the elevation (in relation to the benchmark) where water will begin to exit the pond.
4. Find the elevation of the ground at the future filter location. The top of the chamber must be set at this elevation when installed.

Now that these elevation relationships are known, the required height of the type D inlet can be determined. From the survey, the bottom of the pond outlet pipe is 2'1" lower than the pond overflow weir (pond outlet elevation is 97'11"). Based on the head loss experiment, twenty four inches of Black and Gold Pond Media ™ will encounter nine inches of head loss at the specified flow. Therefore, the bottom of the outlet pipe on the filter must be nine inches lower than that of the pond outlet pipe, or at an elevation of 97'2". A free space of two inches is placed between the bottom of the filter outlet and the top of the pollution control layer. The pollution control layer is two feet deep, so the bottom of the pollution control layer is at an elevation of 95'. The inlet pipe to the filter (from the skimmer) is 4" PVC, and a 2" space below this pipe allows the larger, heavier particles to settle without clogging the filter. This positions the bottom inside of the type D inlet at an elevation of 94'6". The type D inlet contains a 6" thickness of concrete on all sides, so the bottom outside of the structure should be at an elevation of 94'. The land elevation for the chosen filter location is 102', so the inside of the filter should be 7' in length, with a total height of 8' (outside length). This also concludes that an eight-foot deep hole should be dug at the specified location. Extra space should be allowed for rocks to be placed underneath the structure to prevent sinking. A diagram of the filter is shown in Figure 4.7, which includes the six inches of concrete thickness but not the cleanout pipe.

The type D inlet, because of its large size, ships in two pieces, top and bottom. The main step to installing the filter is digging and preparing the hole. Because of the hole depth and proximity to groundwater at the site, the pond was dewatered for three days prior to installation. This allowed for less water during the excavation to minimize sloughing of the sides. Following dewatering, the following steps are performed:

1. Dig a hole with a depth of nine feet, with a width large enough so the sides do not cave in.
2. Dig a trench from the hole to the pond for the inlet pipe of the filter.
3. Place one foot of rocks at the bottom of the hole for a base to prevent sinking and shifting of the structure.
4. Position the bottom half of the type D inlet on top of the rock base, making sure the structure is level on all sides. Keep surveying equipment available on site to make sure of the depths and elevations. At this time, check the elevation of the bottom of the structure (in relation to the pond overflow weir) and adjust until the elevations conform to those in Figure 4.7**Error! Reference source not found.**.
5. Place two strips of tar/rubber connectors in between the bottom and top half of the inlet to seal the structure.
6. Lower the top half of the inlet onto the tar/rubber strips.
7. Place the 4" PVC inlet pipe into the structure and join with water cement.
8. Insert a section of pipe into the outlet hole and hold in place until the correct elevation is measured. Secure it with water cement.
9. Cut a hole in the top half of the existing pond concrete outlet pipe large enough for the 4" filter outlet pipe to fit.
10. Connect the filter outlet pipe to the pond outlet pipe with more water cement.
11. Assemble and attach the skimmer to the filter inlet pipe.
12. Install two posts in the pond and loop a rope that connects to the skimmer around the posts to prevent the skimmer from bending the inlet pipe during large storm events.

The upflow filter uses two feet of Black and Gold Pond Media ™ for pollution removal. This media must be positioned six inches above the bottom of the structure to allow room for the 4" influent pipe and space for the heavier particles to settle. The pollution control media has a bulk density at maximum water holding capacity of 61.35 lb/ft^3 (Penn State Agricultural Analytical Services Laboratory, 2006), so the supports must be able to hold this weight.

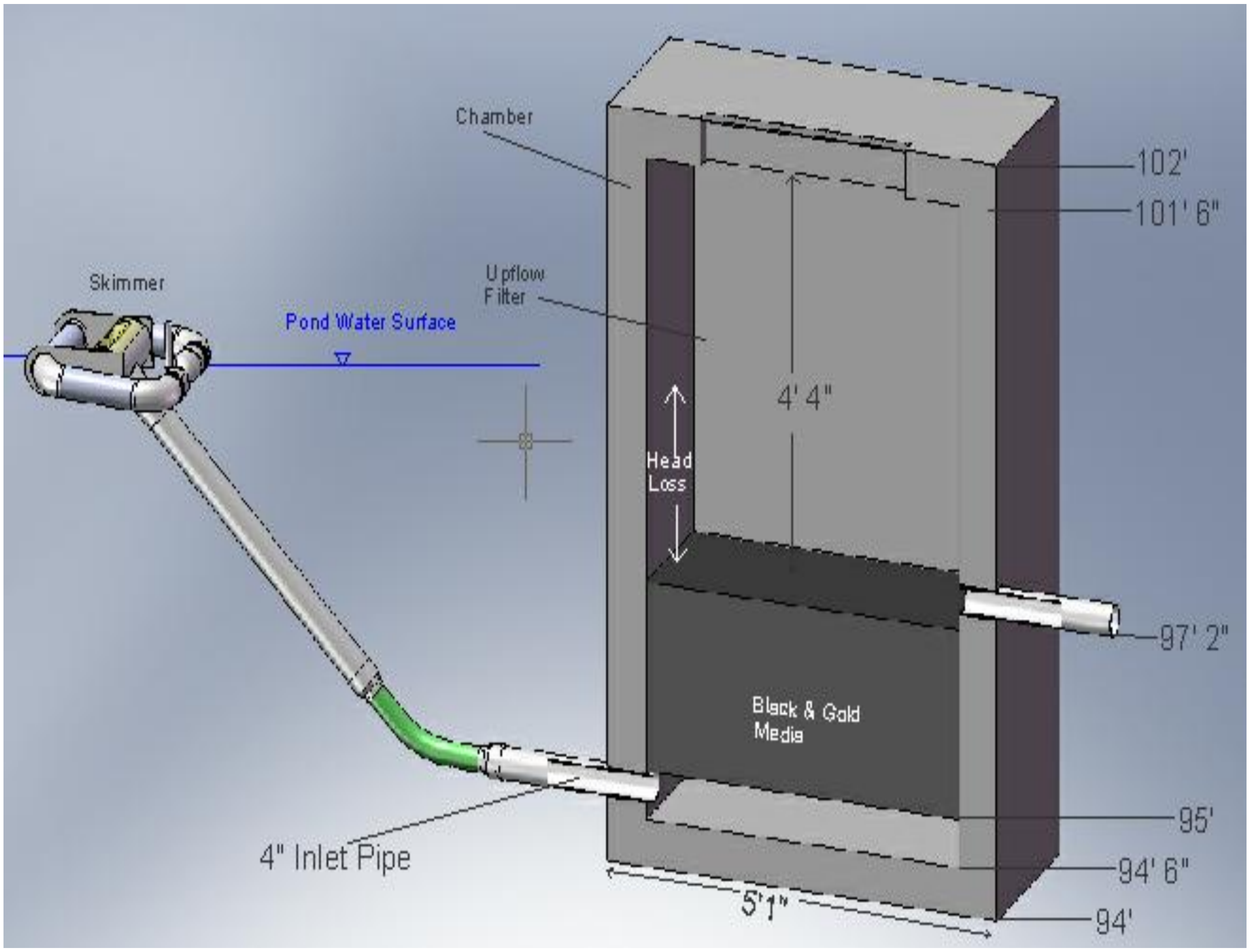


Figure 4.7: Red Bug Pond upflow filter with example elevations (cleanout pipe not pictured)

Milk crates, cut to the specified height of six inches, support the media and allow heavier particles to flow through the gaps in the crates. The bottoms of the crates have a structure able to support more than the greatest weight of the pollution control media and water. Necessary supports above the media and fabric prevent them from shifting up with the water flow. These consist of a structure of galvanized unistrut, cut into dimensions and held in place with tapcon screws through the concrete. A cleanout pipe with a radius of six inches travels through the filtering media to the bottom of the structure and allows the hose of a suction pump to reach the bottom of the filter structure. Two U-shaped notches in the end of the pipe allow space to pump out sediment and debris, which would not be possible if the pipe rested flush with the bottom of the filter structure. The pump then removes the heavier particles that settle out in the bottom. Assembling the filter device was performed as follows:

1. Cut the milk crates to fit inside the 4ft x 3ft inlet structure, with a height of 6 inches each. Some crates must be cut in half to piece together inside the structure.
2. Cut a 4" hole in the side of one crate that will be placed next to the inflow pipe of the filter.
3. Cut a hole large enough to pass a 6" PVC cleanout pipe in the top of another crate that will be used in the opposite corner from the inflow pipe.
4. Secure the crates to each other with zip ties and trim the tag ends.
5. Place a sheet of fabric over top of the crates, cutting slits in the corners so some of the fabric rises up the sides of the structure. Also cut a hole for the 6" cleanout pipe.
6. Cut two U-shaped notches in the end of a length of 6" PVC pipe (used as the cleanout pipe).
7. Install the 6" PVC pipe vertically though the hole in the milk crate, with the notches at the bottom of the filter structure. The required length of the pipe depends on the height of the filter structure.
8. Secure the fabric to the wall of the concrete structure and cleanout pipe with epoxy.
9. Spread and pack 24 cubic feet of Black and Gold Pond Media ™ on top of the fabric layer.
10. Place another fabric layer on top of the media, again leaving enough extra fabric to wrap up the sides of the structure. Cut a hole for the cleanout pipe and attach with epoxy.
11. Add a hose clamp around the cleanout pipe over top of the fabric to hold the fabric in place.
12. Install the lengths of galvanized unistrut around the sides of the structure, over the black fabric mat, with tapcon screws. This will prevent the sides of the fabric mat from lifting up with a flow of water.
13. Attach to each concrete side two U-shaped pieces of galvanized unistrut over top of the fabric to prevent the center of the fabric from lifting up with a flow of water.

Water Quality

For a detention pond that remains aerobic, it can be assumed that ammonia nitrogen in the runoff changes forms through nitrification. The reason for this change lies in the chemical equations for nitrification, which are

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Nitrifying bacteria convert ammonium to nitrite and then nitrite to nitrate in the presence of oxygen. Nitrite is relatively unstable and easily oxidized to the nitrate form. Ammonia-N should occur in the ionic form, due to the relatively neutral pH of stormwater. The pK for the ammonia species is 9.25, which represents the pH where 50% of both species are present. Below this pH, the ammonium ion exists in greater proportions, and at levels below pH 7, the ammonium ion is predominant (Metcalf and Eddy, 2003). Nitrification also consumes alkalinity, reducing the buffering capacity of the surface water.

The upflow filter uses Black and Gold Pond Media ™ to improve water quality in the stormwater runoff. This mix consists of 45% expanded clay, 45% tire crumb, and 10% saw dust. Laboratory tests performed on the Black and Gold Pond Media ™ (Penn State AASL, 2006) show the following parameters:

- Bulk density (dry weight basis) = 34.87 lb/ft^3
- Bulk density (at maximum water holding capacity) = 61.35 lb/ft^3
- Water permeability = 3.8 in/min
- Total pore volume = 62.4%

The CUFS accomplishes nitrogen removal through denitrification. Because the filter media contains water on the top and bottom and is contained within a closed chamber, the media is not exposed to air, developing anoxic conditions. These conditions allow the removal of nitrate through denitrification. In denitrification, nitrate is used as the terminal electron acceptor, and reduces ultimately to nitrogen gas, which releases into the atmosphere. Denitrification also increases the alkalinity of the water, providing more buffering to the surface water.

The tire crumb, expanded clay, and sawdust in the Black and Gold Pond Media ™ all contribute to pollutant removal from the water. The tire crumb and expanded clay are responsible for phosphorus removal via sorption, in which phosphate sorbs onto the media and leaves the water. Sawdust is the electron donor under anoxic conditions, allowing nitrate to become the terminal electron acceptor for denitrification, therefore reducing the nitrate concentration in the water.

Laboratory parameters measured in the comparison of the CUFS filtered stormwater to the detention pond only stormwater include the following: pH, alkalinity, turbidity, orthophosphorus, total phosphorus, nitrate + nitrite (NOx), total nitrogen, total suspended solids, total dissolved solids, and dissolved oxygen. The procedures followed for measuring each parameter are located in Appendix D of Ryan (2008). The pH of the water allows it to be classified as acidic, neutral, or basic and is tested with a pH probe. Alkalinity shows the buffering capacity of the water and is measured using a titration with 0.02 N sulfuric acid to reduce the pH of the sample to 4.5. Turbidity is measured in nephelometric turbidity units (NTU) with a turbidimeter. Total suspended solids include dirt and sediment picked up with the stormwater runoff as it travels over land and settle out of the pond water in the space at the bottom of the CUFS. Total dissolved solids can be removed by the CUFS via sorption with the Black and Gold Pond Media ™. Dissolved oxygen indicates whether the upflow filter is anoxic and capable of achieving denitrification.

Experimental Design

The field experiment was performed for nine months with water quality samples taken after storm events that contribute at least 0.2 inches of rainfall. During times of no rainfall, baseflows from the detention pond were sampled. The goal of stormwater runoff sampling from the detention pond is to measure the highest effluent nutrient concentration. This means sampling at a time when the highest concentration leaves the pond. The peak outflow from the Red Bug Road detention pond occurs 12.5 hours into the storm event for a 25 year, 24 hour storm ("Drainage Report/Calculations", 1990). The sampling times following a rainfall event vary to collect a range of samples for comparison. Rainfall is documented using an on-site rain gauge and a backup U.S. Geological Survey tipping bucket rain gage located 1.5 miles away (USGS).

