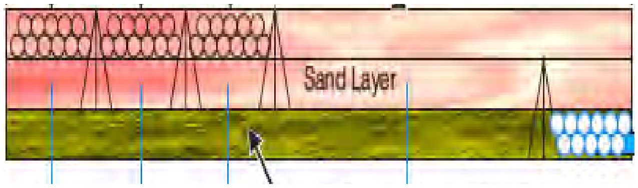
Onsite Sewage Treatment and Disposal Systems Evaluation for Nutrient Removal



Interim Report
Submitted to Florida Department of Environmental Protection

Submitted by

Dr. Ni-Bin Chang, Dr. Marty Wanielista, Dr. Ammarin Daranpob
Fahim Hossain, Zhemin Xuan, Junna Miao, Sha Liu,
Zachary Marimon, Shalimar Debusk

Stormwater Management Academy
University of Central Florida

January 7, 2010

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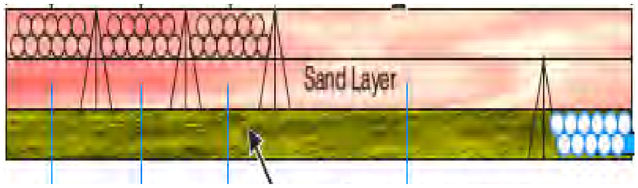

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Executive Summary

There are increasing nutrients in many of the ground and surface waters of the State. Higher levels of nutrients have resulted in impaired waters. Loss of resource utilization has resulted, especially in spring areas. Elevated nutrient levels in ground water and surface water may cause public health problems, such as blue baby syndrome, and may impair or destroy environmentally sensitive ecosystem habitat through algal blooms and eutrophication. Impaired waters and loss of resource utilization has resulted in increased cost and loss of recreational opportunities.

The major causes of these problems are widely acknowledged to be from nonpoint sources of pollution, especially those from both urban and rural areas and include conventional septic tanks, or onsite sewage treatment and disposal systems (OSTDS). Approximately one-third of Florida's population is served by OSTDS representing about 2.5 million systems (Briggs, Roeder et al. 2007). OSTDS systems are currently regulated by the Florida Department of Health (FDOH) and in specific nutrient terms, a limiting nitrate level of 10 mg/L is set. However, this level is about one order of magnitude too high to protect springs and other water bodies from nutrient degradation. Nitrogen compounds cannot be significantly reduced in the conventional OSTDS and thus nitrogen levels within ground waters may increase.

In many Florida aquifers and springs, nitrate concentrations have been increasing with time. For 56 Upper Floridian aquifer wells in Marion County, Phelps (2004) measured nitrate concentrations of up to 12 mg/L, with a median of 1.2 mg/L, during 2000-2001. For Wakulla Springs, Katz (2009) reported that there has been a steady increase in nitrate levels to about 0.9 mg/L over the past 30 years. The median nitrate levels beneath a Wakulla area conventional OSTDS drain field was measured at 19 mg/L.

Because of the concern for nitrate levels from OSTDS, scientists, engineers, regulators and manufacturers in the wastewater treatment industry have developed a wide range of alternative technologies designed to address removal of specific nutrients and pathogens from OSTDS. Another concern is the use of energy for some of the more advanced performance based systems. FDOH has been promoting performance based OSTDS in the Florida Keys and other areas, but they are expensive to install and operate and may not always produce a consistent nutrient reduction. Among OSTDS treatment trains, passive systems are of interest because of their consistent nutrient reduction capabilities and relatively low initial and operating cost.

Within this report are the results of a Florida Department of Environmental Protection sponsored research program using three passive OSTDS treatment trains operating at the University of Central Florida (UCF) Onsite Wastewater Test Center. The first OSTDS treatment train is a conventional design to include a septic tank with and without a media recirculation tank and two drain fields in parallel. The drain fields have a different type of sand media. The second OSTDS treatment train is a Bold & Gold^{TM} (B&G) drain field with green sorption media. The third is a subsurface upflow wetland (SUW) with innovative subsurface hydraulic flow patterns, green sorption media and various plant species.

To obtain the best possible nutrient reduction from the conventional septic tank and drain field, a recirculation tank was added to the conventional treatment train at the Test Center. Thus, effluent water quality comparisons can be made for the B&G and SUW to the conventional system with the best effluent water quality from a conventional system. During a year of operation and testing, two alternative passive OSTDSs, namely B&G and SUW with new sorption media and flow patterns, have proven to 1) be effective in nutrient reduction, 2) maintain operating reliability, and 3) have no energy requirements. All three factors are major concerns of any OSTDS application. The newly developed passive technologies, B&G and SUW systems, installed at the UCF Test Center underwent an intensive sampling for system performance, modeling of the pollutant transport and fate, and an assessment for integration of the planning, design, installation, maintenance, and management functions for future implementation. Average effluent concentrations of the sorption media B&G and the sorption media with plants, called SUW, are compared in Table ES-1. The comparison illustrates that the nutrient removal effectiveness of the B&G and SUW systems are more effective compared to the conventional OSTDS with and without recirculation. Nitrates in particular are less than 10 mg/L with the B&G and SUW sorption systems.

Also from ground water measurements below the drain field of the conventional OSTDS, elevated nutrient levels were noted. Nitrate nitrogen was as high as 29.9 mg/L. These elevated levels beneath the drain field of a conventional OSTDS were also noted beneath the drain fields of a conventional OSTDS in the Wakulla basin (Katz, 2009).

Table ES-1 Comparison of average effluent concentrations for two conventional OSTDS and two sorption OSTDS namely B&G and SUW

	Conventional DF with recirculation	Conventional DF no recirculation	B&G Sorption Drain Field	SUW – Sorption with Canna Plants
CBOD5 (mg/L)	7	1	8	4
Nitrate-N (mg/L)	29.8	38.9	3.15	0.006
TN (mg/L)	31.1	55.7	12.9	1.96
SRP (mg/L)	6.44	4.73	1.00	0.018
TP (mg/L)	6.78	5.52	1.39	0.096
Fecal (cfu/100mL)	1	1	11	657
E.Coli. (cfu/100mL)	1	1	9	7

Using construction, operating, and unit cost data, B&G and SUW are the least costly for nutrient removal as shown in Table ES-2. The cost for conventional OSTDS cannot be compared when additional nutrient removal is needed. The cost data are based on a design flow rate of 500 gpd. The cost of the conventional, B&G, and SUW are from actual installation records while the cost of the performance ones (last two rows in Table ES-2) were estimated from previous reports (Mayer and Sherman, 1998). All costs were verified with local OSTDS installers. The annual operating cost for the conventional and the B&G are based on inspection and hydraulic repair cost only, which in many situations is zero but assumed equal to $200 for this analyses. It should be noted that these costs are highly variable from region to region in our State, but the relative cost of each should not change.

Table ES-2 Cost Comparison (mid-year 2009 basis) of a conventional OSTDS with systems that have a higher level of nutrient removal including B&G and SUW and based on a 500 gpd flow

	Construction Cost with 20% contingency ($)	Annualized Construction Cost at 6% interest rate and 20 years ($)	Annual Operating cost ($)	Unit Cost $/1000 gallons
Conventional OSTDS	$ 6,920	$ 600	$ 200	$ 4.38
B&G with sorption media	$ 9,320	$ 810	$ 200	$ 5.53
SUW with sorption media and plants	$ 10,200	$ 890	$ 400	$ 7.07
Continuous Feed Cyclic Reactor & Drip Irrigation	$ 18,200	$ 1,590	$ 1,800	$ 18.58
Recirculation Tank & Drip Irrigation	$ 27,800	$ 2,420	$ 1,850	$ 23.40

Based on full scale operation and measurement at the UCF OSTDS Test Center, it is recommended that the State of Florida require the implementation of the passive options of a green sorption media drain field (B&G) and a subsurface upflow wetland with green sorption media and plants (SUW). They both are effective alternatives for reduction of nutrients in OSTDS, produce reliable operation, and consume no energy. Furthermore, they have the least construction and operation costs relative to others that remove more nutrients than the conventional systems.

Chapter 1: Introduction

1.1 Objectives

Aquifer and springs are vulnerable to impacts from anthropogenic activities, especially in areas where the aquifer is not confined or only thinly confined, such as throughout much of central and north Florida. Nitrate concentrations have increased in the Floridian aquifer and in springs since the 1950s, exceeding 1 mg/L in recent years at some springs. As an example, Phelps (2004) measured nitrate concentrations of up to 12 mg/L, with a median of 1.2 mg/L, for 56 Upper Floridian aquifer wells sampled in Marion County during 2000-2001. Elevated nutrient levels in ground water may even cause public health problems, such as blue baby syndrome, and may impair or destroy environmentally sensitive surface water ecosystems through algal blooms and eutrophication.

Nonpoint sources of pollution are the primary cause of water quality impairment in Florida. In addition to agricultural and urban stormwater, some of the impacts on the aquifers, surface waters, and springs are coming from septic tanks and their associated drain fields. There are more than 2 million septic tanks and drain fields in the State of Florida. When urban regions gradually expand due to regional development, centralized sewage collection, treatment, and disposal is often unavailable for economic reasons. Thus, decentralized or on-site sewage treatment and disposal systems (OSTDS) (i.e., septic tank systems) are necessary to protect public health. In rural communities, nitrates are contributed from fertilized landscaped areas and failed septic tank effluents from residential areas. The most common type of OSTDS is a septic tank followed by a drain field system, A.K.A. “septic system”. The most significant benefit of OSTDS is their cost effectiveness and ease of operation and maintenance. To reduce the impacts of OSTDS on ground water, the Florida Department of Health (FDOH) has required performance-based OSTDS in the Florida Keys and certain springsheds. However, recent experience has shown that these systems are expensive to install, operate, and maintain. Additionally, their ability to consistently reduce nutrients is highly variable. Passive nutrient removing OSTDS provide the promise of higher levels of nutrient reduction in a cost effective and relatively maintenance free manner.

Given the need to reduce nitrates and total nitrogen in the springs, surface water, and aquifers of Florida, the objectives of this study are to:

1) Evaluate the removal efficiency of nutrients (nitrogen and phosphorous) associated with new passive OSTDS treatment trains and compare to conventional designs.

2) Document the operation and cost of these systems, and

3) Document the fate and transport of nutrients in vadose zone and ground water aquifer from a conventional drain field.

In short, the focus of this work is on the development and evaluation of performance-based, passive nutrient removing on-site wastewater treatment technologies. Based on previous research by the Principal Investigators and an extensive literature review of the myriad of alternative technologies available (passive and non passive), three of them are selected for testing. Existing and alternative treatment media (natural sand and amendment mixtures) in on-site wastewater treatment process are studied, focusing on the use of a filtering device, a subsurface wetland, and an innovative passive drain field with soil substitution systems. To verify the cost-effectiveness and nutrient removal performance, a septic tank with a conventional drain field is used as a control for comparative basis.