To select the correct sized skimmer, a design surface loading rate range of 2 – 5 gpm/ft^2 is used. The maximum inflow for a 4" skimmer is 18, 267 ft^3 in 24 hours, or 0.2114 cfs (Faircloth and Son, 2005), which is divided by the inside surface area of the filter, as shown in the equation for SLR calculation below. The calculated SLR value exceeds the ranges tested for the head loss experiment, but ranges from 2 to 10 gpm/ft^2 are typically used for rapid granular bed filtration (Cleasby and Logsdon, 1999).

The outflow pipe in the upflow filter must also be large enough to handle the inflow. The filter outflow pipe is sized using the orifice equation (Equation 1), solving for H, which is the head on the pipe. From the calculations, the outflow pipe should be at least 4" in diameter.

Equation for SLR Calculation

$$Q_{in} = \frac{18{,}267\, ft^3}{24hr} * \frac{hr}{60\min} * \frac{7.48\, gal}{ft^3} = 94.9\, gpm$$

$$SLR = \frac{Q_{in}}{SA} = \frac{94.9\, gpm}{3\, ft\, x\, 4\, ft} = 7.9\ \frac{gpm}{ft^2}$$

Equation 1: Orifice Size Calculation

$$Q = C_d A\sqrt{2gH}$$

$C_d = 0.60$

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(4in * \frac{ft}{12in})^2 = 0.0873 ft^2$$

$$g = 32.2\frac{ft}{s^2}$$

$$H = \frac{(\frac{Q}{C_d A})^2}{2g} = \frac{(\frac{0.211cfs}{0.6 * 0.0873 ft^2})^2}{2(32.2\frac{ft}{s^2})} = 0.252\, ft * \frac{12\, in}{ft} = 3.02\ in$$

For sampling, this experiment compares the detention pond outflow to the CUFS outflow. Since the CUFS is installed in parallel with the detention pond, the two concentrations are directly compared. A lid on top of the chamber of the CUFS allows access to the top of the filter when opened. Water samples are taken from the CUFS with a water bottle attached to a string, and the samples are stored in one liter dark plastic bottles. When conditions and manpower allow, one liter of sample is taken directly from the outflow pipe of the filter, which requires walking into the concrete outflow pipe from the stormwater pond. One liter of sample is also taken from the surface of the detention pond near the outlet structure, in line with the skimmer.

The filter sampling bottles and one liter sample bottles are cleaned between sampling events with distilled water. EPA guidelines are used for times of lab analysis following a sampling event, and additional details are given in Ryan (2008).

4.7 Results and Discussion

Water Quality

A total of thirty-five sampling dates compare the red bug pond (referred to as “RBP” in the sample tables) outflow water quality to the Red Bug CUFS (referred to as “RBF”) filter effluent water quality. These samples are from twenty-eight storm events and seven baseflows collected over a period of nine months. The storm samples are taken at different time intervals following the event, with time ranges shown in Figure 4.8. Ten stormwater samples collected at the UCF pilot compare the pond (referred to as “AP”) to the pilot scale CUFS filter outflow (referred to as “AF”). The raw data for each sampling date for the Red Bug and the UCF pilot is located in the master spreadsheet in Appendix E of Ryan (2008).

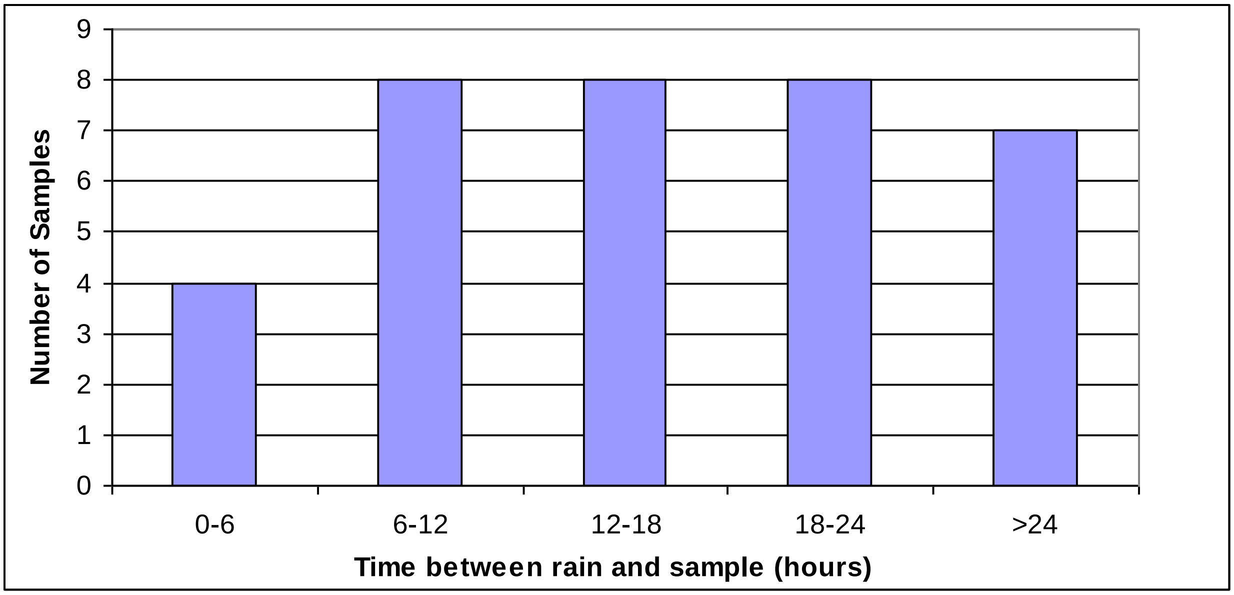


Figure 4.8: Number of samples taken at different time intervals

Quality assurance and quality control is conducted for each parameter in a sample set. To measure precision, duplicate samples are analyzed to produce a relative percent difference (RPD) between the two measurements. The accuracy of the measurements is determined by spiking a sample with a known concentration of the parameter and calculating the percent recovery. The measured duplicate and spiked samples are recorded (Ryan, 2008).

Another method of quality assurance and quality control compares the measured water quality values from the data analysis performed at UCF to those measured by a certified laboratory. This shows how well the testing methods and procedures predict the data and if any unknown factors, such as interferences, occur that cannot visually be determined. Table 4.6 shows the comparison for nitrogen and phosphorus species measured in the laboratory at UCF to those measured by Environmental Research and Design (ERD).

Table 4.6: UCF and ERD laboratory comparison for measurements on July 10, 2007

7/10/07	NOx (mg/L N)		Total - N (mg/L N)		Ortho - P (mg/L P)		Total - P (mg/L P)	
	UCF	ERD	UCF	ERD	UCF	ERD	UCF	ERD
RBP	0.067	0.019	0.30	0.287	0.01	0.001		0.024
RBF	0.043	<0.005	0.19	0.223	0.01	<0.001	0.04	0.011
AP	2.093	3.872	3.13	4.493	0.03	0.007	0.04	0.031
AF	1.841	2.186	2.54	2.569	0.03	0.005	0.04	0.017

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS, NOx = Nitrite + Nitrate

The total nitrogen data shows very similar concentrations between the two labs for three of the four samples measured. Both phosphorus parameters are lower for the concentrations measured by ERD compared to the UCF lab, but all concentrations are on the same order of magnitude with both labs. Exceedingly low concentrations are also difficult to measure with the procedures followed in the UCF lab, so some error is expected. The data in Table 4.6 shows the procedures and methods followed in the UCF lab can reasonably measure the concentrations of the nutrient parameters listed.

Statistical analysis is performed on each parameter to determine if there is a difference between the means of the red bug pond (RBP) and red bug CUFS (RBF) samples, and also between the UCF pilot scale pond (AP) and pilot scale CUFS (AF) samples. Outliers in the data sets are not determined by statistical analysis due to the varying nature of rainfall events and pollution carried by stormwater runoff. An unusually high value may just be a characteristic of a large storm event, or a recent fertilizer application in a nearby neighborhood. However, visual inspection and laboratory notes are used to eliminate some samples from the data sets.

pH and Alkalinity

Table 4.7 shows the pH and alkalinity averages for thirty-two samples at the red bug site and ten samples at the UCF pilot scale site. The Black and Gold^{TM} media in the CUFS for both locations did not alter the pH. The alkalinity increased slightly in the CUFS at the red bug pond site and more substantially at the UCF site. However, the increases for both locations were not enough to conclude that the means are not equal based on the statistical hypothesis testing using a 95% confidence interval. Detailed calculations are shown in Ryan (2008).

Table 4.7: pH and Alkalinity Data Summary

	pH				Alkalinity (mg/L $CaCO_3$)			
	RBP	RBF	AP	AF	RBP	RBF	AP	AF
Avg.	6.94	6.87	6.49	6.71	44	47	75	91
St. Dev.	0.29	0.29	0.46	0.45	18.41	31.97	48.88	48.14
n	32	32	10	10	32	32	10	10

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS

Turbidity

The turbidity ranges from 8.19 NTU to 1.94 NTU for the red bug pond and 4.54 NTU to 1.38 NTU for the CUFS based on thirty-two observations. The pond and filter effluent values are shown in Table 4.4. The average turbidity effluent of the CUFS is lower than that of the pond outflow at both the Red Bug and the UCF locations. For the turbidity measured at the Red Bug site, there is sufficient statistical evidence to conclude that the means are not equal at a 95% confidence interval, and thus the turbidity values leaving the CUFS are statistically lower than those in the red bug pond (Ryan, 2008).

Table 4.8: Turbidity Data Summary

	Turbidity (NTU)			
	RBP	**RBF**	**AP**	**AF**
Avg.	3.55	2.29	4.83	3.08
St. Dev.	1.39	0.66	3.23	1.72
n	32	32	9	9

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS

Solids

Thirty-one measurements are used to compare the total suspended solids (TSS) and total dissolved solids (TDS) concentrations for the red bug pond and CUFS. As shown in Table 4.9, the CUFS at the Red Bug site reduced the TSS concentration almost in half while the pilot scale UCF CUFS actually increased the TSS concentration. The increase at the UCF pond is probably caused by the small pond size, in which the top of the chamber of the CUFS would actually be submerged under water when a large storm event raised the water level in the pond over the bank. This would introduce dirt and sediments carried by the rapidly flowing water through the top of the chamber door and into the CUFS. An addition of suspended solids at the Red Bug CUFS also occurred during large storm events due to dirt and sediment entering through the small creases in the chamber door, even though the chamber door was not under water. This was prevented by covering the top of the chamber with black fabric mat, which is held down with a concrete block on each corner. This inhibits the CUFS from false contamination due to solids entering the filtered water above the media. The only statistically significant difference in the means at a 95% confidence interval is the total suspended solids concentration for the Red Bug CUFS. The Red Bug CUFS is statistically lower in TSS concentration than the red bug pond.

Even though the total dissolved solids concentrations decreased in both locations of the CUFS, there was not enough evidence to reject the equality of the two means.

Table 4.9: Solids Data Summary

	TSS (mg/L)				TDS (mg/L)			
	RBP	RBF	AP	AF	RBP	RBF	AP	AF
Avg.	9	5	7	9	109	102	183	171
St. Dev.	6.8	4.7	4.5	4.5	40.7	38.2	81.4	87.1
n	31	31	9	9	30	30	9	9

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS

Phosphorus

The ortho-phosphorus (OP) and total phosphorus (TP) concentrations are measured using thirty-seven samples at the Red Bug site and eleven samples at the UCF site. For the majority of the sampling dates, total phosphorus consists of mostly orthophosphorus and very little organic phosphorus. The OP values for the red bug pond are very low, but the CUFS reduces the values almost in half (Table 4.10). Mean hypothesis testing at a 95% confidence interval confirms the reductions of both OP and TP from the Red Bug CUFS. The UCF CUFS also shows a reduction in OP and TP compared to the pond outflow, although the reduction is not statistically significant for the number of samples taken.

Table 4.10: Phosphorus Data Summary

	Ortho-P (mg/L P)				Total-P (mg/L P)			
	RBP	RBF	AP	AF	RBP	RBF	AP	AF
Avg.	0.028	0.015	0.048	0.037	0.052	0.039	0.071	0.052
St. Dev.	0.024	0.012	0.024	0.015	0.024	0.015	0.039	0.020
n	37	37	11	11	34	35	11	11

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS

Nitrogen

The nitrogen forms include nitrate + nitrite (NOx) and total nitrogen (TN). To document that denitrification may have occurred, dissolved oxygen measurements were taken periodically below the filter in the CUFS, above the filter in the CUFS, and in red bug pond itself. As indicated in Table 4.11, anoxic conditions occur within the filtering media of the CUFS, allowing denitrifying bacteria to utilize nitrate and remove it from the water.

As with orthophosphorus, the red bug pond discharges very low concentrations of nitrite + nitrate (Table 4.12). The average TN concentration of the Red Bug CUFS is relatively lower than the pond outlet, but at a 95% confidence interval there is not enough data to conclude that the two means are not equal. The UCF CUFS reduces NOx concentrations from the pond by about one-third and TN concentrations by almost one-half. The UCF CUFS significantly reduces the TN concentration with a 95% confidence interval.

Table 4.11: Dissolved Oxygen Concentrations at Red Bug CUFS and Pond(mg/L)

Date	Above Filter	Below Filter	Pond
6/19/07	0.4	1.1	3.3
7/23/07	0.4	1.4	3.8
8/7/07	0.3	2.5	4.4
8/25/07	0.3	1.0	2.0
9/1/07	0.3	0.6	2.5
9/18/07	0.3	1.1	4.2
9/20/07	0.3	0.5	1.7
10/2/07	0.6	1.8	3.4
10/3/07	0.9	1.6	3.4
10/6/07	0.8	1.7	3.5
10/27/07	0.9	1.6	2.9
10/29/07	0.6	2.4	3.2
10/31/07	0.4	1.6	3.9
11/30/07	0.3	1.5	3.4
Avg.	0.5	1.5	3.2

Table 4.12: Nitrogen Data Summary

	NOx (mg/L N)				TN (mg/L N)			
	RBP	**RBF**	**AP**	**AF**	**RBP**	**RBF**	**AP**	**AF**
Avg.	0.03	0.03	1.04	0.68	1.11	0.92	2.93	1.54
St. Dev.	0.02	0.02	1.35	0.93	0.86	0.66	0.81	0.86
n	34	33	7	6	24	24	6	6

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = UCF Pond, AF = UCF CUFS, NOx = Nitrite + Nitrate

Storm Events and Baseflows

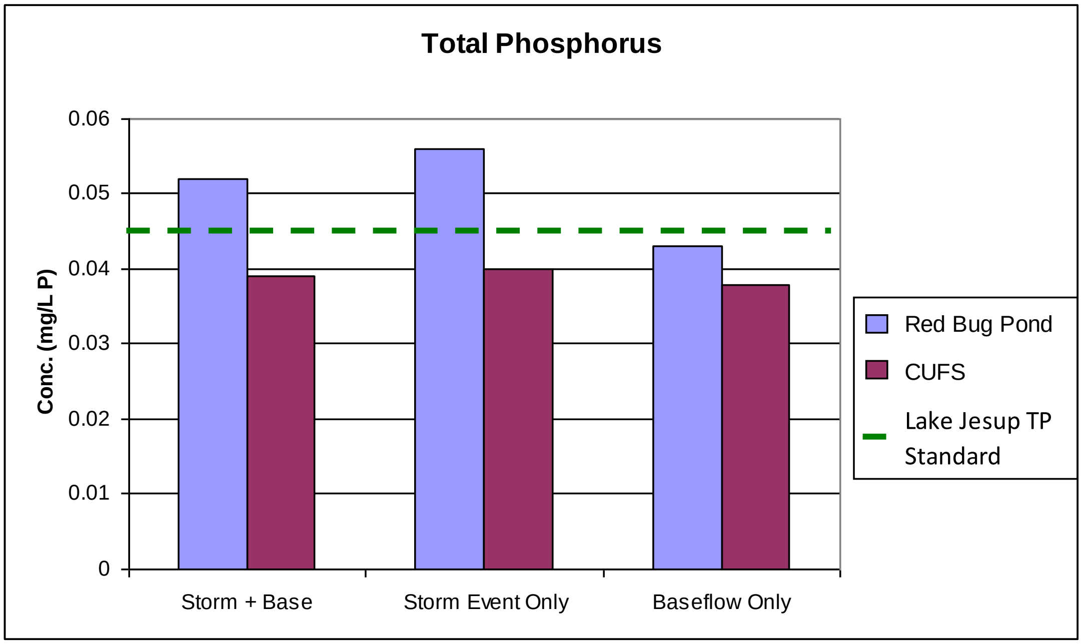
The data are for twenty-eight storm events and seven baseflows in the red bug pond, and are shown in summary form in Table 4.13.

Table 4.13: Storm Events and Baseflows Separated at Red Bug Pond and CUFS

	Sample	pH	Alk (mg/L $CaCO_3$)	Turbidity (NTU)	OP (mg/L P)	TP (mg/L P)	NOx (mg/L N)	TN (mg/L N)	TSS (mg/L)	TDS (mg/L)
Storm Event	RBP	6.91	42	3.59	0.026	0.056	0.02	1.33	9	111
	RBF	6.89	45	2.36	0.014	0.040	0.03	1.11	4	103
Base flow	RBP	7.09	52	3.40	0.031	0.043	0.04	0.54	14	102
	RBF	6.80	57	1.92	0.017	0.038	0.04	0.43	10	99

*RBP = Red Bug Pond, RBF = Red Bug CUFS, NOx = Nitrite + Nitrate

A graph comparing the combined storm events and baseflows to storm event only and baseflow only is shown below for TP and TN (Figure 4.9). The standards chosen for Lake Jesup (0.044 mg/L TP and 0.61 mg/L TN) are also shown on the graphs. As shown in Figure 4.9, the CUFS reduces TP below the standard concentration for all the samples (Storm + Base) and the storm events. The baseflow TP concentration from the red bug pond does not exceed the standard concentration. The contribution of TN from the storm events is shown in the Total Nitrogen graph in Figure 4.9. The "baseflow only" concentration in red bug pond does not exceed the standard, but the storm event concentration exceeds the standard. The CUFS reduces the TN concentration, but not below the standard of 0.61 mg/L N.



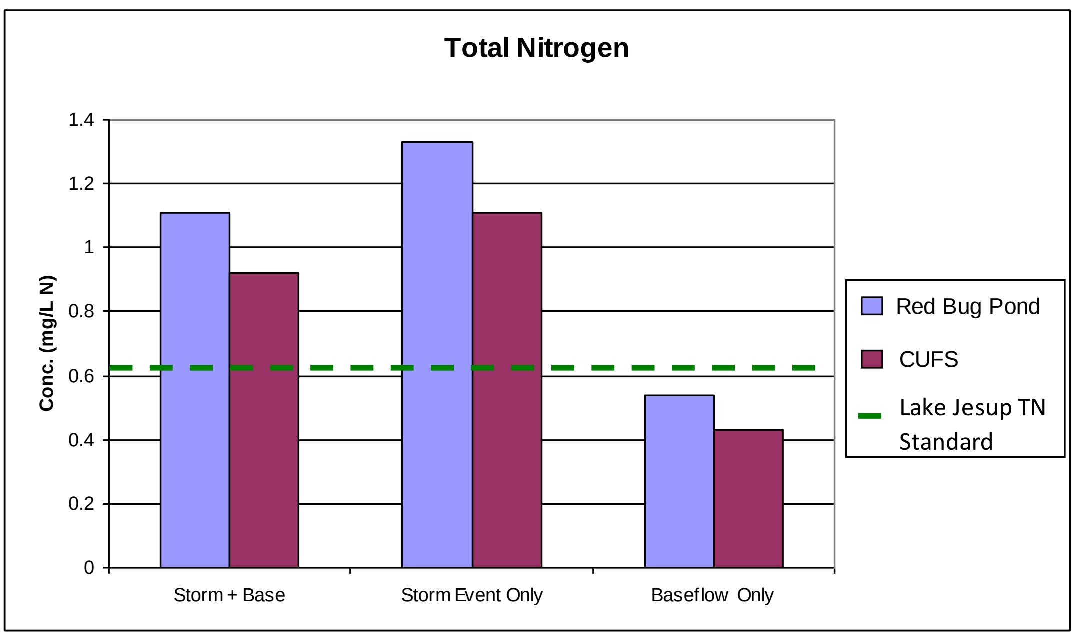
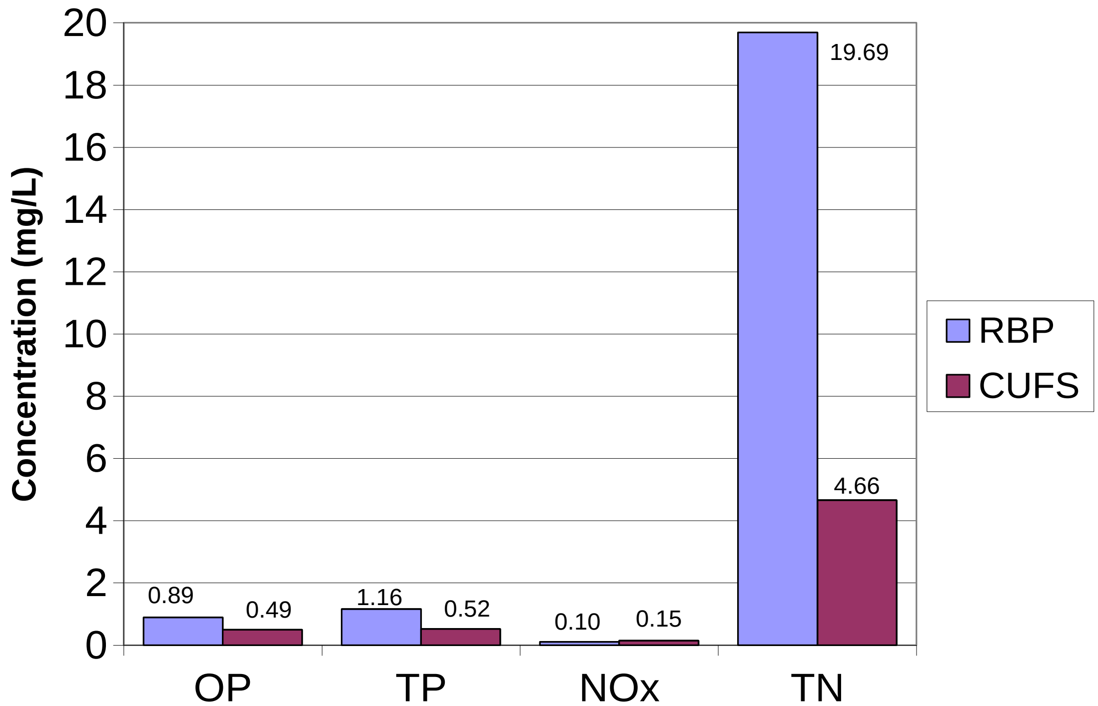


Figure 4.9: Storm Event and Baseflow Comparison for TP and TN

Simulated Event Comparison

The nutrient concentrations leaving the red bug detention pond are relatively low compared to typical stormwater detention ponds. To see how the CUFS performed under higher nitrogen and phosphorus loading conditions, two experiments were conducted to increase the nutrient concentrations in the pond and inflow to the CUFS. Fertilizer was scattered into the detention pond near the skimmer, and samples were taken at periodical times after the introduction of fertilizer. Flow measurements were taken from the CUFS to see how long it would take the water to cycle through the filtering system, so representative samples from the pond and CUFS could be directly compared. The graphs in Figure 4.10 display the average concentrations from the two experiments for phosphorus and nitrogen.



*NOx = Nitrite + Nitrate

Figure 4.10: Simulated Event Summary at Red Bug Detention Pond

The addition of fertilizer increased the phosphorus concentration in the pond with mainly OP as expected, because fertilizer supplies phosphorus in a form readily available for plant uptake. The CUFS reduced the two phosphorus species approximately in half and increased the OP/TP ratio compared to the pond. In the analysis of nitrogen, the CUFS increased the NOx (nitrite + nitrate) concentration compared to the pond. This could be caused by nitrification of the ammonia in the fertilizer (the TN of the selected fertilizer consisted of urea/ammonia mix). The water in the CUFS begins in the skimmer and inlet pipe, which is still under aerobic conditions until it reaches the filtering media. Therefore, the water in the CUFS is exposed to aerobic conditions for a longer time before sampling than the pond, which will allow nitrifying bacteria more time to convert ammonia to nitrate. Because this experiment was performed during a period of no rainfall, the flow measurements indicate that it will take the water approximately two hours to cycle through the CUFS. Theoretically the NOx (nitrite + nitrate) should be removed by denitrification in the anoxic filter, but the removal rate might be lower than the formation rate due to the excessive ammonia concentrations, and the NOx concentrations will increase.

Evidence of denitrification in the filter is shown in the comparison of TN values. It is known that the NOx concentrations are relatively low, but the TN concentration in the pond is close to 20 mg/L N. Since the selected fertilizer contains TN in the form of urea and ammonia, the TN concentration is composed of mainly ammonia or ammonium ion. The reduction in TN is presumably due to denitrification in the media after the ammonia is converted to nitrate before entering the filtering media. This does not remove all the TN because 4.7 mg/L N remains in the

CUFS samples, which is assumed to be ammonia or organic since the NOx concentration is low. Also low dissolved oxygen was in the effluent (lower than 1 mg/L were measured).

Flow Measurement

The flow measurement is performed by using the “volumetric” method. This method achieves a direct measurement for the flow rate. It can be used to measure the flow because the water is free-flowing from a small pipe and is small enough to capture in a bucket without overflowing (NPDES, 1992). The flow is taken directly from the outlet pipe of the filter, which discharges into the stormwater effluent pipe coming from the pond. This requires walking into the concrete pipe with a flashlight, bucket, and stopwatch to take a measurement.

A five gallon bucket was used to capture the water from the filter outlet pipe, and a stopwatch was used to measure the time until the bucket was almost full. The actual volume of water in the bucket was measured with one-quart containers. The volume, in gallons, is equal to the number of quarts divided by four quarts per gallon. The flow is then computed by dividing the volume of water collected by the time it took to collect that volume of water.

Since the flow through the filter increases with head (pond water elevation), a water surface measurement was taken from the outlet weir structure. This involved a tape-down from the top of the structure to the water surface. The head on the filter outlet pipe was also measured, and all the measurements taken for the flow analysis are shown in Table 4.14.