Ground water wells are used for monitoring the water quality within the vadose zone and the surrounding aquifers. Treatment trains for comparison testing are constructed at University of Central Florida (UCF) where the soil and water table conditions are representative of environmental settings in much of Florida where OSTDS are used widely. Accordingly, the general findings gained in this study are transferable to many communities statewide.

This research aims at addressing the following critical questions that have not been fully answered in the literature:

1) What are effective treatment media for removing nutrients from septic tank effluent?

2) What are the underlying processes of such treatment media and their associated function, effectiveness, and longevity?

3) What insights are available on how such systems have been designed, installed, maintained, controlled, and replaced that may be applicable to on-site sewage treatment?

4) What comparative basis can be used when different sorption media are used in passive treatment processes and are compared against other treatment trains, such as the use of a conventional drain field?

The research team provided a thorough literature review of possible passive nutrient removal treatment media, such as sawdust, zeolites, tire crumb, decayed vegetation, and spodosols etc, and developed recommendations for on-site applications. The project thus focuses on clarifying these four questions through full scale testing. The following chapters of this report explain the facilities operational scenarios, sampling scheme, modeling analysis, monitoring results, and cost assessment separately and in great detail.

OSTDS have been constructed, operated, and monitored at the UCF Test Center since spring 2008. There are three treatment technologies. The first treatment technology consists of a septic tank, a recirculation tank, and two types of conventional drain fields in parallel to allow testing of two differing types of sand to be arranged with the same influent. The first drain field uses washed builder's sand as its filtrating media while the second drain field design uses Astatula (citrus grove sand). The second treatment technology has a septic tank followed by a lined drain field filled with Bold and Gold ^{TM} sorption media (called "Bold & Gold^{TM}" or B&G drain field in our study). The third treatment technology consists of four wetland cells in parallel. Three wetland cells each contain a different plant species, and the last wetland cell does not have any plants serving as a control cell. All the four wetland cells are filled with sorption media with a unique recipe. All of these OSTDS treatment technologies at UCF Test Center received typical Florida residential wastewater from a student scholarship house which includes a kitchen, a clothes washer, and bathrooms. When students are not in the scholarship house, additional wastewater comes from the UCF presidential reception house.

1.2 Nutrient Impact Resulting from Conventional On-site Wastewater Treatment

On-site sewage contains organic matter (biochemical oxygen demand), suspended solids, nutrients, and some pathogens, which can cause a number of diseases through ingestion or physical contact. Since the nitrate (NO_3^-) ion is not easily bound to the soil, OSTDS can represent a large fraction of nutrient loads to ground water aquifers and surface waters. Nutrients such as ammonia, nitrite, nitrate, and phosphorus are common contaminants in water bodies all over the world. All these nutrients have direct and indirect acute and chronic harmful outcome for human beings and ecosystems. Ammonia is an important compound in freshwater ecosystems. It can stimulate phytoplankton growth, exhibit toxicity to aquatic biota, and exert an oxygen demand in surface waters (Beutel, 2006). Hence, primarily due to the limited nitrogen-removal treatment capabilities of conventional septic systems, their density of use in a watershed can produce adverse and undesired aquatic resource impact through accelerated eutrophication. Besides, unionized ammonia is very toxic for salmonid and non-salmonid fish species (Tarazona et al., 2008). Fish mortality, health and reproduction can be hampered by the presence of minute amount of ammonia-N (Servizi and Gordon 2005). Nitrate can cause human health problems such as liver damage and even cancers (Gabel et al, 1982; Huang et al., 1998). Nitrate can also bind with hemoglobin and create a situation of oxygen deficiency in an infant's body called methemoglobinemia, or Blue-baby syndrome (Kim-Shapiro et al., 2005). Additionally, nitrite can react with amines chemically or enzymatically to form nitrosamines that are very strong carcinogens (Sawyer et al., 2003).

In addition, wastewater also carries bacteria microorganisms such Escherichia coli and Salmonella typhi, protozoa like Cryptosporidium parvum and Giardia lamblia, helminthes and viruses like hepatitis A. These microorganisms are responsible for different kinds of diseases like diarrhea, jaundice, food poisoning, dysentery and nausea (Metcalf and Eddy, 2003; WEF and ASCE, 2005). On the other hand, those OSTDS-related diseases may include but are not limited to shigellosis, salmonellosis, typhoid fever, and infectious hepatitis (Katzenelson et al., 1976).

As a consequence, nutrient and pathogen removal is very important for the sustainability of the aquatic ecosystem and human health. There are alternative OSTDS typically referred to as "Performance-based OSTDS" that are available instead of conventional septic tanks for homeowners. However, performance-based OSTDS are energy intensive and they are very expensive to install, operate, and maintain. In addition, they are designed to achieve an effluent with 10 mg/L nitrate which may be fine to prevent Blue-baby syndrome but is much too high to protect springs and other water bodies. Accordingly, there is a need for promoting enhanced nitrogen and pathogen removal in a passive OSTDS that is more cost effective. Additionally, a better understanding is needed of nutrient removal behavior as the effluent plume passes through the OSTDS and the soil to the ground water and possibly a receiving water body.

A septic system consists of three (3) main components. The first component is a home's indoor plumbing, which is a system of drains and pipes located inside a home used for transporting wastewater outside to the next major component, the septic tank. The septic tank is normally an underground, watertight container, made of concrete, fiberglass, or other durable material, which provides primary wastewater treatment (settling of solids). The third component is the standard drain field that is constructed by a series of parallel, underground, perforated pipes that allow septic tank effluent to percolate into the surrounding soil in the vadose (unsaturated) zone where it is assumed that most of the residual nutrients may be assimilated. Several types of effluent distribution are applicable in standard drain field systems. These include gravity systems, low pressure dosed systems, drip irrigation systems, etc. and some of them require having an additional pump. Through various physical, chemical, and biological processes, most bacteria, viruses and nutrients in wastewater are expected to be consumed or filtered as the wastewater passes through the soil. After treatment, the effluent enters the vadose zone and ultimately a ground water aquifer acts as a receiving water body. When properly constructed and maintained, the septic system can provide years of safe, reliable, cost-effective service, which have been viewed as important information for decision making (Etnier et al., 2000).

Due to widespread concerns about the impacts of OSTDS on ground and surface waters, scientists, engineers, and manufacturers in the wastewater treatment industry have developed a wide range of alternative passive technologies designed to address increasing hydraulic loads, energy saving requirements, and improved removal of nutrients and pathogens from on-site wastewater treatment. These alternative systems require increased testing to verify system performance, pollutant transport and fate, resultant environmental impacts, and an integration of the planning, design, siting, installation, maintenance, and management functions. Cost effectiveness, system reliability, and proper management become the major concerns in their use. In general, passive technologies (those without more than one pump) might be advantageous due to their cost effectiveness, system reliability, and low maintenance requirement. This triggers an acute need to perform a thorough technology assessment, screening, and prioritization.

1.3 Passive On-site Wastewater Treatment

Passive on-site wastewater treatment is defined by the Florida Department of Health as a type of OSTDS that excludes the use of aerator pumps, includes no more than one effluent dosing pump with mechanical and moving parts, and uses a reactive media to assist in nitrogen removal. Reactive media are materials that effluent from a septic tank or pretreatment device passes through prior to reaching the ground water. This may include but are not limited to soil, sawdust, zeolites, tire crumb, vegetative removal, sulfur, spodosols, or other media. Hence, a new generation of passive performance-based, as opposed to conventional, on-site wastewater treatment technologies to effectively remove nutrients and better protect public health and our ground and surface waters in a cost-effective manner are needed. It is the aim of this project to develop and evaluate passive OSTDS for use in Florida. The project evaluates two innovative designs, a newly developed cost-effective underground drain field with soil amendments (sorption media), and an upflow wetlands with soil amendments all constructed at the UCF Test Center.

1.4 Current Regulation of Water Quality and OSTDS Standards

The Florida Department of Environmental Protection is charged with implementing the requirements of the Federal Clean Water Act and the Florida Water Pollution Control Act set forth in Chapter 403, Florida Statutes. DEP has established by rule a water body classification system and the supporting surface water quality standards which are designed to protect the beneficial uses set forth in the water body classes. With respect to nutrients, DEP has adopted a narrative nutrient criterion which states that nutrient levels shall not create an imbalance of flora and fauna. DEP currently is working on numeric nutrient criteria and has established water body specific ones with the adoption of Total Maximum Daily Loads (TMDLs) for those water bodies impaired by nutrients. For example, the TMDL for Wekiwa springs is a monthly average of 286 ug/L nitrate. In addition, DEP has adopted the Safe Drinking Water Act standards which establish nitrate and nitrite maximum contamination levels (MCL) in ground water aquifers and potable water. These should not be above 10.0 mg/L nitrate-nitrogen ($N0_3^{-}N$) and 1.0 mg/L nitrite-nitrogen (NO_2-N), respectively The Florida Department of Health is charged with regulating OSTDS through their authority in Chapter 381, F.S., and their implementing regulations in Chapter 10D-6, F.A.C. DOH's mission is the protection of public health, not water quality, and they use the drinking water standard of 10 mg/L nitrate as their goal.

1.5 NSF 245 Standard

National Sanitation Foundation and the American National Standards Institute (NSF/ANSI) Standard 245 were developed for residential wastewater treatment systems designed to provide for nitrogen reduction in 2007. The evaluation involves six months of performance testing, incorporating stress tests to simulate wash day, working parent, power outage, and vacation conditions. The standard is set up to evaluate systems having rated capacities between 400 gallons and 1500 gallons per day. Technologies testing against Standard 245 must either be Standard 40 certified (ANSI-40) or be evaluated against Standard 40 at the same time (NSF, 2009). The NSF 245/ANSI-40 influent concentration standards for testing are:

- BOD_5 : 100 to 300 mg/L
- TSS : 100 to 350 mg/L
- TKN : 35 to 70 mg/L as N
- Alkalinity : greater than 175 mg/L as $CaCO_3$ (alkalinity may be adjusted if inadequate)
- Temperature : 10 to 30 ºC
- pH : 6.5 to 9 SU

Environmental Technology Verification (ETV) protocols are developed for specific technology areas and serve as templates for developing test plans for the evaluation of individual technologies at specific locations. The ETV protocols for suggested average influent requirements are (NSF, 2009):

- Only suggested ranges:
- $CBOD_5$: 100 – 450 mg/L
- TSS : 100 – 500 mg/L
- TKN : 25 – 70 mg/L
- Total P : 3 – 20 mg/L
- Alkalinity : greater than 60 mg/L
- Temperature : 10º C – 30º C

The NSF Standards 245 would allow chemical addition to adjust influent's alkalinity using – sodium bicarbonate. Throughout the testing, samples are collected during design loading periods and evaluated against the pass/fail requirements.

NSF states that an OSWT system must meet the following effluent concentrations averaged over the course of the testing period in order to meet Standard 245 (NSF, 2009):

- $CBOD_5$: 25 mg/L
- TSS : 30 mg/L
- TKN : less than 50% of average of all influent TKN samples
- pH : 6.0 – 9.0 S.U.