Table 4.14: Flow Measurements from the CUFS

Date: 11/30/07 Tape down from top right of outlet concrete structure: 16" Filter outlet pipe head (measured from inside of pipe to water surface): 2.5" Time: 0900 Measurement 1: 18.5 quarts / 1 minute * 1 gal / 4 quarts = 4.625 gpm Time: 0920 Measurement 2: 18.0 quarts / 1 minute * 1 gal / 4 quarts = 4.5 gpm
Date: 1/23/08 Tape down from top right of outlet concrete structure: 12.5" Filter outlet pipe head (measured from inside of pipe to water surface): 2.8" Time: 1030 Measurement 1: 24.0 quarts / 1 minute * 1 gal / 4 quarts = 6.0 gpm Time: 1055 Measurement 2: 25.5 quarts / 1 minute * 1 gal / 4 quarts = 6.375 gpm

Calculation of a surface loading rate requires the surface area of the filter that allows water to flow through it. The red bug chamber measures 4' X 3', equating to an inside area of 12 ft^2. However, part of this area is occupied by the 6" cleanout pipe, which reduces the surface area to 11.8 ft^2. With this surface area, the surface loading rate of the CUFS for the measurements on November 30, 2007 and January 23, 2008 are 0.39 and 0.54 gpm/ft^2, respectively. These surface loading rates correspond to a pond water elevation that is 16 inches and 12.5 inches below the top of the concrete overflow structure of red bug pond. Although the peak flow rate through the CUFS during this experiment would be important data, obtaining a flow measurement when the water flows over the concrete structure would be too dangerous due to the large flow of water coming from the pond. In fact, obtaining a measurement when the pond water elevation rises higher than 12.5 inches below the concrete outflow structure would be very dangerous.

The largest surface loading rate measured, 0.54 gpm/ft^2, is smaller than the range of loading rates considered in the laboratory (1 – 5 gpm/ft^2). However, in this measurement, the water level in the outlet pipe of the CUFS only occupied 70% of the outlet pipe cross-sectional area. The bench scale study was also performed with clean tap water and new media, with fewer solids to restrict the flow through the media.

Nutrient Loading Reduction

The nutrient removals from the CUFS can be expressed in the form of nutrient loading reductions by multiplying the flow and concentration. These calculations show the amount of mass per time that can be removed by the CUFS during storm events. The two flow rates measured (4.5 and 6.0 gpm), the inflow to the CUFS (0.052 mg/L TP and 1.11 mg/L TN), and the outflow from the CUFS (0.039 mg/L TP and 0.92 mg/L TN) create a loading reduction range of 0.12 to 0.16 kg/year of TP and 1.70 to 2.27 kg/year of TN. For the simulated event using the same two measured flow rates, the loading reduction ranges become 5.73 to 7.64 kg/year of TP and 134 to 179 kg/year of TN. However, these loading reductions do not represent the maximum loading reduction possible because the maximum flow from the CUFS was not measured. This section is presented to illustrate the methods.

Detention Pond and CUFS Removal

The phosphorus concentrations leaving the red bug pond are lower than average for wet detention facilities in Florida. Values compiled by Harper and Baker (2007b) from previous studies show that stormwater from single family residential developments contains average concentrations of 0.327 mg/L of TP and 2.07 mg/L of TN. According to Seminole County Engineering (2007), stormwater in the Howell Creek subbasin contains a net concentration of 0.31 mg/L of TP and 1.72 mg/L of TN. These numbers are similar to those found by Harper and Baker (2007b). Harper and Baker (2007a) compiled several treatment efficiencies for wet detention ponds and found an average removal of 69% for TP and 37% for TN. Using these removal efficiencies for a wet detention pond and the typical stormwater concentrations for the Howell Creek subbasin from Seminole County Engineering (2007), the expected effluent concentrations from the red bug pond should be approximately 0.10 mg/L of TP and 1.09 mg/L of TN. The TN value matches the measured concentration from the red bug pond of 1.11 mg/L (Table 4.12). This results in a TN removal efficiency of 35% in the red bug pond. However, more phosphorus removal occurs in the red bug pond than in an average wet detention pond. The measured TP value is 0.052 mg/L for the red bug pond (Table 4.10), compared to the expected value of 0.10 mg/L. This shows a TP removal of 83% assuming the influent concentration is 0.31 mg/L.

As stated in Pond Details section, the design residence time of the red bug pond is 14 days and the permanent pool volume is 12.0 ac-ft. The Permanent Pool Volume was determined from the drawings provided for red bug pond B (Seminole County, 1993). The permanent pool volume was also calculated based on the equation

Equation for Permanent Pool Volume Calculation

$$PPV = (A*c*R*DT) / WS$$

where

A = drainage area = 46.89 ac

R = wet season rainfall depth = 32 in = 2.67 ft

WS = wet season = 153 days (June 1 through October 31)

DT = detention time = 14 days

c = weighted runoff coefficient = 0.81

This method produced a required PPV of 9.3 ac-ft, so the actual PPV is larger than the result of the calculated value.

The high phosphorus removal may be due to the sediment and solids removed by sedimentation in the pond. The basin that includes red bug pond consists of Tavares-Millhopper, Myakka, and Eaugallie fine sands ("Drainage Report/Calculations," 1990). To conclude if dissolved phosphorus was sorbing to the sediment, an extra sample was taken on August 7, 2007 in which the pond water was stirred by walking around the outlet area in the pond. This can physically break the bond between the sorbed phosphate and sediment, resulting in an increase in the OP and TP concentrations. See Appendix E of Ryan (2008) as the "STIR" samples. The OP concentration increased from 0.04 mg/L P to 0.14 mg/L P after the agitation. This indicates good removal of dissolved phosphorus by the sediment in the bottom of the pond. The pond also contains a littoral zone, in which different types of aquatic grasses and plants inhabit. These plants utilize the dissolved phosphorus, removing it from the water.

Under the normal storm events sampled, the CUFS reduced the OP concentration by 46%, the TP by 25%, and the TN by 17% when compared to the pond. Using the typical values for stormwater in the Howell Creek subbasin, the red bug detention pond and CUFS together reduced TP by 87% and TN by 47%. The percent removals are shown below in Table 4.15. The lower removals with nitrogen could be due to the low values of NOx in the pond, limiting denitrification in the filter.

Harper and Baker (2007c) show an average TSS concentration from stormwater in single-family residential subdivisions with curb and gutter of 48.4 mg/L. Using this value as the influent TSS concentration to the detention pond, it removes 81% of the TSS.

Table 4.15: Percent Removals

	TN			TP			TSS		
	IN (mg/L N)	OUT (mg/L N)	% Removal	IN (mg/L P)	OUT (mg/L P)	% Removal	IN (mg/L)	OUT (mg/L)	% Removal
Pond Only	1.72	1.11	**35**	0.31	0.052	**83**	48.4	9	**81**
CUFS Only	1.11	0.92	**17**	0.052	0.039	**25**	9	5	**44**
Pond + CUFS	1.72	0.92	**47**	0.31	0.039	**87**	48.4	5	**90**

Operation of the CUFS

Overall, the CUFS performed with minimal maintenance throughout the life of the experiment. Early in the experiment, problems with the upflow filter lifting up due to a high flow of water occurred, but they were resolved with the installation of the unitsrut pieces to supply more force to keep it down. The UCF pond is proliferated with algae, which causes a clogging problem in the skimmer and upflow filter. Once unclogged, the intake on the skimmer at both locations was wrapped with back fabric mat to prevent the algae, small plants, or fish from entering the system. This solved the problem and both the UCF and red bug CUFS remained unclogged throughout the experiment.

The red bug CUFS was cleaned twice to see how the system responded. Cleaning consists of pumping out the bottom of the chamber by inserting the intake hose of a small pump down the 6” cleanout pipe (as shown in Appendix C of Ryan, 2008). All the water is pumped out of the filter three times to ensure removal of the sediment. The CUFS performed with no problems following the cleanout in both cases.

4.8 Summary

Stormwater runoff can transport pollutants picked up from roadways, landscaping, and other sources into a nearby surface water body. Wet detention ponds, considered one of the more useful BMPs for stormwater quantity and quality control, are found throughout central Florida. However, these ponds on average do not remove sufficient nutrients from the stormwater and pass the pollutants to a nearby surface water body, where eutrophication can occur. The results of this research provide an additional treatment option using a Chamber Upflow Filter and Skimmer (CUFS) coupled with a detention pond, which can increase the removal of phosphorus and nitrogen by the system.

The skimmer floats on the surface of the detention pond and directs water through the upflow filter. The upflow filter consists of two feet of Black and Gold™ pollution control media to remove phosphorus and nitrogen under the anoxic conditions of the filter. Water enters at the bottom of the chamber structure and flows up through the filtering media, allowing heavier particles to settle out before entering the filter to minimize clogging.

This project consisted of a bench study, pilot scale operation, and a full scale operation of a CUFS connected to a detention pond. The bench study determined the amount of head loss from Black and Gold Pond Media ™ over a range of design surface loading rates. The pilot UCF site confirmed the bench study for head loss through the media and developed the procedures for installing a CUFS. The full scale field application of the CUFS at the red bug pond in Seminole County used a larger skimmer and chamber than the pilot study. The field application filters stormwater from a detention pond that eventually flows into Lake Jesup, a eutrophic lake.

A total of ten storm events were sampled from the pilot UCF CUFS, and twenty-eight storm events and seven baseflows were sampled from the red bug pond CUFS. The main pollutants of concern are phosphorus (ortho and total) and nitrogen (NOx and total), but other parameters were also measured to characterize the water. These include pH, alkalinity, turbidity, total suspended solids, total dissolved solids, and dissolved oxygen. Quality assurance and quality control was performed on the samples by using duplicate and spiked samples, in which the relative percent difference (RPD) and percent recovery were calculated. Statistical analysis was performed on the data to test the equality of the mean CUFS pollutant concentration and mean pond pollutant concentration. The conclusions from these results show the benefits of adding a CUFS to a detention pond.

4.9 Conclusions

The head loss determined from actual operation of the CUFS and for the rates of flow through twenty-four inches of Black and Gold Pond Media ™ is nine inches. This value was originally determined in the laboratory with the bench scale study and then confirmed in both the pilot and full scale field applications. With the filter outlet pipe set at an elevation nine inches lower than the pond effluent pipe elevation, the CUFS will begin discharging water when the pond starts discharging water.

A surface skimmer can effectively be used to supply a design flow of water through the upflow filter in the CUFS. It will also improve the discharged water quality by removing water from the top of the water column in the pond, allowing heavier particles to settle and remain in the pond. In ponds with high levels of algae, small plants, or other small debris, a layer of black fabric mat can be placed over the intake of the skimmer to prevent the debris from clogging the upflow filter after short periods of time without affecting the hydraulic performance of the CUFS.

The concentrations of total nitrogen and total phosphorus leaving the red bug pond B wet detention pond exceed the concentrations believed to impair the receiving water body, Lake Jesup. The red bug CUFS reduces the concentration of total phosphorus below the concentration believed to impair Lake Jesup. The CUFS had no significant impact on pH, alkalinity, NOx (nitrite + nitrate), TN, or TDS at the Red Bug location in Seminole County, but the CUFS significantly reduced the concentrations of turbidity, OP, TP, and TSS compared to the pond effluent. The pilot scale UCF CUFS only reduced the concentration of TN compared to the pond effluent for the ten samples collected. The CUFS is also capable of nutrient removals in highly polluted water, as shown in the simulated event comparison.

4.10 Recommendations

A CUFS unit can be used to further improve the water quality leaving a wet detention pond. It is recommended that in water quality limited situations, the CUFS should be considered.

The only maintenance required for a properly designed and installed CUFS entails pumping out the bottom of the chamber to remove the heavier particles that settle below the filter. The pumping frequency depends on the amount of debris and sediment in the pond. The intake skimmer should be covered with black fabric mat. For a pond with minimal debris and the skimmer intake covered, the bottom of the chamber should be pumped twice per year, as performed in this experiment. This should be increased if more debris and sediment are present in the pond.

4.11 Future Research

Adding an additional skimmer to increase the flow of filtered water from the CUFS should be considered. However the water cannot flow too fast as to inhibit adsorption of phosphorus to the media or prevent anoxic conditions in the chamber.

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CHAPTER 5 – PERVIOUS PAVEMENT WITH TIRE CRUMB SUB BASE

5.1 Introduction

Pervious pavements are stormwater management methods that decrease runoff using a porous media that allows for infiltration. Pervious concrete pavement is one type of pervious pavement that can be used as an infiltration practice for stormwater management. It has an open-graded structure and consists of carefully controlled portions of stone aggregate, cement, water, and admixtures. The open-graded structure of the concrete promotes rapid passage of water and allows it to infiltrate underlying soils. A reservoir of select pollution control media can also be added beneath the pervious concrete to remove pollutants. Pervious concrete, already recognized as a best management practice by the Environmental Protection Agency (USEPA, 1999) is included in the draft version of the State Stormwater Rule. If the pavement can have a pollution control media beneath it and still infiltrate, then additional pollutants will be removed before the water enters the groundwater.