Chapter 2 Alternatives to Conventional OSTDS

2.1 UCF OSTDS Testing Center

2.1.1 Introduction to UCF Field-scale Test Center

To achieve the project's objectives, an OSTDS Test Center was constructed on the UCF campus that currently has three OSTDS treatment technologies. The first OSTDS treatment technology consists of a septic tank, an optional sand-filter circulation tank, and two drain fields in parallel (see Figure 1). There are a total of nine (9) sampling points, including S1, and S3-S10 (assuming that the conditions of S2 and S3 are not different). S1 is the raw sewage from the source before it is mixed with the treated wastewater from the sand-filter tank (S4). S2 and S3 are the wastewater after the septic tank (1.5 days retention time). The sand-filter tank has approx. 1-2 hours retention time. S4 is a sampling port at the outlet of the sand-filtered tank. The distribution tank has an approximate 0.5 day retention time. Three (3) lysimeters were installed at 8", 16", and 24" below the infiltrate surface of each drain field. These lysimeters (S5-S10) may collect wastewater infiltrate in the vadose zone as the effluent travels through the sand.

The wastewater source for the Test Center is the 15-person BPW Scholarship House (a female dormitory at UCF campus), which contains a kitchen, washing machine, and living quarters. The wastewater is pumped to 3.78 m^3 (1,000 gallon) and 5.10 m^3 (1,350 gallon) septic tanks from where the effluents are divided into different final disposal alternatives. While the former septic tank handles both the B&G drain field (Figure 1) and the wetland system (Figure 1), the latter one handles both standard drain fields (Figure 1). A dosing tank is connected to one septic tank for handling the collected effluent from B&G and wetland treatment processes. On average, the pump and pipe arrangement delivers an average of 0.75 m^3/day (200 gpd) to each of the four drain fields, including two convention ones with different sands, the B&G drain field, and the wetland system with four cells. Each conventional drain field and the B&G drain field received about 200 gallons of wastewater daily, whereas each wetland cell received 50 gallons of wastewater daily. There are four (4) cells of wetlands (Figure 1). Three different plant species of plants were planted into three separate wetland cells for testing. One wetland cell is set up as the control case, which has no plants. Each cell of the wetland has 5 sampling ports. The sampling ports are located at 2’, 4’, 6’, 8’, and 10’ from the inlet of each cell. The estimated hydraulic retention time is 1 day.

There are two sets of monitoring wells at UCF Test Center, eight (8) drain field monitoring wells and eight (8) background monitoring wells (Figure 1). The eight (8) drain field monitoring wells are located near the two standard drain fields to monitor the water quality of the ground water up gradient, immediate, and down gradient of each standard drain field. The eight (8) background wells are located along the perimeter of the test site to monitor the flow regime and the water quality underground. The background monitoring wells (MW1-MW8) were sampled once in a month. The drain field monitoring wells were sampled on a biweekly basis for monitoring their water quality.

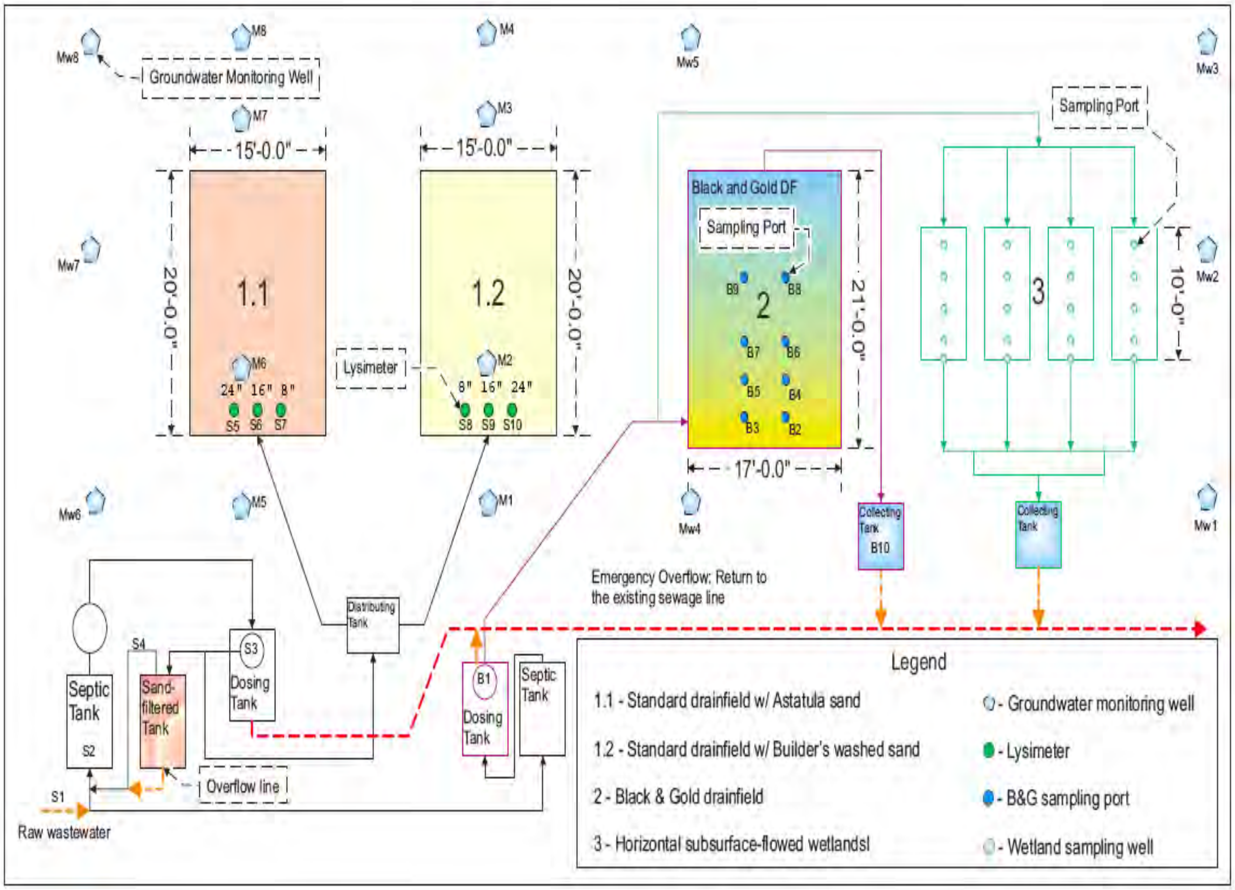


Figure 1 A simple layout of OSTDS at UCF test center.

2.1.2 Influent conditions

Formal sampling campaign was launched on Oct. 13 2008 in the conventional drain field and B&G drain field. The influent concentrations of sewerage are shown in Table 1.

Table 1 Influent concentration - average and standard deviation
(a)basic parameters (mg/L)

Parameter	ALK	TSS	BOD_5	$CBOD_5$
Influent (S1) (Oct '08 – Sep '09)	296 ± 62	208 ± 162	230 ± 225	130 ± 100
NSF/ANSI 40	> 175	100 - 350	-	100 – 300

*ALK: alkalinity, TSS: total suspended solid, BOD5: 5 day biochemical oxygen demand, CBOD5: 5 day carbonaceous biochemical oxygen demand

(b) Influent average and standard deviation concentrations – nitrogen parameters (mg/L)

Parameter	Ammonia-N	Nitrate-N	Nitrite-N	TKN	Organic N	TN
Influent (S1) (Oct '08 – Sep '09)	39.0 ± 16.1	0.335 ± 1.123	0.183 ± 0.518	51.7 ± 15.9	12.7 ± 12.8	50.7 ± 16.2
NSF/ANSI 40	-	-	-	35 – 70		

*TKN: Total Kjeldahl Nitrogen, Organic N: Organic nitrogen, TN: Total nitrogen

(c) Influent average and standard deviation concentrations – phosphorus parameters (mg/L)

Parameter	SRP	Organic P	TP
Avg. Influent (S1) Phase I	4.59 ± 1.5	2.15 ± 1.8	7.12 ± 2.6

* SRP: Solvable reactive phosphorus, Organic P: organic phosphorus, TP: Total phosphorus

2.2 Nutrient removal mechanism and sorption media

2.2.1Nutrient removal mechanism

The adsorption, absorption, ion exchange, and precipitation processes are actually intertwined with the overall physicochemical process in the UCF Test Center nutrient removal drain fields no matter if they are conventional or innovative (newly developed). Some nutrients, such as phosphorus removed by inorganic media, are likely a sorption/precipitation complex. The distinction between adsorption and precipitation is the nature of the chemical bond forming between the pollutant and sorption media. Yet the attraction of sorption surface between the pollutant and the sorption media causes the pollutants to leave the aqueous solution and simply adhere to the sorption media. This approach to wastewater treatment has "green" implications because of the inclusion of recycled material as part of the material mixture promoting treatment efficiency and effectiveness.

In the context of using various green sorption media for nutrient removal, it might appear that sorption is followed by precipitation or occurs at the same time in the same physicochemical process. The nitrogen cycle in either engineered systems or the built environments are well understood. Within the microbiological process, if there are organic sources in the wastewater streams, hydrolysis converts particulate organic nitrogen (N) to soluble organic N, and ammonification in turn releases ammonia into the water bodies. In addition to ammonification, important biochemical transformation processes include nitrification and denitrification. They result in the transformation of nitrogen between ammonia, nitrite, and nitrate forms via oxidation and reduction reactions in microbiological processes. In the presence of ammonia-oxidizing bacteria (AOB) and oxygen in the aerobic environment, ammonium is converted to nitrite (NO_2^-) and nitrite-oxidizing bacteria (NOB) convert nitrite to nitrate (NO_3^-) continuously. Collectively these two reactions are called nitrification. Conversely, denitrification is an anaerobic respiration process using nitrate as a final electron acceptor with the presence of appropriate electron donors, resulting in the stepwise reduction of NO_3^- to NO_2^-, nitric oxide (NO), nitrous oxide (N_2O), and nitrogen gas (N_2). Denitrification also requires the presence of an electron donor, which may commonly include organic carbon, iron, manganese, or sulfur, to make the reduction happen. As long as the hydraulic retention time (HRT) is sufficiently long to promote removal, microbe-mineral or sorption media interface can be initiated for either or both nitrification and denitrification process. In our case, sawdust is used as electron donors. The relationships between the various nitrogen species are well defined and are shown in drawings and by equations. Detailed literature review of the effects of nitrification and denitrification within the nitrogen cycle can be seen in US EPA (2005), Chang et al 2008b, and FDOH, 2009.

The two steps of ammonia oxidation can be summarized as below in equations 1 and 2 (Metcalf and Eddy, 2003):

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O \qquad (1)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad (2)$$

and the denitrification of wastewater is shown in equation 3 (Metcalf and Eddy, 2003),

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10OH^- \qquad (3)$$

All of these three types of reactions are expected to occur in our B&G drain field.

2.2.2 Sorption media

As already described, passive OSTDS use a reactive media to assist in nitrogen removal. Reactive media used in OSTDS have included soil, sawdust, zeolites, tire crumb, sulfur, spodosols, or other media. Some passive OSTDS technologies use a reactive media to assist in nitrogen removal including sawdust and other wood products, zeolites, tire crumb, vegetation, sulfur, spodosols, etc. (Chang et al., 2008a).

Soil augmentation with sorption media mixes result in improvements in nutrient removal of current treatment technologies used for stormwater management, wastewater treatment, landfill leachate treatment, ground water remediation, and treatment of drinking water (Chang et al., 2008b). The use of these sorption media in the engineered and natural processes may remove not only the nutrients, but also some other pollutants, such heavy metals, pathogens, pesticides, and toxins (TCE, PAH, etc.).

In this project, we have evaluated four types of green sorption media including Bold & Gold media, Pollution Control media, Growth media, and Recirculation media. Table 2 summarizes a list of sorption media previously used for wastewater treatment and their corresponding references. Table 3 summarizes the media and their recipes being applied at UCF pilot study.

Table 2 Sorption media used to treat wastewater

No.	Sorption media	Additional environmental benefits	Physical/Chemical Properties	References
1	Sand filter			Bell et al., 1995
2	Tire crumb/Tire chips	2,4-dichlorophenol (DCP), 4-chlorophenol (CP)	D= 20.00 to 40.00 mm	Shin et al., 1999
3	Zeolite + Expanded Clay		D= 2.50-5.00 mm	Gisvold et al., 2000
4	Polyurethane porous media		Porous structure, Average diameter 3.00-5.00 mm, External pore diameter 300 micron.	Han et al., 2001
5	Limestone		D= 2.38 to 4.76 mm	Zhang, 2002
	Sulfur		D= 2.38 to 4.76 mm	
6	Sand granules			Espino-valdés et al., 2003
7	Clay			Gálvez et al., 2003
8	High density module			Rodgers and Zhan, 2004
9	Sandy clay loam (SCL)		Sand (53.28%), Silt (24.00%), Clay (22.72%)	Güngör and Ünlü 2005
	Loamy sand (LS)		Sand (78.28%), Silt (10.64%), Clay (11.08%)	
	Sandy loam (SL)		Sand (70.28%), Silt (14.64%), Clay (15.08%)	

No.	Sorption media	Additional environmental benefits	Physical/Chemical Properties	References
10	Masonry sand		Bulk density of masonry sand is 1670 kg/m^3; Porosity of masonry sand is 0.30.	Forbes et al., 2005
	Expanded shale		Expanded shale (SiO_2 62.06%, Al_2O_3 15.86%, Fe_2O_3 5.80%, CaO 1.44%, MgO 1.68%); Bulk density of expanded shale is 728.00 kg/m^3; Porosity of expanded shale is 0.59.	
11	Oyster shell powder		Powder form, 28.00% Calcium, Average particle size 200 micron, Surface area 237.00 m^2/g	Namasivayam et al., 2005
12	Limestone		D =2.38 to 4.76 mm	Sengupta and Ergas, 2006
	Oyster shell			
	Marble chips		$Mg(OH)_2$ and $CaCO_3$	
13	Soy meal hull	Direct and acid dye	D<0.125 mm	Arami et al., 2006
14	Clinoptilolite			Hedström et al., 2006
	Blast furnace slag		Composed of melilite, merwinite, anorthite, gehlenite	
15	Perlite			Rebco II, 2007
16	Clinoptilolite		D = 0.30 -4.76 mm	Smith et al., 2008
	Expanded clay		D = 0.40-5.0 mm	
	Tire crumb		D = 0.30-5.00mm	
	Sulfur		D = 2.00-5.00 mm	
	Crushed oyster shell		D = 3.00-15.00 mm	
	Utelite (expanded shale)		D = 0.40-4.50 mm	

Note: D is the diameter of the media

Table 3 UCF developed green sorption media

Sorption Media	Recipe	Note
Bold & Gold (B&G)	68% Astatula sand 25% Tire crumb 7% Sawdust	This sorption media is used at the bottom layer in the B&G drain field.
Pollution Control Media	50% Astatula sand 20% Limestone 20% Tire crumb 10% Sawdust	This sorption media is used in the middle layer of wetlands.
Growth Media	75% Expanded clay 15% Florida moss 10% Vermiculite	This sorption media is used in the top layer of wetlands.
Recirculation Media	50% Citrus grove sand 20% Limestone 15% Tire crumb 10% Sawdust 5% Expanded clay	This sorption media is used in the top layer of recirculation tank in one of the three testing stage

2.3 Bold & Gold^{TM} (B&G) drain field with sorption media

Engineered, functionalized, and natural sorption media can be used to treat stormwater runoff, wastewater effluents, ground water flows, landfill leachate and sources of drinking water for nutrient removal via physicochemical and microbiological processes (Chang et al., 2008b). The media may include but are not limited to sawdust, peat, compost, zeolite, wheat straw, newspaper, sand, limestone, expanded clay, wood chips, wood fibers, mulch, glass, ash, pumice, bentonite, tire crumb, expanded shale, oyster shell, and soy meal hull (Chang et al., 2008b). This approach has “green” implications because of the inclusion of recycled material as part of the media mixture (Chang et al., 2008b). The choice of media mixes depend on the desired length of service, residence time during an operating cycle, and pollutants in the wastewater.

With the aid of green sorption media, one of the main objectives of this study is to evaluate the basic functionality and effectiveness of the B&G drain field with its unique recipe to remove both nutrients and pathogens. This innovative passive underground drain field is highly sustainable, will fit in any landscape now used for a conventional drain field, and is highly applicable to a wide variety of septic tank designs (Wanielista et al., 2008). The sorption media soil amendments in the B&G drain field are used in a manner to foster both a saturated anaerobic or anoxic environment. The appropriate arrangement of the piping system for correct dosing, along with the optimal sizing of the anoxic environment with adequate partition, eventually sustain the functionality of these green sorption media in passive drain fields (Wanielista et al., 2008). A lab-scaled study was carried out in which sorption isotherm and microcosm tests were used to prove the concept (Chang et al., 2008a, 2008b). However, comparative full scale testing studies are required to prove the advantageous features of passive treatment technologies within the treatment trains at the UCF Test Center.

Figure 2 shows the schematic of the B&G drain field with a green sorption material mixture filling the horizontal underground cells beneath a sand layer. It is expected that the influent side of the B&G layer (left side in Figure 2) can be designed as an aerobic zone followed by an anoxic zone before the effluent is discharged. The drain field is filled with green sorption material mixture to provide an alternating cycle of aerobic and anoxic environments to transform and remove nutrients and pathogens in wastewater. In the drain field, the hydraulic pattern is used in combination with an alternating cycle of aerobic and anoxic environments, which repeats the reaction mechanism of nitrification and denitrification sequentially, to remove nutrient content from the influent. Some vertical pipes (i.e., oxygenators) for venting in the beginning of the drain field close to the header pipe may induce air into the initial portion of cell so that the aerobic environment can be promoted periodically when needed. In all circumstances, the B&G drain field has an impervious liner at the bottom to keep all nitrification and denitrification processes in an isolated environment.

When the system is operational, household sewerage may be directed into the underground B&G drain field with sorption media being placed in an open channel within the box partitioned by baffles. The total number of baffles required depends on the influent pipe arrangement and the need to prevent short circuiting. Dosing the sewerage in the front cell of the manifold (inflow pipe) may happen periodically. Perforated pipes at the front cell may be controlled to maintain the aerobic condition at the left part of channel (see Figure 2). Then the baffles guide the flow through the drain field. While the first part of the channel consumes air and alkalinity for nitrification, the dissolved oxygen would gradually decrease making the subsequent process anoxic before the riser where denitrification may occur. All cells before the riser baffle in the open channel must be filled with sorption media to promote the targeted reactions. After having 3-5 days retention time, flow eventually passes through a perforated outlet pipe to the disposal chamber. However, the retention time necessary for such a treatment should be verified in our study later on. The disposal chamber is for sampling purposes and to allow pumping back to a central sewer which was required by the FDOH for this experimental site. Infiltrate may percolate down into the vadose zone gradually in the end.

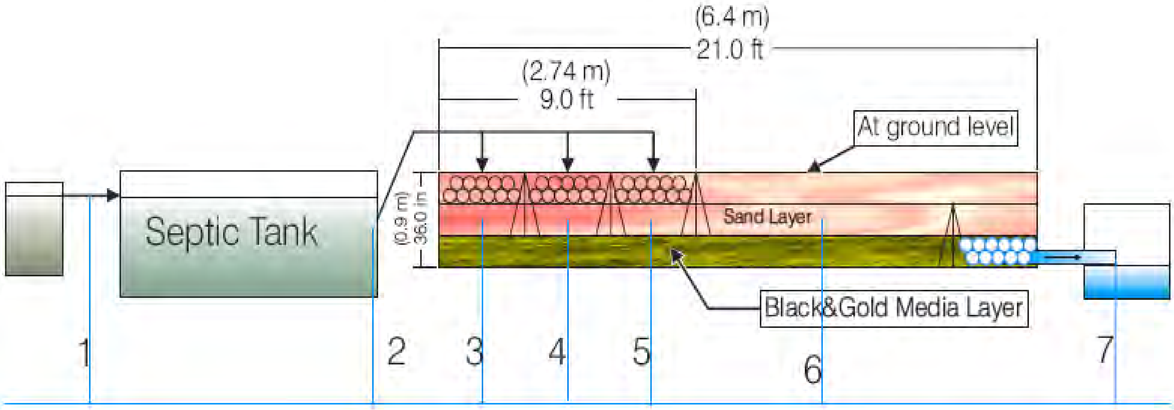


Figure 2 Schematic of the B&G Drain Field (Wanielista et al., 2008). Numbers refer to sampling points in the treatment train.

2.4 Upflow wetlands with sorption media and plant species

2.4.1 Upflow wetlands design with sorption media

Wetlands play an important role in water conservation, climate regulation, soil erosion control, flood storage, and environment purification. Both natural and constructed wetlands have been shown to be effective in treating wastewaters and stormwater. The wetland system removes nitrogen in the water through a variety of mechanisms including biological, physical and chemical reactions. Biological functions such as ammonification, nitrification-denitrification and plant uptake under appropriate conditions are regarded as the mechanisms for nitrogen transformation and removal. Precipitation of particular form of phosphorus is the main path for phosphorus removal. Besides, microbial absorption and accumulation also are important.