However, a lack of data, particularly with respect to infiltration capacity and water quality, leads to hesitation in using pervious concrete as an acceptable stormwater management practice alternative. An important part of this research involved determining the infiltration rates through pervious concrete with a Black and Gold Reservoir Media™. Past field investigation of pervious concrete parking lot sites was completed and reported on in a previous report (Wanielista, et. al., January 2007). In this study, eight pervious concrete parking areas, all of which have been operational for on the average 10 years, were investigated for hydraulic infiltration capacity. The results showed that for measuring infiltration over time, the sub base materials had to be included in the cross section. Thus, in this report an embedded ring infiltrometer kit (ERIK) was used to measure the infiltration rates.

Parking areas such as at the Seminole County Jones Trailhead site provide an opportunity to use pervious concrete with a Black and Gold Reservoir Media™ to infiltrate runoff waters. Thus, the reservoir beneath the pervious concrete can be built to pass the runoff water, and the material in the reservoir can have the potential for removal of pollutants. The pervious concrete system (pervious concrete plus reservoir) has the potential to not only attenuate flow and decrease volume of runoff, but to also remove pollutants.

5.2 Objective

The objectives of this field application are to construct a pervious concrete parking lot for an exercise trail in Seminole County Florida with a Black and Gold Reservoir Media™ and then to"

1) Determine if this parking lot could be used to support traffic and to visually measure the wear of the pavement.
2) Measure the limiting infiltration capacity of the pervious concrete system.

5.3 Limitations

The results are constrained by the location, design of the pervious concrete section and the climate of the central Florida area.

5.4 Background Pervious Pavement Studies

When it rains, the transport of water from an impervious parking surface to adjacent stormwater transport and storage occurs. Impervious areas prevent water from infiltrating into the soil underneath. However, with the use of pervious concrete and a reservoir beneath it, the possibility exists to use the parking lot for both water quality improvement and runoff volume and rate reduction and thus the parking lot becomes part of a stormwater management plan.

The addition of impervious parking lots can increase the hydrologic and water quality impacts to the environment by altering the natural water cycle. The runoff from the impervious surfaces results in at least three main problems: (1) a decrease in groundwater recharge due to lack of infiltration, (2) an increase in the volume of runoff water that has to be treated, and (3) transportation of contaminants, deposited on impervious surfaces, to receiving water bodies. Thus, the introduction of impervious areas has an impact on both surface and subsurface water quantity and quality, in addition to adding to the cost of treating runoff.

Changing natural flow patterns with impervious surfaces can cause flooding of naturally occurring channels unaccustomed to handling larger flows of water (Brattebo and Booth, 2003). Furthermore, contaminants including heavy metals (e.g. copper, lead and zinc), nutrients (e.g. phosphorous and nitrogen), and sediment material can travel in runoff water and be deposited in receiving water bodies. These materials severely alter and destroy aquatic habitats, which results in the death of organisms dependent upon that habitat.

Traditionally, runoff peak rates have been controlled and attenuated using storm sewer systems with detention or retention basins (Schluter and Jeffries, 2002). These systems collect the runoff primarily from impervious areas and store the water where it can either infiltrate (retention basin) or be discharged at a controlled rate to a water body (detention basin). Design, operation, and maintenance of these basins are governed by regulations established by state, regional or local government agencies. The size of these basins and the monetary investment in their construction can be lowered if the runoff water is passed through pervious concrete and treated for water quality improvement before entering the ground water.

Pervious Concrete

Pervious concrete is used as the porous pavement. There are other pervious surfaces, but the pervious concrete one had been used before. It contains about 18-20% pore spaces and allows water to pass through at a relatively high and sometimes what most would consider a rapid rate.

Pervious concrete used for parking areas is the focus of this report. It is a material that consists of open-graded coarse aggregate, Portland cement, water and admixtures. Generally the aggregate is evenly graded to have a size of approximately 3/8 of an inch; sand is omitted from the process leaving the space in between coarse aggregate empty. Typical sections of pervious concrete have an average of 20 percent void space; some sections may have values as high as 35 percent (Brown, 2003). Most void spaces are interconnected which allows water and air to pass through the section. Newly placed pervious concrete sections have been reported to drain at rates ranging from two to 18 gallons per minute per square foot (Brown, 2003).

Pervious concrete is known to have the advantages of reducing runoff volume and may improve water quality in ground water recharge (Legret et al, 1996). By allowing stormwater runoff to infiltrate, pervious concrete filters sediment and other contaminants that would otherwise make their way to waterways. Similarly, because water can infiltrate through the concrete layer, pervious concrete parking lots and other installations can serve as recharge basins. Other known advantages of pervious concrete include better road safety because of increased skid resistance, road sound dampening, and dampening of the "heat island" effect (Yang and Jian, 2003), (USEPA, 1999), (Brown, 2003).

Pervious concrete has begun to receive greater attention as a viable stormwater management practice. The American Concrete Institute has established a committee (ACI Committee 522, 2006) to determine guidelines for the proper use of pervious concrete. To enhance this document, the committee needs data on the long-term performance of pervious concrete systems. Data are needed on design characteristics, durability, maintenance plans, and effective infiltration rates after years of service.

This information would also be valuable to water management districts in an effort to provide a standard for use of pervious concrete in stormwater runoff control. In Florida, stormwater management criteria are largely developed and implemented by the Department of Environmental Protection (DEP) and the regional water management districts. Currently, only the DEP provides credit for pervious concrete as a stormwater management practice. However, others at the State of Florida regional water management districts levels are considering it as an option. There is provision and national standards that are used on a site-by-site basis using design guidelines to apply for credit (Training Manual, 1998, NRMC, 2004, and FCPA in Pervious Pavement Manual, 2006). It is anticipated that the data of this report will facilitate the application for credit.

There are some tradeoffs between pervious concrete, the most notable of which is cost. The initial cost of pervious concrete can be up to 1.5 times that of other conventional paving methods. This excess of cost is a function of two things. First, pervious concrete is a specialty product requiring experienced skilled labor to install the concrete properly. This specific experience requirement accompanied with low demand drives the price up. Secondly, there is also an extra depth associated with pervious concrete. The extra depth is a function of a couple of factors including a need for extra rainfall storage within the concrete layer and an increased necessary thickness for strength reasons.

Though there is an expected increase of cost for pervious concrete, that cost can potentially be recouped by the increase in developable area that comes with a decrease in the area required for stormwater management. Other benefits include better traction during wet whether due to free draining pavement, reduction in road noise due to dampening effects in the concrete, and glare reduction at night (Ferguson, 2005), (ACI, 2006).

Pervious concrete has been in existence in the United States for nearly 50 years (Brown, 2003). Though not a widely used product, pervious concrete has been proven effective as a porous pavement in applications such as parking lots, low-volume roadways, and pedestrian walkways. It is necessary to develop standard design, manufacturing, and installation methodology that will establish pervious concrete as a reliable product capable of performing adequately for these uses. Currently there are no regulations or standard design criteria for this technology, thus it is not validated as a presumptive stormwater management method. Pervious concrete has the potential to reduce the amount of, or eliminate the area set aside for stormwater management practices, thus maximizing the amount of land available for development. If a compilation of data shows an agreeable evaluation of long-term performance, this material may become more widely accepted for its beneficial properties.

Such information could be used to develop statewide design, construction, inspection, and maintenance requirements within stormwater regulations.

5.5 Site and Pavement Conditions

The site for the parking area is in Seminole County Florida. Three parking places, each 7 feet by 20 feet were constructed of a 6 inch depth pervious concrete over a 10 inch deep mixture of Black and Gold Reservoir Media^{TM}. The media mix was 25% by volume of tire crumb and 75% of coarse sand. It was compacted to 95% modified Proctor to sustain the expected loading. The slope of the parking is flat. A diagram is shown in Figure 5.1. The construction cost is about 25% higher than normal concrete cost.

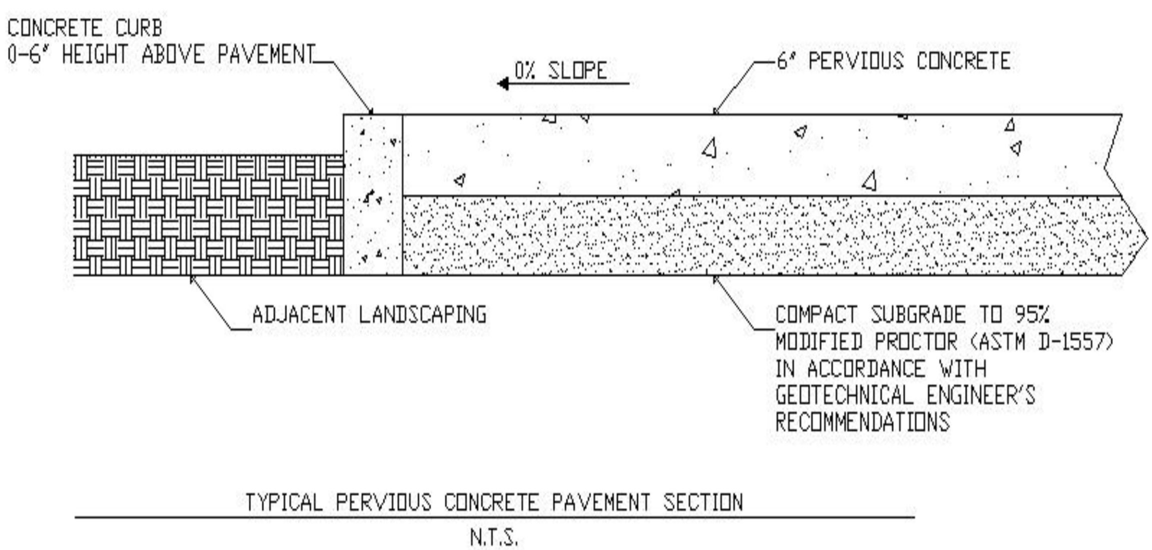

Figure 5.1 Pervious Concrete Parking Lot Construction Section

5.6 Infiltration Measurement

For new construction, an infiltration test device that is embedded into the pervious concrete and the sub base materials at the time of construction would eliminate the need for coring. Also the in-situ embedded infiltrometer would provide initial construction infiltration rate data verification and continued infiltration rate data with time. Thus the concept of the embedded ring infiltrometer with a measurement kit was made, and called ERIK.

The ERIK consists of inner embedded 6 inch diameter pipe, an outer embedded 12 inch diameter pipe, a 2 inch ID graduated “reservoir” cylinder with red marks indicating every inch drop in water level within the embedded ring, and a timing device with a recording pad. The complete set up is shown in Figure 5.2. On the present model, there are two manually adjusting valves located near the bottom to control flow of water out of the reservoir cylinder. A 6 inch and 12 inch ID PVC pipe are included for the embedment and testing applications. Also it has been shown that a single ring infiltrometer functions to measure infiltration rates just as accurately as a double ring.

Procedure for using the embedded ring infiltrometer is as follows:

1. Place the inner (six (6) inch pipe) and the outer (nine (9) inch pipe) on the top of the embedded pipes.
2. Apply bead of silicone caulking around bottom of 6 inch and 9 inch test pipes.
3. Allow time for drying or about 15 minutes with the silicone used.
4. Fill rings with water until saturation is reached and check for side leakage
5. Using tape measure, pour water until desired head is reached and mark inside wall of the inner pipe with permanent marker
6. Adjust valves on reservoir to keep a constant head desired in the inner pipe
7. Record time it takes for water level to drop to each marked interval

Figure 5.2 - Embedded Ring Infiltrometer Kit (ERIK) Showing On-Site Measurement

5.7 Results and Discussion

Infiltration Rates from Field Testing Using the ERIK

Infiltration rate is related inversely to the compaction of the sub base. Increased compaction will decrease the rate of infiltration. However, it is important to keep the sub base materials at a compaction level that will support the traffic loads. Pitt (2002) reported a limiting soil infiltration rate of about 5 inches per hour for modified compacted sandy soils similar to that used in the reservoir at the parking lot. He used a 4.5 inch head for the test. Soil compaction and site soil variability are believed to control the rate more than the small head difference between his reported data and the field testing.

Twenty-seven infiltration tests were completed. Two of the tests were conducted when the ground adjacent to the parking area appeared to be near saturated. The average rate of infiltration for all twenty seven tests was 31.0 inches per hour, with a standard deviation of 16.9 inches per hour. The maximum recorded rate of infiltration was 68.1 inches per hour. The minimum rate was 6.1 inches per hour. This minimum rate was recorded when the adjacent ground was near saturation. The data are shown in Table 5.1.

If the infiltration measures are averaged to not include the measurements conducted during the saturation times, the average value is 33.0 inches per hour, with a standard deviation of 16.0 inches/hour. The minimum infiltration rate is 11.3 inches per hour. The rates with and without the two saturated values do not appear significantly different meaning that the infiltration rates during wet conditions at the site should be included in the statistical infiltration values.

The infiltration rates exceeded the 1.5 inches per hour rate which is frequently used in stormwater management to indicate a proper functioning retention area. An acceptable rate of infiltration for yearly volume control and using these designs is 1.5 inches per hour (Wanielista et.al, Jan 2007). This 1.5 inch per hour infiltration rate using the rainfall volumes for central Florida would produce an annual collection effectiveness of at least 80% for level pervious concrete and provided there were no additional off site runoff contribution.

There were 35 visits to the parking lot in 18 months. In all but two visits there was no water in the collection devices placed under the pavement. Eight visits were made expressly for water quality sampling. On these two occasions, the water was sampled for nutrients. The nutrient concentrations were about equal to rainfall or the Orthophosphate was about 0.2 mg/L and the nitrate nitrogen was 0.4 mg/L.