Constructed wetlands can be divided into two main types: surface flow (SF) wetland and subsurface flow (SSF) wetland. Surface flow wetlands (SF) include emergent vegetation, some sort of subsurface barrier to prevent seepage, soil or medium to support the emergent vegetation, and a water surface above the substrate. This kind of constructed wetland is particularly efficient in pathogens removal, due to the high exposure of the wastewater to the UV component of the sunlight. However, these systems may provide habitat to breed mosquito and the denitrification may be reduced due to the exposure of the wastewater to the air. In the subsurface flow wetland systems (SSF), the wastewater is routed below the surface and passes through the filter media until it reaches the outlet zone. Given sufficient retention time of the wastewater in the filter, nitrogen reduction is significant with horizontal flow systems, but full nitrification is limited due to a lack of oxygen that is characteristic for this kind of systems. There are various designs used for constructing a SF or SSF wetland depending upon the objectives. How to optimally assemble the physical, chemical and biological mechanisms to optimize nutrient removal through choosing and co-locating the different kinds of sorption media and vegetation always captures the design imagination of individuals throughout the world.

The potential of a constructed wetland for treating onsite and varying types of wastewater has been explored continuously as evidenced by a large body of literature. Johnson et. al. (1995) conducted a pilot project in Santa Rosa County where a conventional OSTDS was replaced with a constructed wetland system. They demonstrated that the three cell wetland system removed

88% of the orthophosphate, 60% of the ammonia-N, and 77% of the TKN. Steer (2002) evaluated the effectiveness of improving water quality for a single-family septic tank/constructed wetland system in Ohio. They concluded that domestic treatment wetlands can reduce output of fecal coliform 88 ± 27%, total suspended solids 56 ± 53%, biochemical oxygen demand 70 ± 48%, ammonia 56 ± 31% and phosphorus 80 ± 20%. Mbuligwe (2005) presented the performance of a coupled septic tank/engineered wetland (ST/EW) system for treating and recycling from a small community. The coupled ST/EW system was able to remove ammonia by an average of 60%, nitrate by 71%, sulfate by 55%, chemical oxygen demand (COD) by 91%, and fecal coliform as well as total coliform by almost 100%. Tanaka et al (2006) tried an integrated system of emergent plants and submerged plants to polish the effluent from a septic tank treating domestic sewage from a student dormitory. The overall pollutant removal efficiencies were 65.7% BOD, 40.8% COD, 74.8% ammonium nitrogen (NH_4^+-N), 38.8% nitrate nitrogen (NO_3^--N), 61.2% phosphate (PO_4^{3-}), 65.8% total suspended solids (TSS), and 94.8% fecal coliform. A thorough review of the use of constructed wetlands with horizontal sub-surface flow for various types of wastewater covering municipal, industrial and agricultural sectors can be seen in the literature (Vymazal, 2009). Various media have been studied and suggested. It was shown that green sorption medium consisting of recycled and natural materials provide a favorable environment for nutrient removal (Xuan et al., 2009). One of the main objectives of this study is to prove the cost-effectiveness of a newly developed subsurface upflow wetland (SUW) system with sorption media and selected plant species.

2.4.2 Wetland plant species

Plants are an extremely important component of a wetland system both in terms of nutrient uptake and by serving as a habitat for microorganisms. In the subsurface wetland system, the plant rhizosphere provides a potential attachment site for denitrifying bacteria in an anaerobic environment. Based on the characteristics of oxygen transmission, the rhizosphere shows an aerobic-anaerobic-anoxic state, thereby creating the equivalent of series or parallel anaerobic–anoxic–oxic (A2O) processing unit. Aerobic areas near the root zone are conducive to nitrification and anaerobic areas away from the roots work for denitrification, both of which may perform the final clean-up of residual nitrogen from the septic tank effluent. It is expected that nitrate may thus be effectively removed by denitrification in rhizospheric zones. TN and TP can be removed if the plants are harvested routinely. Seidel's work (1955) is known as the first trial to use the wetland vegetation to remove various pollutants from wastewater. Since then, researchers have studied different vegetation species to optimize pollutants removal efficiency. In Table 4, a literature review using different kinds of vegetation with natural soil as substrate for wastewater treatment throughout the world is shown. From

Table 4, only Phragmites Australis (in case 1b and 1f in SF) showed a good result with respect to the nutrients removal (about 90% TN removal). However, Phragmites Australis is a kind of typical emergent vegetation, which is unsuitable to be planted in subsurface wetland.

The importance to developing specific wetland media instead of conventional soil, sand and gravel to gain better pollutants removal capacity is widely recognized. Mann's (1993) represented the pioneer trial in the early period from which the comparison of laboratory-scale phosphorus adsorption was conducted between regional gravels and alternative adsorptive media including industrial slag and ash by-products. The results showed the maximum adsorption capacity of regional gravels 25.8 to 47.5 µg P/g, blast furnace slag 160 to 420 µg P/g and fly ash 260 µg P/g, which warranted the further research via the inclusion of industrial waste media. Coombes and Collett (1995) used crushed basalt and limestone chippings in their horizontal flow *Phragmites australis* wetland. Ammonia nitrogen in the effluent averaged less than 2 mg/l. Three types of root bed media (Lockport dolomite, Queenston shale and Fonthill sand) were used by Pant et al (2001) with Fonthill sand having better performance in removing P from wastewater. Vohla et al (2007) tried a designed oil-shale ash derived from oil-shale combustion for P retention. The life cycle time was not 8 years as calculated from laboratory batch experiments, but several months due to the possible saturation or clogging in terms of quick biofilm development on the ash particles. Korkusuz et al (2007) carried out an investigation of blast furnace granulated slag (BFGS) and showed that BFGS has high phosphorus (P) sorption capacity removing TP concentrations from 6.61 ± 1.78 mg L^{-1} to 3.18 ± 1.82 mg L^{-1} due to its higher Ca content and porous structure. Park and Polprasert (2008) investigated the ability for P removal using an integrated constructed wetland system packed with oyster shells (OS) as adsorption and filtration media. The removal efficiency of the integrated system was found to be 85.7% of N and 98.3% of P. Tee et al (2009) reported a better performance of planted constructed wetlands with graveland raw rice husk-based media for phenol and nitrogen removal compared with unplanted ones.

Table 4 Wetland performance throughout the world by different kinds of vegetation

SF	Plant	Removal Efficiency	Reference
1a	*Typha Latifolia, Phragmites Australis, Sparganium Erectum*	80% COD, 83% BOD, 45% TN, 47% TP	Cadelli (1998)
1b	*Phragmites Australis,*	98% SS, 87% COD, 96% BOD, 91% TN, 60% OrthoP	Cadelli (1998)
1c	*Phragmites Australis, Scirpus Lacustris*	68% COD, 83% BOD, 26% TN, 2% Ortho P	Cadelli (1998)
1d	*Lemna Sp.*	96% SS, 75% COD, 90% BOD, 43% TN, 47% TP	Cadelli (1998)
1e	*Lemna Sp.*	98% SS, 96% COD, 94% BOD, 49% TN, 49% TP	Cadelli (1998)
1f	*Phragmites Australis,*	87% COD, 97% BOD, 89% TN, 46% TP	Cadelli (1998)
1	*Phragmites*	90% COD, 96% BOD, 92% SS, 63% TP, 36% TN	Haberl (1998)
2	*Scirpus Cyperinus, Typha Latifolia*	73.4% NH_4^+-N, 67.5% TKN	Huang (2000)
3a	*Typha Latifolia, T. Angustofolia, Scirpus Taebormontanii*	92% BOD, 87% TSS, 99.6% Fecal, 41% TN, 50% TP	Henneck (2001)
3b	*Typha Sp.*	82% BOD, 86% TSS, 92.4% Fecal, 51% TN, 59% TP	Henneck (2001)
3c	*Typha Latifolia*	83% BOD, 81% TSS, 99.9% Fecal, 54% TN, 97% TP	Henneck (2001)
4a	*Phragmites Mau Ritianus*	25.2% NH_4^+-N, 56.3% COD, 57% TC, 68% FC	Kaseva (2004)
4b	*Typha Latifolia*	23% NO_2-N, 23% NH_4^+-N, 60.7% COD, 60% TC, 72% FC	Kaseva (2004)
5a	*Cyperus Papyrus*	75.3% NH_4^+-N, 83.2% TRP	Kyambadde (2004)
5b	*Miscanthidium Violaceum*	61.5% NH_4^+-N, 48.4% TRP	Kyambadde (2004)
6	*Phragmites Australis*	30% of TP , 50% Denitrification	Brix (2005)
7	*Phragmites & Typha*	27% TKN, 19% NH_4^+-N, 4% Nitrite	Keffala (2005)
8a	*Juncus effusus L.*	54% NH_4^+-N, 55% TN, 95% TP	Xuan (2009)
8b	*Panicum Hemitomon*	88% NH_4^+-N, 85% TN, 94% TP	Xuan (2009)
8c	*Zizaniopsis Miliacea*	78% NH_4^+-N, 79% TN, 95% TP	Xuan (2009)

Note: Surface flow wetland (SF); Subsurface wetland (SSF); Ammonium-nitrogen (NH_4^+-N); Ammonium (NH_4^+); Nitrite (NO_2^-); Total Reactive Phosphorus (TRP); Total Kjeldahl Nitrogen (TKN); Nitrite-nitrogen (NO_2-N); Fecal Coliform (FC); total carbon (TC) total suspended solid (TSS); Biochemical Oxygen Demand (BOD); Chemical Oxygen Demand (COD), Total Phosphorus (TP); Total Nitrogen (TN)

There are four parallel 1.52 m wide × 3.05 m long × 0.91 m deep (each 5 ft wide × 10 ft long × 3 ft deep) cells in this test bed. Each of four cells contains an impermeable liner, a gravel substrate, green sorption media and selected plants; a gravel-filled gravity distribution system including header pipe, distribution pipe, collection pipe, flow meter, various lysimeters, and a planted bed of special green sorption media with an underdrain collection system. These wetlands operated as a subsurface upflow wetland (SUW). With the aid of a suite of selected plant species, this SUW is configured to handle 189 liters per day (50 GPD) influent. The hydraulic retention time (HRT) is about 6-7 days, based on a porosity of 30%. In addition, an innovative upflow (i.e. outlet of SUW is higher than inlet) design was introduced to avoid clogging, which is the main disadvantage of the conventional subsurface flow wetlands. Three sets of plant species were tested against the control which had no plant species. Figure 3 shows a plan-view of the SUW system test configuration.

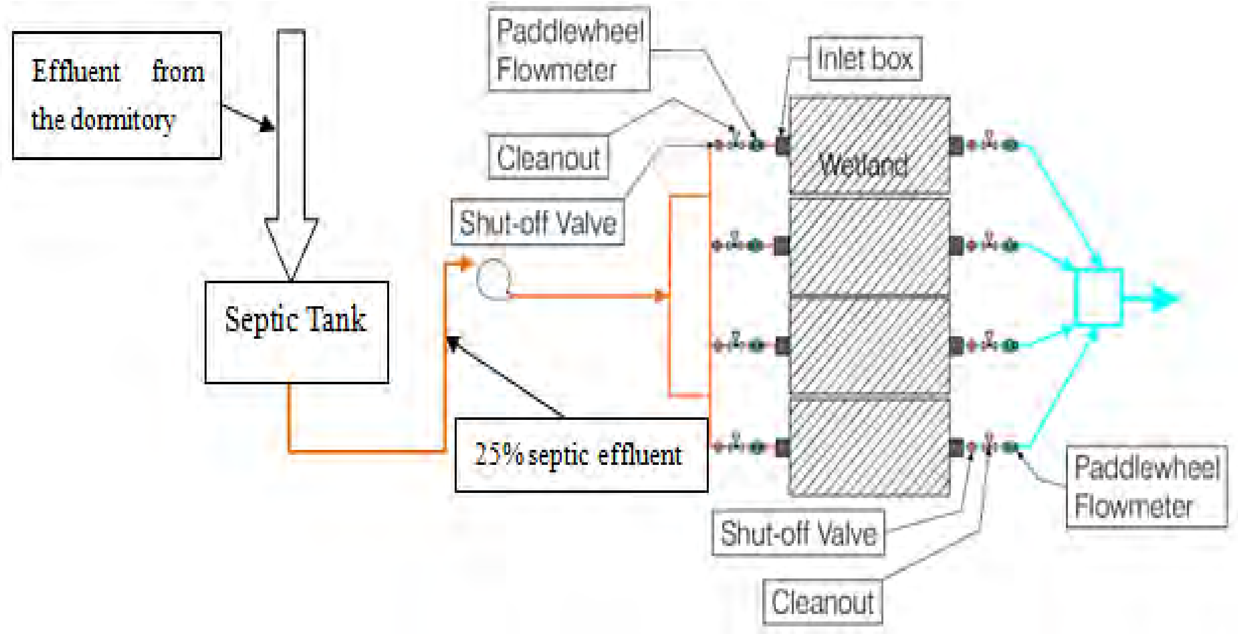


Figure 3 Configuration of septic tank followed by a 4-cell wetland system including a shut-off valve, a cleanout, and a flow meter.

2.5 *Conventional septic system with recirculation tank*

The Florida Keys On-site Wastewater Nutrient Reduction Systems (OWNRS) Demonstration Project was initiated in 1995 to demonstrate the use of a OWNRS to reduce the concentrations of nutrients discharged to the coastal region of the Keys (Anderson et al., 1998). One of the five treatment trains in the OWNRS was a septic tank followed by a recirculation sand filter (RSF). The overall treatment effectiveness of this passive OSTDS was shown to be about 96.5% TSS, 95.5% TKN, 47.6% TN and 92.8% TP (Anderson et al. 1998). Healy et al. (2004) found the removal efficiencies of 83.2% TN, 100% NH_4-N, 43.3% P and 100% SS from dairy parlor washing with 6.6 days hydraulic retention time (HRT) and recirculation ratio of 3.0. If properly operated, an RSF can remove 87% of NH_3-N, 96% of BOD, 96%of TSS, and 50% of

TP (IDNR, 2007). Urynowicz et al. (2007) tried to evaluate the performance of RSF in terms of nitrogen removal from septic tank wastewater and found 72.0% nitrogen removal with recirculation ratio of 5.0 and 63.0% nitrogen removal with recirculation ratio of 3.7 (Urynowicz et al., 2007).

Figure 4(a) shows a conventional passive septic system diagram in which the nitrification can be promoted in the RSF while denitrification mainly occurs in septic tank and drain field. Shown in Figure 4(b) are the sampling locations at the UCF Test Center for this treatment train,

The nitrification and denitrification mechanisms (i.e. equations 4-7) can be expressed as below:

- Nitrification:

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

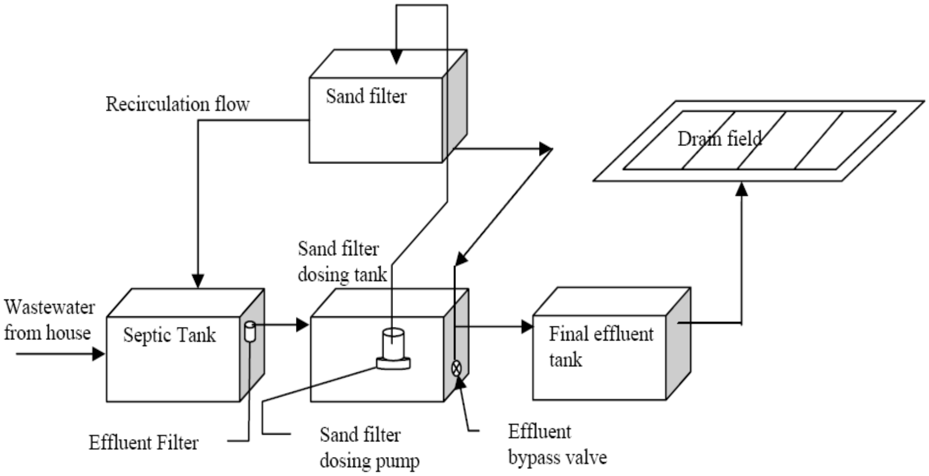
$$2NO_2^- + O_2 \rightarrow 2NO_3^- \quad (5)$$

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \quad (6)$$

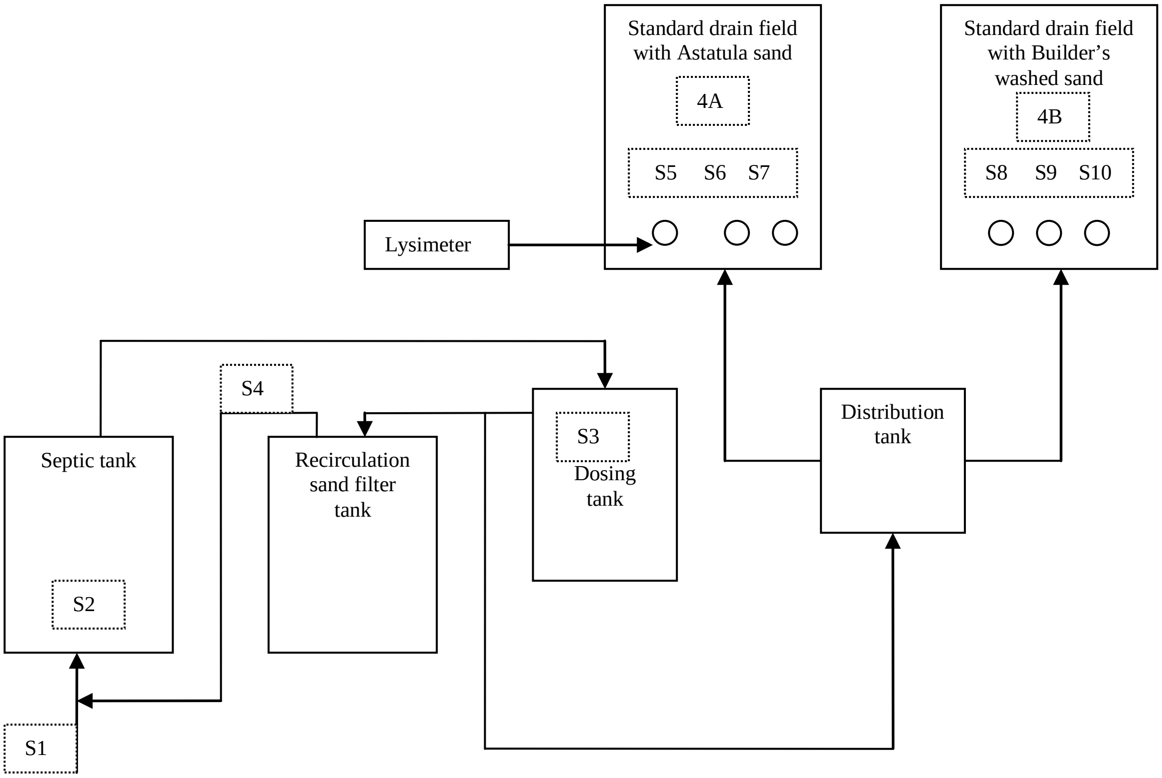
- Denitrification:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10OH^- \quad (7)$$

One of the problems associated with RSF is their potential clogging due to physical (i.e. solid accumulation), chemical (i.e. precipitation reaction) and biological (i.e. biofilm growth or slow decomposition of organic matters) activities going on in the filter (Venhuizen, 1998; Hurst, 2006). A RSF may be a chamber for simultaneous nitrification and denitrification if properly designed. However, until now, little has been known about the performance of nitrification and denitrification in a RSF and how the performance could be improved by using different sorption media. Accordingly, the replacement of sand in the recirculation tank may have value in nutrient reduction and an RSF with sorption media is also part of the UCF Test Center operation..



(a). Flow diagram of the UCF conventional OSTDS with RSF



(b): Sampling locations at UCF conventional OSTDS

Figure 4 Schematic flow and sampling diagrams of the UCF conventional OSTDS with RSF

Chapter 3 Conventional Passive On-Site Wastewater Treatment System with Ground Water Impacts

3.1 Conventional drain field

The conventional passive OSTDS at UCF consists of a RSF and two drain fields The first uses washed builder's sand as the filtrating media of the drain field, while the second uses Astatula sand (A.K.A. Citrus Grove sand). The performance of these two systems with respect to water quality improvement was measured for a one year period. Also the impact on the ground water was measured.

3.2 Conventional drain field with a recirculation tank

To explore the feasibility of using sorption media to replace the tradition fine or coarse sand in the RSF, three different designs were used in this study. The first design using fine sand as media in the RSF was conducted between Oct – Nov 2008. The second design using coarse sand as media in RSF was conducted between Mar – Apr 2009. Finally the third design using green sorption media was conducted on Sep – Oct 2009. The experimental settings of these three designs are summarized in Table 5.

Table 5 A summary of the experimental settings of conventional passive OSTDS

ID	Date	Number of Dataset	Experimental Settings
Recirculation I	Oct – Nov 2008	3	• Septic tank – Recirculation – Drain Field • Astatula sand used as the filtrating media in the recirculation tank
Recirculation II	Mar – Apr 2009	4	• Approx. 3:1 Return-To-Forward ratio • Very coarse sand media in the recirculation tank
Recirculation III	Sep – Oct 2009	3	• Precisely 3:1 RTF ratio • Green Sorption Media

3.2 Ground water quality impact below the conventional OSTDS

There are 16 monitoring wells at the UCF OSTDS site. Eight of them monitor the ground water around the perimeter of the test site, whereas the other eight wells concentrate on monitoring the ground water at and around the two conventional drain fields. There is no need to monitor the ground water around the B&G drain field and the SUWs because they are lined with impermeable material. Figure 5 shows the overall flow direction of the ground water at the test site. It flows from northeast to southwest. The SUWs are located upstream, the B&G are in the middle, and the two conventional drain fields are downstream (Astatula or citrus grove sand is furthest downstream). Figures 6 - 8 present the ground water conditions, in which the ground water nutrient maps were generated based on the average values of three datasets measured between March and April, 2009.