TABLE 5.1 JONES TRAILHEAD INFILTRATION DATA

			Raw data							
Date	**Description**	**Test #**	**In**	**hr**	**min**	**sec**	**MIN**		**INCR MIN**	**In/hr**
1/11/2007	**6" Constant**	**1**	**1**	0	1	38	**1.63**		**1.63**	**36.7**
	Single		**2**	0	4	4	**4.07**		**2.43**	**24.7**
			3	0	6	2	**6.03**		**1.97**	**30.5**
			4	0	8	25	**8.42**		**2.38**	**25.2**
			5	0	10	50	**10.83**		**2.42**	**24.8**
								28.4	**avg in/hr**	
		2	**1**	0	2	2	**2.03**		**2.03**	**29.5**
			2	0	4	30	**4.50**		**2.47**	**24.3**
			3	0	7	10	**7.17**		**2.67**	**22.5**
			4	0	9	21	**9.35**		**2.18**	**27.5**
			5	0	11	58	**11.97**		**2.62**	**22.9**
								25.3	**avg in/hr**	
		3	**1**	0	2	3	**2.05**		**2.05**	**29.3**
			2	0	4	19	**4.32**		**2.27**	**26.5**
			3	0	7	7	**7.12**		**2.80**	**21.4**
			4	0	9	32	**9.53**		**2.42**	**24.8**
			5	0	12	23	**12.38**		**2.85**	**21.1**
								24.6	**avg in/hr**	
	6"Constant	**1**	**1**	0	6	25	**6.42**		**6.42**	**9.4**
	Double		**2**	0	11	25	**11.42**		**5.00**	**12.0**
			3	0	17	4	**17.07**		**5.65**	**10.6**
			4	0	20	48	**20.80**		**3.73**	**16.1**
			5	0	28	4	**28.07**		**7.27**	**8.3**
								11.3	**avg in/hr**	
		2	**1**	0	5	37	**5.62**		**5.62**	**10.7**
			2	0	9	48	**9.80**		**4.18**	**14.3**
			3	0	13	48	**13.80**		**4.00**	**15.0**
			4	0	18	3	**18.05**		**4.25**	**14.1**
			5	0	24	35	**24.58**		**6.53**	**9.2**
								12.7	**avg in/hr**	
1/14/2007	**6" Constant**	**1**	**no data**							
	Single		**4**	0	34	34	**34.57**		**34.57**	**6.9**
	saturated ground		**5**	0	44	28	**44.47**		**9.90**	**6.1**
								6.5	**avg in/hr**	
		2	**2**	0	17	30	**17.50**		**17.50**	**6.9**
			3	0	25	26	**25.43**		**7.93**	**7.6**
			4	0	37	59	**37.98**		**12.55**	**4.8**
			5	0	49	20	**49.33**		**11.35**	**5.3**
								6.1	**avg in/hr**	
1/17/2007	**1" Constant**	**1**	**1**	0	3	12	**3.20**		**3.20**	**18.8**
	Single		**2**	1	6	35	**6.58**		**3.38**	**17.7**
								18.2	**avg in/hr**	

TABLE 5.1 CONTINUED JONES TRAILHEAD INFILTRATION DATA

3/6/2008	2" Constant	1	1	0	0	45	0.75		0.75	80.0
	Dbl infiltrometer		2	0	1	39	1.65		0.90	66.7
			3	0	2	42	2.70		1.05	57.1
			4	0	3	29	3.48		0.78	76.6
			5	0	4	29	4.48		1.00	60.0
								68.1	avg in/hr	
		2	1	0	0	53	0.88		0.88	67.9
			2	0	1	59	1.98		1.10	54.5
			3	0	2	59	2.98		1.00	60.0
			4	0	4	11	4.18		1.20	50.0
			5	0	5	19	5.32		1.13	52.9
								57.1	avg in/hr	
		3	1	0	1	2	1.03		1.03	58.1
			2	0	2	33	2.55		1.52	39.6
			3	0	3	35	3.58		1.03	58.1
			4	0	5	36	5.60		2.02	29.8
			5	0	7	31	7.52		1.92	31.3
								43.3	avg in/hr	
	2" Constant	1	1	0	2	52	2.87		2.87	20.9
	Sinlge infilt		2	0	6	0	6.00		3.13	19.1
			3	0	9	25	9.42		3.42	17.6
			4	0	13	5	13.08		3.67	16.4
			5	0	16	28	16.47		3.38	17.7
								18.3	avg in/hr	
5/17/2007	6" Constant	1	1	0	1	40	1.67		1.67	36.0
	Double		2	0	3	25	3.42		1.75	34.3
			3	0	4	41	4.68		1.27	47.4
			4	0	6	45	6.75		2.07	29.0
			5	0	8	4	8.07		1.32	45.6
								38.5	avg in/hr	
		2	1	0	1	43	1.72		1.72	35.0
			2	0	3	24	3.40		1.68	35.6
			3	0	5	8	5.13		1.73	34.6
			4	0	6	40	6.67		1.53	39.1
			5	0	8	21	8.35		1.68	35.6
								36.0	avg in/hr	
		3	1	0	1	27	1.45		1.45	41.4
			2	0	3	3	3.05		1.60	37.5
			3	0	4	51	4.85		1.80	33.3
			4	0	6	39	6.65		1.80	33.3
			5	0	7	58	7.97		1.32	45.6
								38.2	avg in/hr	

TABLE 5.1 CONTINUED JONES TRAILHEAD INFILTRATION DATA

	1" Constant Double	**1**	**1**	0	1	23	**1.38**		**1.38**	**43.4**
			2	0	3	33	**3.55**		**2.17**	**27.7**
			3	0	5	47	**5.78**		**2.23**	**26.9**
			4	0	7	8	**7.13**		**1.35**	**44.4**
			5	0	9	20	**9.33**		**2.20**	**27.3**
								33.9	**avg in/hr**	
		2	**1**	0	1	37	**1.62**		**1.62**	**37.1**
			2	0	3	38	**3.63**		**2.02**	**29.8**
			3	0	5	35	**5.58**		**1.95**	**30.8**
			4	0	7	10	**7.17**		**1.58**	**37.9**
			5	0	8	58	**8.97**		**1.80**	**33.3**
								33.8	**avg in/hr**	
		3	**1**	0	1	45	**1.75**		**1.75**	**34.3**
			2	0	3	47	**3.78**		**2.03**	**29.5**
			3	0	5	59	**5.98**		**2.20**	**27.3**
			4	0	7	36	**7.60**		**1.62**	**37.1**
			5	0	9	42	**9.70**		**2.10**	**28.6**
								31.4	**avg in/hr**	
6/5/2007	**1" Constant single infilrometer**	**1**	**1**	0	3	25	**3.42**		**3.42**	**17.6**
			2	0	5	35	**5.58**		**2.17**	**27.7**
			3	0	8	12	**8.20**		**2.62**	**22.9**
			4	0	11	31	**11.52**		**3.32**	**18.1**
			5	0	14	13	**14.22**		**2.70**	**22.2**
								21.7	**avg in/hr**	
		2	**1**	0	3	20	**3.33**		**3.33**	**18.0**
			2	0	6	45	**6.75**		**3.42**	**17.6**
			3	0	10	1	**10.02**		**3.27**	**18.4**
			4	0	13	0	**13.00**		**2.98**	**20.1**
			5	0	15	45	**15.75**		**2.75**	**21.8**
								19.2	**avg in/hr**	
7/14/2008	**1" Constant single infilrometer**	**1**	**1**	0	3	57	**3.95**		**3.95**	**15.2**
			2	0	6	36	**6.60**		**2.65**	**22.6**
			3	0	9	58	**9.97**		**3.37**	**17.8**
			4	0	13	48	**13.80**		**3.83**	**15.7**
			5	0	16	51	**16.85**		**3.05**	**19.7**
								18.2	**avg in/hr**	
		2	**1**	0	3	3	**3.05**		**3.05**	**19.7**
			2	0	6	35	**6.58**		**3.53**	**17.0**
			3	0	9	23	**9.38**		**2.80**	**21.4**
			4	0	12	19	**12.32**		**2.93**	**20.5**
			5	0	15	49	**15.82**		**3.50**	**17.1**
								19.1	**avg in/hr**	

TABLE 5.1 CONTINUED JONES TRAILHEAD INFILTRATION DATA

	3	**2**	0	6	1	**6.02**		**6.02**	**10.0**
		3	0	8	45	**8.75**		**2.73**	**22.0**
		4	0	11	54	**11.90**		**3.15**	**19.0**
		5	0	15	41	**15.68**		**3.78**	**15.9**
							16.7	**avg in/hr**	
7/14/2008 1" Constant single infilrometer	**1**	**1**	0	1	18	**1.30**		**1.30**	**46.2**
		2	0	2	17	**2.28**		**0.98**	**61.0**
		3	0	3	26	**3.43**		**1.15**	**52.2**
		4	0	4	44	**4.73**		**1.30**	**46.2**
		5	0	5	46	**5.77**		**1.03**	**58.1**
							52.7	**avg in/hr**	
	2	**1**	0	1	13	**1.22**		**1.22**	**49.3**
		2	0	2	14	**2.23**		**1.02**	**59.0**
		3	0	3	26	**3.43**		**1.20**	**50.0**
		4	0	4	28	**4.47**		**1.03**	**58.1**
		5	0	5	33	**5.55**		**1.08**	**55.4**
							54.4	**avg in/hr**	
	3	**1**	0	1	4	**1.07**		**1.07**	**56.3**
		2	0	2	5	**2.08**		**1.02**	**59.0**
		3	0	3	13	**3.22**		**1.13**	**52.9**
		4	0	4	17	**4.28**		**1.07**	**56.3**
		5	0	5	16	**5.27**		**0.98**	**61.0**
							57.1	**avg in/hr**	
	4	**1**	0	1	27	**1.45**		**1.45**	**41.4**
		2	0	2	35	**2.58**		**1.13**	**52.9**
		3	0	3	53	**3.88**		**1.30**	**46.2**
		4	0	5	25	**5.42**		**1.53**	**39.1**
		5	0	6	30	**6.50**		**1.08**	**55.4**
							47.0	avg in/hr	

N=25			N=27		
Average without saturation	**33.0**	in/hr	average of all tests	**31.0**	in/hr
Std deviation without saturation	**16.0**	in/hr	standard deviation	**16.9**	in/hr
Maximum without saturation	**68.1**	in/hr	Maximum	**68.1**	in/hr
Minimum without saturation	**11.3**	in/hr	Minimum	**6.1**	in/hr

5.8 Summary

A pervious concrete parking area was constructed in Seminole County, Florida with a reservoir made of Black and Gold Reservoir Media^{TM}. The reservoir was composed of select media consisting of sand and tire crumb and was chosen for strength and pollution control.

The site was monitored over an 18 month period for infiltration rate and water quality. Visual observation of the surface was also recorded. Infiltration and water quality data were collected and presented over the course of this study and provided evidence that pervious concrete retains an infiltrative capacity, provided proper installation.

5.9 Conclusions

The pervious concrete installation process was demonstrated. The pervious concrete by visual appearances is not breaking down and is taking the wear of car stopping, movements and parking. There was no visual wear noted for the concrete.

Limiting infiltration rate measures were estimated for both surface mounted infiltrometers and embedded ones. The embedded ones also penetrate the sub base materials gave a more accurate accounting of the infiltration rates. The surface mounted ones produced much higher values, presumably because the water once within the pervious concrete traveled in a lateral direction through the pervious concrete. During construction of the pervious concrete, embedded infiltrometers were placed at two locations. Infiltration rates were measured using an embedded ring infiltrometer kit (ERIK). These measures were taken at three different heads, and as expected the higher heads produce generally higher estimated rates of infiltration. The average limiting rates of infiltration for the Twenty-seven samples was 31 inches per hour. An acceptable rate of infiltration for an 80 percent yearly volume control and using these designs is 1.5 inches per hour.

Water quantity and quality at the bottom of the reservoir was measured but only on two occasions was there water in the collection devices. Water quality was measured based on orthophosphate (dissolved phosphorus), and nitrates (dissolved nitrogen fraction). Water quality in terms of dissolved phosphorus and nitrates leaving the reservoir was about equal to rainwater quality. The yearly rainfall at the rest area was about average over the 18 months.

5.10 Recommendations

Pervious concrete parking areas should be considered for stormwater management. The infiltration rate, runoff volume reduction, water quality improvement, and structural stability make it a viable option.

An embedded ring infiltrometer should be placed in the pervious concrete and about 4 inches into the sub-soil during the construction phase and used for testing infiltration rates in the future.

5.11 Future Research

Infiltration tests should be continued on a yearly basis to document the performed over a longer period of time. The testing frequency is now set at once every two years however, there is no documented frequency in the literature. Also the testing can be used to determine the need for vacuum sweeping.

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CHAPTER 6 – EXFILTRATION SYSTEMS

6.1 Introduction

An exfiltration trench is a stormwater management system in which the runoff from a watershed is directly routed through a perforated or slotted pipe into the groundwater. It can be wither an off-line or on-line structure, but either system must have an infiltration potential to infiltrate the stored runoff water. Traditionally, exfiltration trenches are constructed without sorption media for the removal of pollutants. Also, there are limited water quality data on the impact this system has on the groundwater quality. If the runoff contains a significant quantity of pollutants, then this system could be having adverse effects on the ground water quality.