Figure 6 shows the ammonia-N concentration in the ground water with the highest ammonia-N concentration located downstream from the conventional drain fields (slightly higher downstream of the washed builders sand). The SUW and B&G drain field should not release any nutrients into the ground water due to the use of impermeable material to prevent any leakage. It is believed that the peak on the upstream end (right-hand side) was from historic fertilizer use. Figure 7 shows the nitrate-N concentrations in the ground water. It was observed that peak values appeared downstream of the Astatula sand drain field and correlated with the high level trends of ammonia-N (see Figure 6). There are two possibilities of having a high level of nitrate at this location. First, the nitrate was introduced by the Astatula sand drain field (most downstream rectangular in Figure 7). Second, the ammonia released from the washed builder's sand drain field was converted to nitrate and travel downstream. The gradient of ammonia concentration in Figure 6 confirms that such transport of ammonia is highly likely.

Considering the levels of ammonia-N and nitrate-N at the downstream location of the washed builder's sand drain field, it was highly likely that the washed builder's sand drain field released nitrogen into the ground water. The nitrate-N concentration gradient shown in Figure 7 indicates the source of nitrate-N is from the washed builder's sand drain field. Figure 8 shows the soluble reactive phosphorus (SRP) in the ground water downstream from the Astatula sand drain field. It is unknown which conventional drain field contributes most of the SRP to the ground water. Nevertheless, there is a higher concentration of SRP in the ground water downstream of the conventional drain fields. In parallel with this project, a detailed study conducted by the United State Geological Survey (USGS) and Florida State University (FSU) has been geared toward investigate the fate and transport of pollutants in the vadose zone of drain field and ground water (FDEP, 2009).

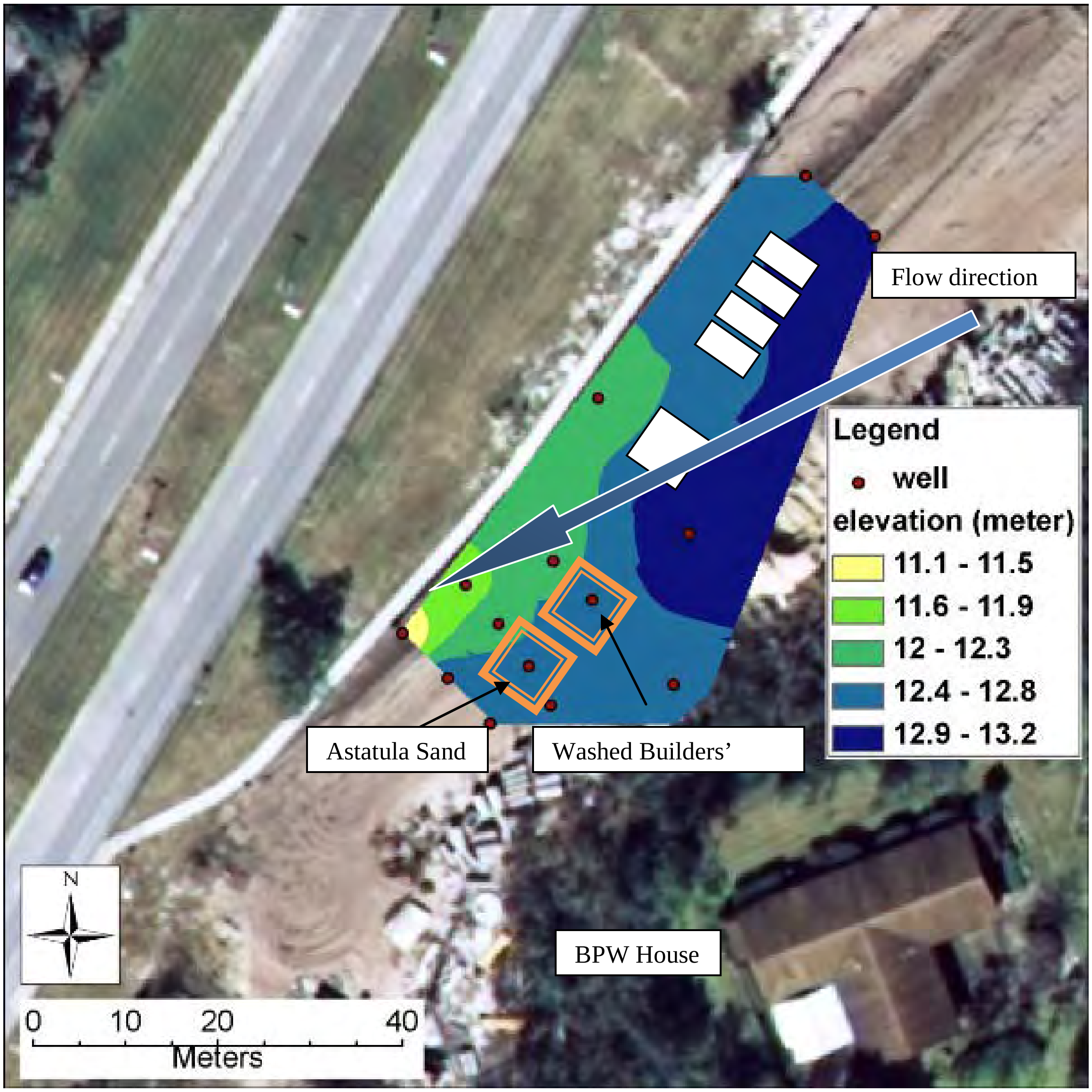


Figure 5 Ground water monitoring wells are located around experimental site at UCF.

Additional monitoring wells are also located inside the conventional drain fields. Ground water flows in the southwest direction as indicated with the arrow. The location of the house generating the sewage flow is also shown and noted as the BPW House.

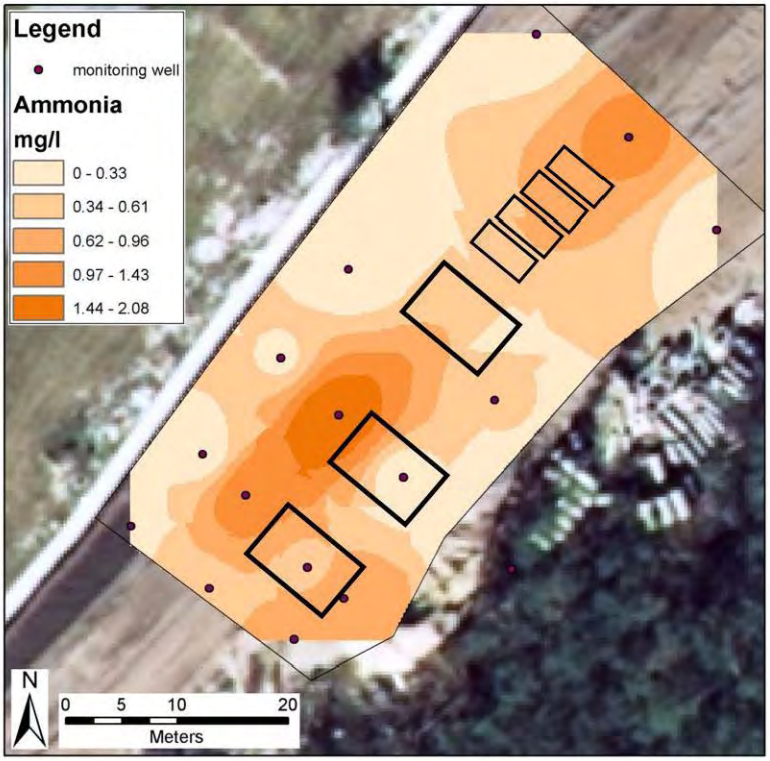


Figure 6 Average Ammonia concentrations in the ground water under UCF test site.

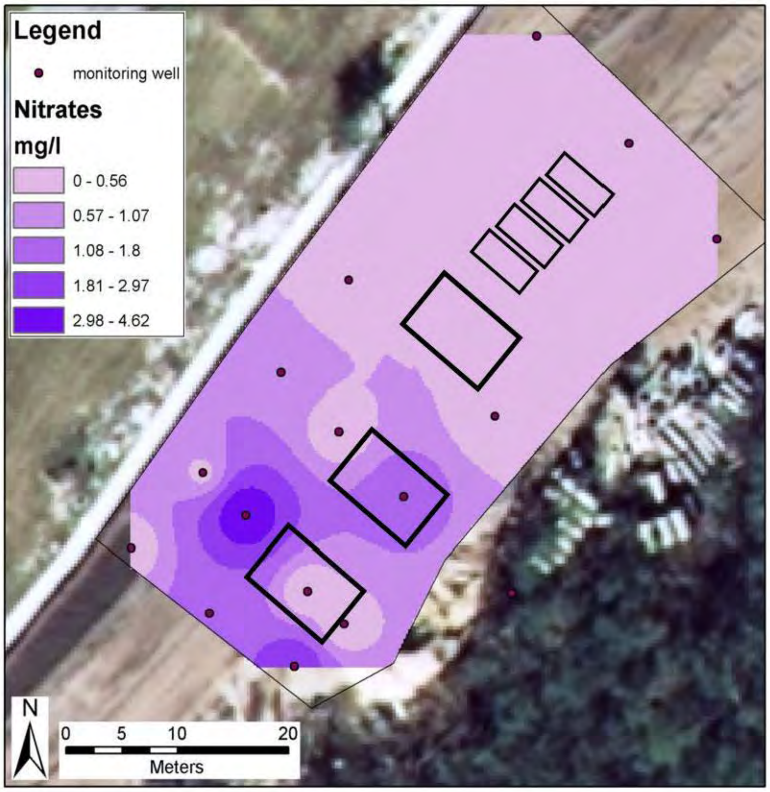


Figure 7 Average Nitrate-N concentrations in the ground water under UCF test site.

Figure 8 Average Soluble Reactive Phosphorus (SRP) concentrations in the ground water under UCF test site.

Chapter 4 Passive On-Site Wastewater Treatment System with Bold & Gold^{TM} Drain Field

4.1 System design of Bold & Gold^{TM} drain field

The B&G drain field is designed to treat 400 gallons per day of pre-treated residential septic tank wastewater effluent. The drain field is designed to provide an aerobic zone for nitrification and an anaerobic zone for denitrification in series to remove nitrogen through nitrification and denitrification processes. The nitrification process is able to convert the organic nitrogen to ammonia and further convert the ammonia to nitrite while the denitrification process is the biological reduction process of nitrite and nitrate to nitrogen gas. In principle, over half of the oxygen consumed in the nitrification reaction can be recovered by denitrification and the alkalinity destroyed in the nitrification reaction is also recovered. Consequently, denitrification can play an important role in reducing the process energy requirements and maintaining the process pH values within the optimal range for nitrification. Figure 9 presents a representative result from one sampling date for nitrogen species, dissolved oxygen, and alkalinity in the septic tank and B&G drain field system. Figure 9 supports expected relationships among the nitrogen species for nitrification and denitrification conditions.