Stormwater runoff contains many different pollutants. Some of the common pollutants in stormwater are nutrients and heavy metals. Nitrogen and Phosphorus are the most common nutrients causing impacts to receiving waters. Roadway runoff has been documented as a major source of groundwater nitrogen contamination in urban areas of Florida and groundwater contamination by phosphorus has not been as widespread, or as severe (Pitt, Clark, & Field, 1999). Roadway runoff is managed through a variety of best management practices (BMP), and a widely used roadway runoff BMP used in Florida is an exfiltration trench. Water quality sampling of the groundwater surrounding an exfiltration tank first using no sorption material and then using the Black and Gold Exfiltration Media™ will be helpful in examining water quality benefits.

6.2 Objective

The objective of the field investigation is to evaluate the effectiveness of Black and Gold Exfiltration Media™ for nutrient removal in an exfiltration trench. The exfiltration trench selected for this study is located on East Lake Brantley Drive in Seminole County, Florida. Ground water is analyzed before and after Black and Gold Exfiltration Media™ is added to the exfiltration system. The comparison of the water quality of the samples before and after the addition of Black and Gold Exfiltration Media™, is the basis of the analysis.

6.3 Limitations

This study is conducted in the central Florida and thus subject to the climate of the area. Also, the stormwater comes from a roadway off East Lake Brantley Drive, in Seminole County which is a two lane urban street. Lastly, the sampling occurs during the months of December to July.

6.4 Background

An exfiltration trench is defined as a subsurface system consisting of a conduit such as perforated pipe surrounded by natural or artificial aggregate which temporarily stores and infiltrates stormwater runoff. The perforated pipe is generally used because it increases the storage volume of the trench relative to trench backfill with highly porous material. Also, the pipe evenly distributes the stormwater runoff which will promote infiltration (Evans,1990). An overflow weir, commonly called a smart box, is usually included in the design of exfiltration trench. The purpose of this device is to route a specific amount of runoff to the system. The excess runoff is generally routed to another stormwater management device (DEP, 2007). In order for the exfiltration trench to work, the soil must have a soil permeability and groundwater table condition suitable to allow the required volume of stormwater to infiltrate into the soil over a specified time frame after the storm event. A typical exfiltration trench cross section is shown in Figure 6.1.

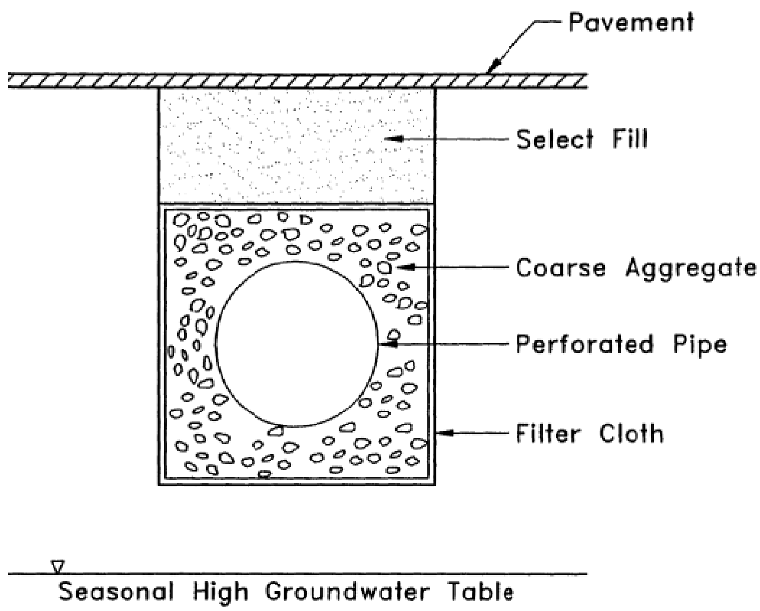

Figure 6.10: Exfiltration Trench Cross-Section

The exfiltration trench is a widely used BMP in areas where land is expensive or there is a lack of available land for traditional surface BMPs. Some of the common areas in which an exfiltration system is used include collection from roof drains, parking lots, tennis courts and roadways (DEP, 2007). They are also considered a retention system because the system does not discharge the treated volume into a surface water body. Instead, the exfiltration trench discharges the treated volume directly into the groundwater. Thus, this system could be used as a means to help recharge surrounding wetlands, prevent saltwater intrusion in coastal areas, and to maintain groundwater levels in aquifer recharge areas (FDER, 1988).

Nitrogen and phosphorus are usually deposited on a impervious surfaces from both vehicular traffic and from adjacent soils that have been fertilized. Impervious surface runoff has been found to be a major source of nitrogen contamination in urban areas of Florida. Phosphorus contamination has not been as widespread or severe as nitrogen (Pitt, 2001). Runoff waters carry these nutrients and other pollutants in the stormwater transport system to a stormwater management method. This method could be a dry retention system from which the runoff water goes into the groundwater.

Once runoff is introduced to groundwater using, there is a potential for groundwater contamination. The contamination is influenced by many factors. Some of these factors include the pollutant concentration in the runoff directed to the exfiltration device and the ability of the underlying soil to remove the pollutant. The groundwater contamination potential of some pollutants, even those with high concentrations and moderate-to-high mobility, can be reduced with proper pretreatment before infiltration (Clark & Pitt, 2007).

A water quality study was conducted on three stormwater management systems for roadway runoff in central Florida (Schiffer, 1989). Five test sites were selected which included two ponds, two swales, and an exfiltration trench. The systems were compared using the groundwater quality in the surficial aquifer. It was found that the nitrate nitrogen was significantly higher in the swales and exfiltration trench. The phosphorus (and reactive phosphorus) was significantly higher in the exfiltration trench. This shows how more nutrient pollutants pass through an exfiltration trench compared to the other stormwater management systems.

There have been new methods to reduce the nutrient loads going into the groundwater. One such method is to use bioretention. Bioretention is a up-land water quality and water quantity control practice that uses the chemical, biological and physical properties of plants, microbes and soils for removal of pollutants from storm water runoff. A study for nutrient removal efficiencies of the bioretention was conducted by Davis, Shokouhain, Sharma, & Minami, (2006). They found that the system removed 70-85% of the phosphorus and 55-65% of the total Kjeldahl nitrogen. However, the nitrate reduction was less than 20%. In some of the situations, the nitrate concentration actually increased. They concluded that the system as designed is not effective at removing nitrates.

A study was conducted using tire crumb as a filter media on a golf course (Lisi, Park, & Stier, 2004). The tire crumb was used as an intermediate layer and as gravel for a golf course green. Then, these where compared to the tradition USGA green profile. The results of this study showed a significant reduction in nitrate concentration in the leachate water for each of the tire crumb greens. This reduction was 58.6% when the gravel was replaced by tire crumb, and 23% when tire crumb was used above the gravel as an intermediate layer compared to the traditional USGA green profile. The reactive phosphorus concentration was statistically equivalent for all tree alternative gold course green profiles. Therefore, there was no significant reduction in reactive phosphorus concentration when using tire crumb.

Tire crumb was also used for green roofs (Hardin, 2006). The nutrients and other parameters were monitored to document the best pollution control mix of media for green roofs. It was showed that a mixture of tire crumb with expanded clay significantly reduced the ortho-phosphorus and phosphorus concentrations. Also, it showed a slight reduction in the nitrate-nitrite concentration, even thought it was not statistically significant.

The exfiltration system is a widely used BMP used in Florida. However, exfiltration systems do allow more nutrient pollutants to pass through them without a sorption media compared to swales and ponds (Schiffer, 1989). To lower the nutrient pollutants, exfiltration systems can contain a sorption media. Therefore, Black and Gold Exfiltration Media™ which is a blend of expanded clay and tire crumb is chosen to be that filtration media. Research already done on other mixes of tire crumb has shown its potential for reducing nitrogen and phosphorus species. Therefore, the media has shown the ability to reduce the amount of nutrients reaching the groundwater.

6.5 Watershed Location

An existing exfiltration system located on East Lake Brantley Drive in Seminole County, Florida is selected. This exfiltration trench is part of the East Lake Brantley Drive stormwater management system. This roadway is a two lane urban street located in a residential zone that uses septic systems. In Figure 6.11 is shown a picture of the roadway and the location of the exfiltration trench.

Figure 6.11: East Lake Brantley Drive Aerial Photo

The exfiltration trench has the dimensions of 12' by 75' by 1.6' and is backfilled with #4 coarse aggregate. The aggregate meets the standard for use in exfiltration systems and was shown by Evans (1990) to function for a long time period. The exfiltration trench contains five 72' long, 12" diameter perforated pipes that the stormwater is routed through. A schematic of the system is shown in Figure 6.3.

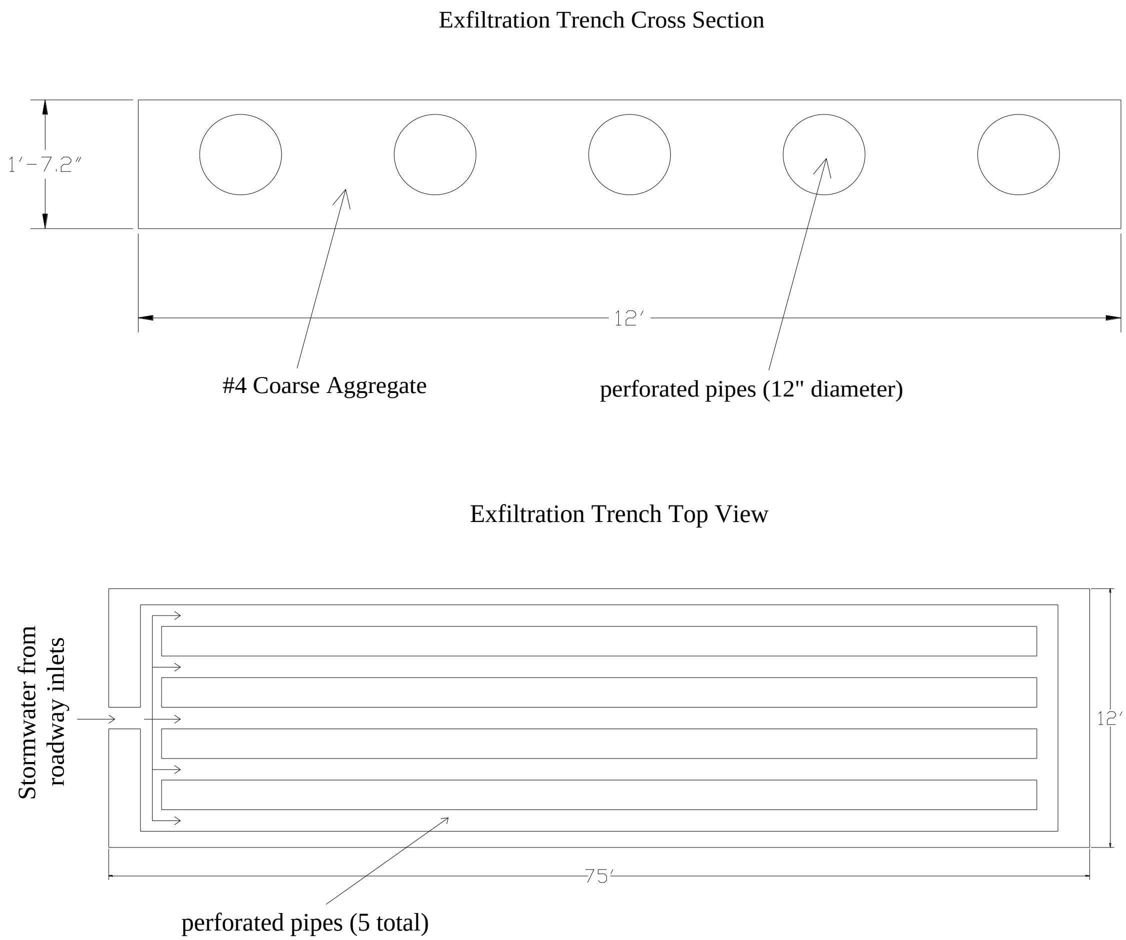

Figure 6.3: Schematic of East Lake Brantley Drive Exfiltration Trench

Sampling Plan

Groundwater samples are collected using four observations wells placed around the exfiltration trench. A diagram of the system is shown in Figure 6.4.

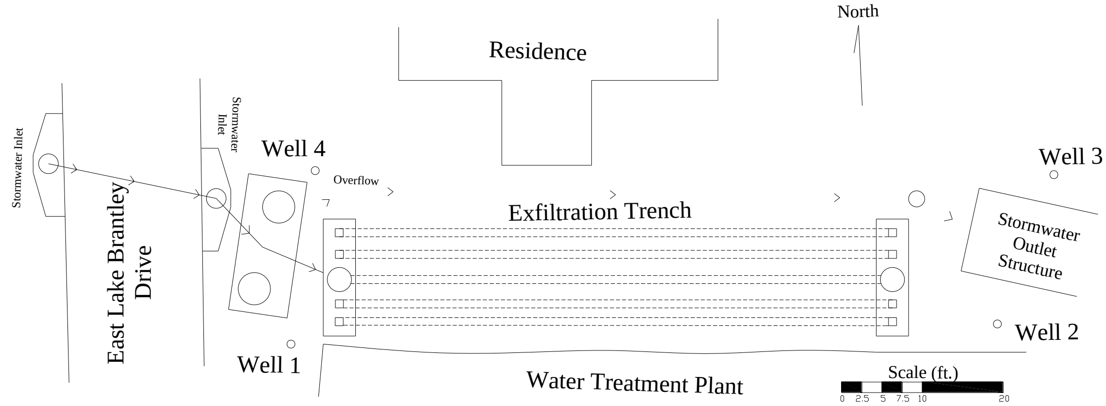

Figure 6.4: System Layout

The sampling wells are constructed using guidelines from the U.S. Geological Survey Water-Resource Investigation Report 96-4233 (Lapham, Wilde, & Koterba, 1997). The wells are constructed using 2” diameter PVC pipes. There is a 3” diameter hole dug to approximately 2-3 ft below the normal water table. Then, a 5 ft. long 0.01 ft. screened section connected to an unscreened PVC pipe is inserted into the hole. 20-30 sieve sand is used to fill the hole surrounding the screened section of the well. An annular seal is used to fill the remainder of the hole. Finally, the well top is sealed using cement. A sample well is shown in **Error! Reference source not found.**.5.

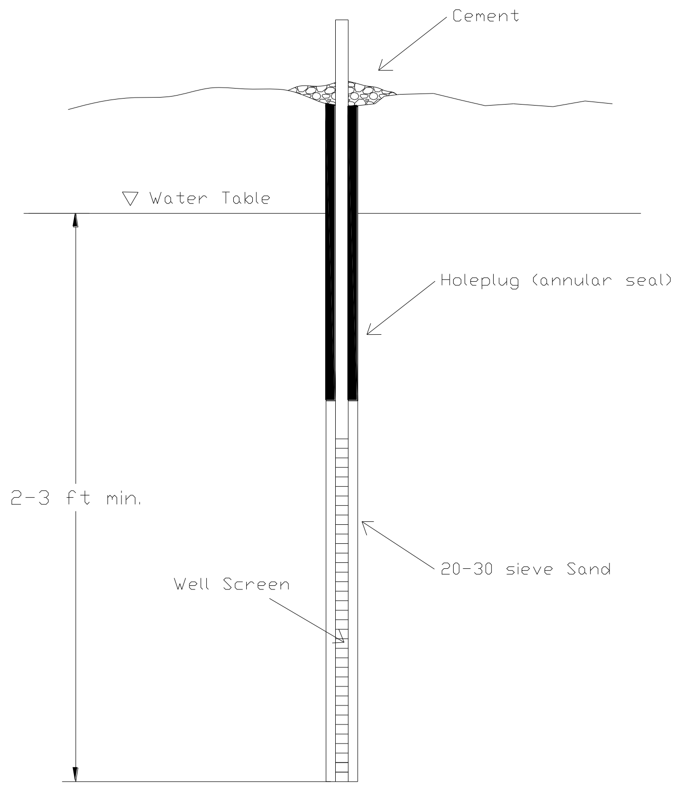

Figure 6.5 Groundwater Sampling Well

The groundwater samples are collected using low-flow groundwater sampling procedures (Puls & Barcelona, 1996) that require minimal drawdown of no more than 0.1m (0.3 ft) during sampling. The minimal drawdown is achieved by controlling the speed of the pump. Also, 2-3 casing volumes of water should be purged before collecting a sample. The purge ensures the water collected is not the stagnate water located in the well. Finally, to ensure a representative sample is collected, pH, temperature, conductivity, and dissolved oxygen (DO) readings are recorded every 3-5 minutes while the well is being purged. Stabilization of the water occurs when three or more successive reading of the above listed parameters are within specific ranges. These ranges are ± 0.1 °C for temperature, ± 0.05 for pH, ± 3% for conductivity and ± 10% for DO.

In the event that the drawdown cannot be maintained at 0.1m (0.3 ft), the following procedure is adopted. The well is pumped dry by placing the pump at the water level in the well and continuously lowered until the well is dry. Once dry, the pump is left in the well as the well recharges. When the well fully recovers, the initial water level is restored and a sample is collected.

Water quality samples of the groundwater are recorded with the existing exfiltration design. Then the sorption material mix is added to the exfiltration tank by "washing" in the mix and samples are again taken after rainfall runoff events. The Black and Gold Exfiltration Media™ is added to the exfiltration system through the clean out holes. Approximately 112.5 ft^3 of the media is added to the exfiltration system. This volume is calculated to produce an eighth of an inch of media in the trench. When the roadway runoff enters through the exfiltration system, the media is pushed through the perforated pipes and into the trench.

6.6 Groundwater Results and Comparisons

Groundwater Levels

It is important to document the groundwater level changes with runoff and the direction of flow. Water level fluctuation is measured during the sampling period and is presented in Figure 6.6. The fluctuation for each well shows how water in wells one and four are always higher than wells two and three. Therefore, the groundwater flows from the roadway to the lake and through the exfiltration system. Also, the water levels in wells two and three follow the same trend or are about equal elevation at the same time. This also holds true for wells one and four. It is also apparent that the groundwater responds to runoff events as shown by the "spikes" in the data following rainfall events.

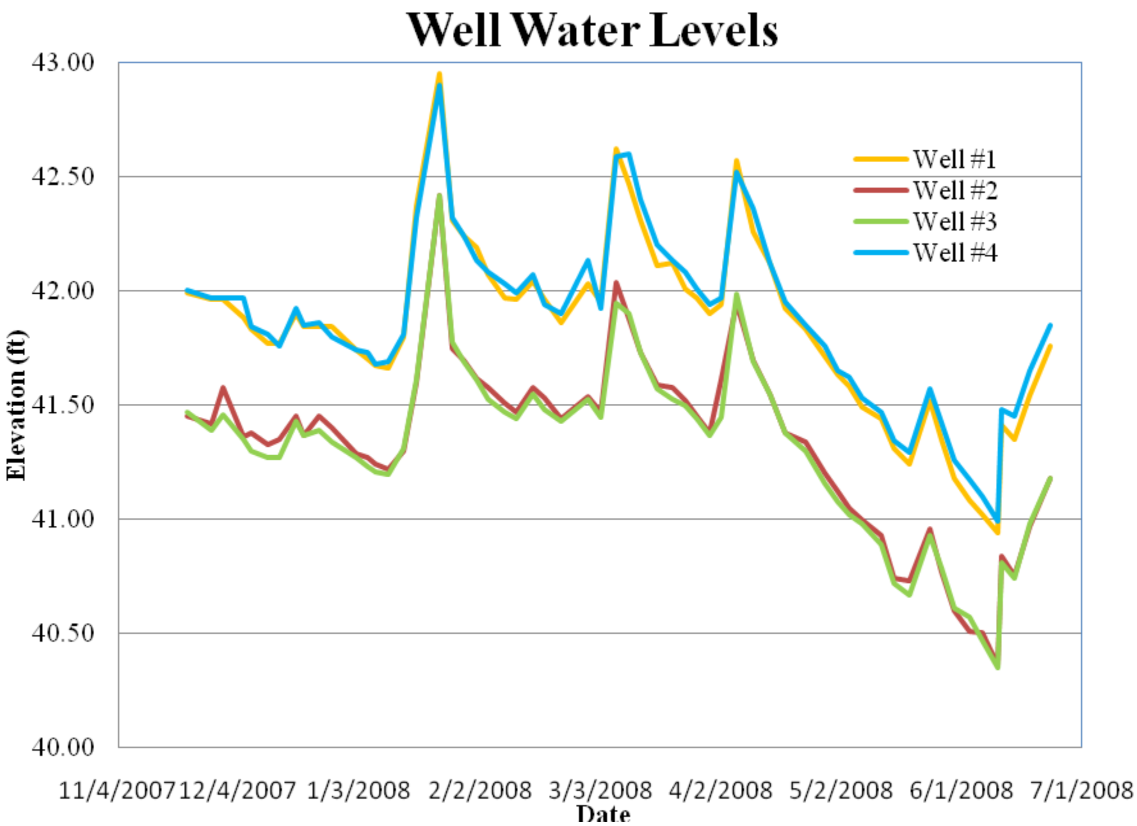

Figure 6.6: Ground Water Levels

Ground Water Quality Comparisons

Groundwater quality samples are taken before and after the addition of Black and Gold Exfiltration Media™ to the exfiltration system. Six samples are taken before media addition and three samples after media addition. The complete results for each sample are found in Rivera (2008). The sample analyses were performed by a ERD Inc, a state certified lab. All the samples were collected and transported under conditions suitable for analyses and completed within the recommended holding time. Average water quality results are shown in Table 6.1 for pH, Turbidity and Nutrients.

Table 6.16: Average Groundwater Quality Pre and Post Media

Sample Description	Condition	pH (s.u.)	Turbidity (NTU)	Ortho-P (μg/L)	Total P (μg/L)	NO_x-N (μg/L)	Total N (μg/L)
Well 1	Pre Media	6.88	6.3	6	28	8972	14407
	Post Media	6.95	13.1	5	77	4758	6324
Well 2	Pre Media	6.40	4.5	4	39	475	1768
	Post Media	6.53	21.3	3	68	58	926
Well 3	Pre Media	7.12	5.1	13	28	2919	5176
	Post Media	7.17	7.6	7	42	1101	3230
Well 4	Pre Media	6.97	108.7	6	166	185	21571
	Post Media	6.90	33.4	5	127	52	14589

The pH comparison of the pre and post media average values for each well is approximately equal. There is also no change relative to each sampling period (Rivera, 2008). Therefore, pH is not affected by the addition of the Black and Gold^{TM} media.

The turbidity of the groundwater tended to increase in the post media samples compared to the pre media samples. This occurred in wells one, two, and three. Wells two and three are the wells that the down gradient or the groundwater is flowing toward them. Therefore, wells two and three would be the ones most affected by the tire crumb addition. Well one also had an increase in turbidity. This shows that the Black and Gold^{TM} media may increase the turbidity of the groundwater.

In all of the wells, the average ortho-phosphorous concentrations decreased with the addition of the Black and Gold Exfiltration Media^{TM}. The average total phosphorus increased in all the wells except well four. Like the ortho-phosphorus, the post media total phosphorus values are about equivalent to the pre media values. Thus, there is most likely based on the sampling not a reduction in the total or ortho-phosphorus concentrations.

The average nitrate + nitrite concentrations are reduced in all four wells. These reductions ranged from 47% to 88%. The average total nitrogen concentrations are reduced in each of the wells. These reductions ranged from 32% to 56%. Therefore, the Black and Gold Exfiltration Media™ reduced the total nitrogen and nitrate + nitrite concentrations.

In Table 6.17 is shown the average metals concentration comparisons for pre and post media addition. The metal concentrations did not change significantly in any of the wells. This shows that the Black and Gold Exfiltration Media™ media will not add unwanted metals to the groundwater, nor was it expected.

Table 6.17: Average Metals Concentrations Pre and Post Media

Sample Description	Condition	Copper (μg/l)	Lead (μg/l)	Zinc (μg/l)	Iron (μg/l)	Nickel (μg/l)
Well 1	Pre Media	4	2	4	379	2
	Post Media	5	2	5	2498	2
Well 2	Pre Media	4	2	7	1663	2
	Post Media	5	2	8	1229	2
Well 3	Pre Media	4	2	6	1162	2
	Post Media	7	2	10	1368	2
Well 4	Pre Media	3	2	4	9577	2
	Post Media	8	2	6	7948	2

6.7 Summary

A widely used roadway runoff best management practice (BMP) used in Florida is an exfiltration trench. Traditionally, exfiltration trenches are constructed without any filtration media. Therefore, the potential for groundwater contamination from impervious surfaces like from roadway runoff exists. Roadway runoff contains metals and nutrient pollutants. Nitrogen and Phosphorus are the most common nutrients causing impacts to receiving waters in the Seminole County area where the exfiltration tank is located. To reduce the impact these pollutants will have on groundwater quality, Black and Gold Exfiltration Media™, which mainly consists of tire crumb, is evaluated.

The exfiltration trench selected for this study is located on East Lake Brantley Drive in Seminole County, Florida. The evaluation is conducted in two phases. The first phase is collecting water quality samples from the groundwater near the exfiltration trench without the Black and Gold Exfiltration Media™ media. The second phase is collecting water quality samples with the Black and Gold Exfiltration Media™. Then the effectiveness of the tire crumb, measured by water quality, as a filtration media is evaluated.

6.8 Conclusions

First it can be concluded that Black and Gold Exfiltration Media™ can be added to an existing exfiltration tank. The distribution of the mix within the pipe however could not be documented within the scope of this work.

Based on the limited sampling program for the exfiltration site, the Black and Gold Exfiltration Media™ was found to be a good sorption media for removal of total nitrogen and nitrate + nitrite. It was found that all of the groundwater wells had experienced total nitrogen removal. These reductions ranged from 32% to 56%. The nitrate + nitrite reduction was also recorded in the four wells. These reductions ranged from 47% to 93% in the three wells.

During the post sampling period, the turbidity of the groundwater increased. This was recorded in three of the four wells. The ortho-phosphorous and total phosphorus concentrations did not change significantly. Also, the metals concentrations did not change significantly.

6.9 Recommendations

The Black and Gold Exfiltration Media™ should be consider as a pollution control sorption media for exfiltration systems. In these systems, the media has the ability to reduce the total nitrogen and nitrate + nitrite pollutants entering the groundwater. It also does not have any adverse effects on the pH, metals concentration or phosphorus concentrations.

6.10 Future Research

There was limited water quality sampling of the system. Thus additional sampling of the groundwater would produce additional comparisons to evaluate the media.

6.11 References

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