It was observed that both nitrification and denitrification processes occurred in the B&G drain field. The transition from septic effluents to B&G aerobic zone shows significant reductions of ammonia and alkalinity while nitrate concentrations were increased due to the nitrification process (see Figure 9). The dataset shown in Figure 9 was collected on April 1st, 2009, which was the latest dataset of the experiment on B&G drain field. There was a trend of high organic nitrogen concentrations in the B&G system in the aerobic zone as well; thus, ammonia concentration increased when the wastewater traveled through the B&G (see Figure 9). This observational evidence confirms that a nitrification process did happen at that right location of the system. Yet some ammonia remained in the B&G aerobic zone indicating an incomplete nitrification process. This is partially due to the insufficient alkalinity available to sustain the noticeable nitrification process all the way to the end.

Denitrification process was observed in the anaerobic zone where nitrate concentrations were reduced considerably (see Figure 9). The fact that nitrate almost completely disappeared in the anoxic zone, but then reappeared at the B&G effluent reveals that a secondary nitrification occurred again between the anoxic zone and the B&G effluent point. This secondary nitrification process was the consequence of the presence of organic nitrogen, ammonia, and dissolved oxygen simultaneously. This implies that a complete nitrification process at the early stage must be obtained in order to better remove total nitrogen from the wastewater, effectively. A relationship between influent dissolved oxygen and effluent nitrate concentration was found. Obviously, the higher the DO in B&G aerobic zone, the lower the nitrate-N concentration in the effluent (see Figure 10).

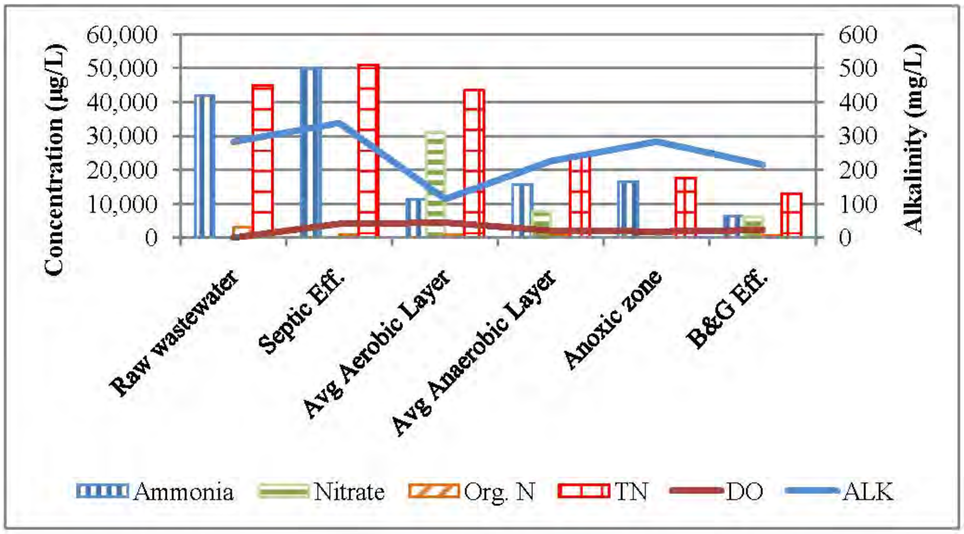


Figure 9 Tracking of nitrogen species in the B&G OSTDS system shows nitrification process in aerobic layer, and denitrification process in the anaerobic layer.

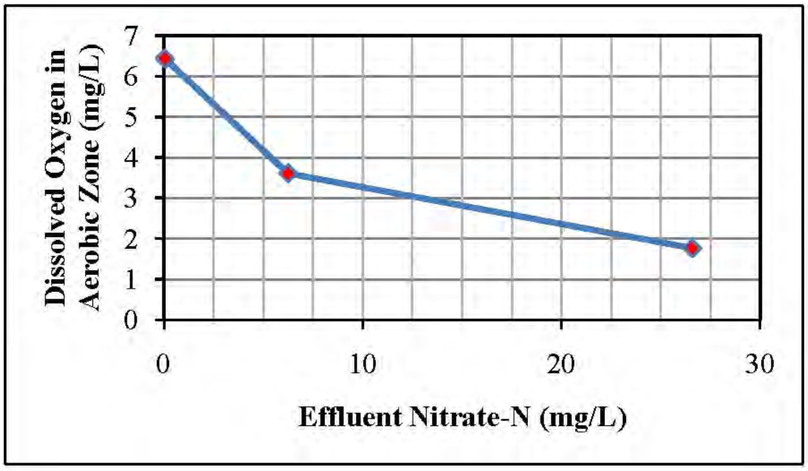


Figure 10 Relationship between influent DO and effluent nitrate-N

4.2 B&G drain field removal efficiency

The B&G drain field shows promising results in treating typical Florida household wastewater streams. Sampling was carried out from Oct. 2008 to April 2009 to collect 5 data sets. Figure 11 summarizes the removal efficiencies between the inlet of septic tank and the outlet of B&G drain field for all pollutants considered. Approximately 70% of total nitrogen and more than 99.99% of bacteria were removed. TSS and CBOD5 were also substantially removed. The nitrification process may be improved by introducing more alkalinity using limestone as an integral part of the sorption media.

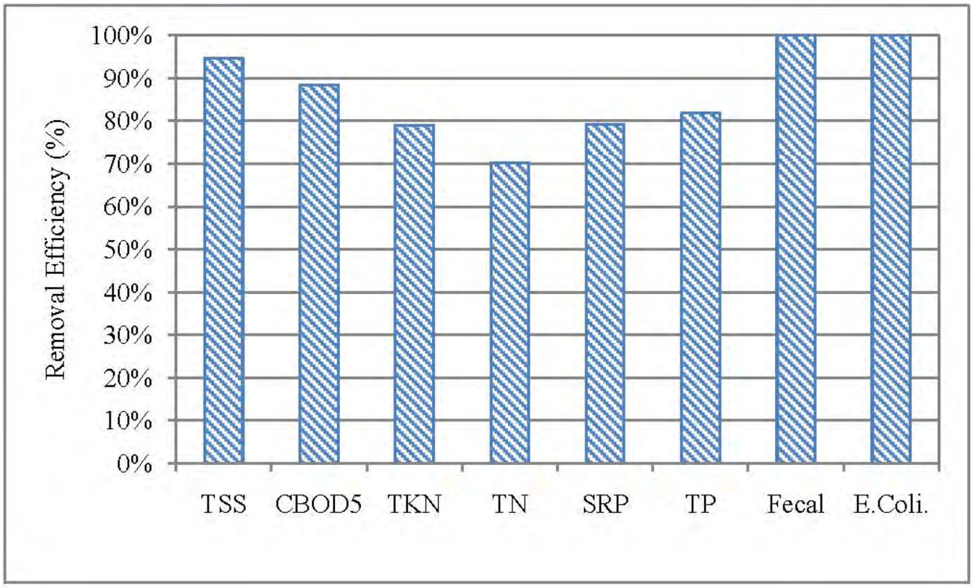


Figure 11 Overall septic and B&G drain field removal efficiency.

4.3 B&G drain field effluent concentrations

It is also important to examine effluent concentrations leaving the drain field and entering the ground water. Average TSS and CBOD$_5$ concentrations were below 11 mg/L and 8 mg/L, respectively or below the NSF standard of 30 mg/L for TSS and 25 mg/L for CBOD$_5$. Total nitrogen concentration in the effluent was about 13 mg/L on average. Nitrate and nitrite concentrations were 3 mg/L and 1 mg/L, respectively, which are below the USEPA MCL for drinking water. Phosphorus concentration in effluent was very low. The bacteria concentration in the B&G was about 10 cfu /100 mL on average. Figures 12-15 collectively present the whole results. Table 6 summarizes mean, minimal, and maximal values of water quality parameters in the effluent of the B&G drain field.

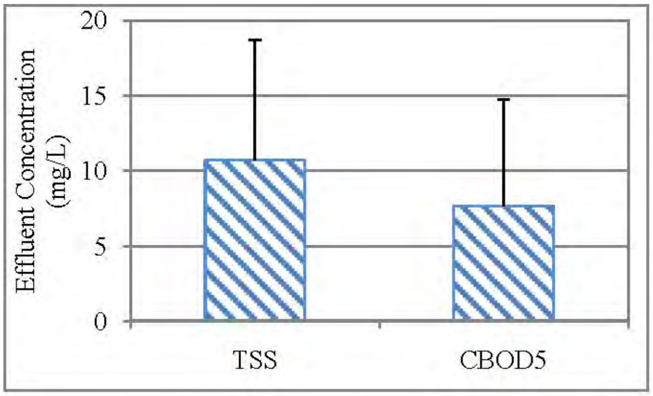


Figure 12 Effluent TSS and CBOD$_5$ of B&G drain field.

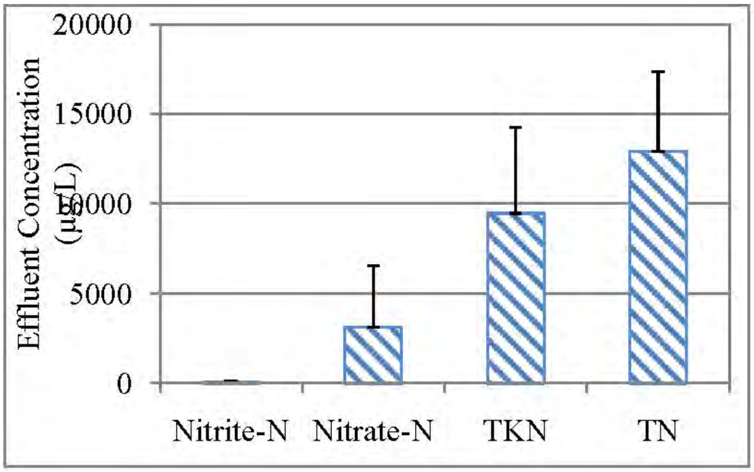


Figure 13 Effluent nitrogen of B&G drain field.

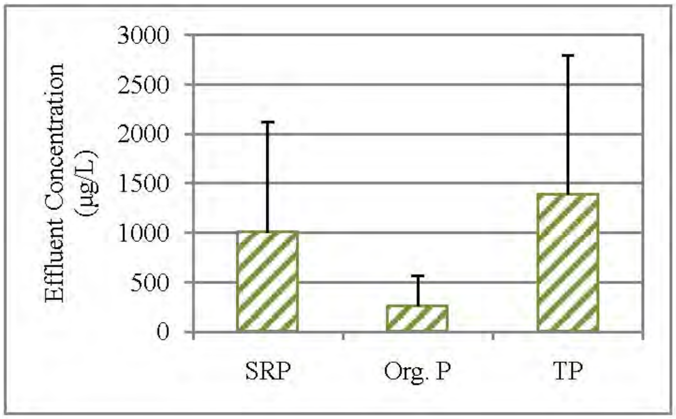


Figure 14 Effluent phosphorus of B&G drain field.

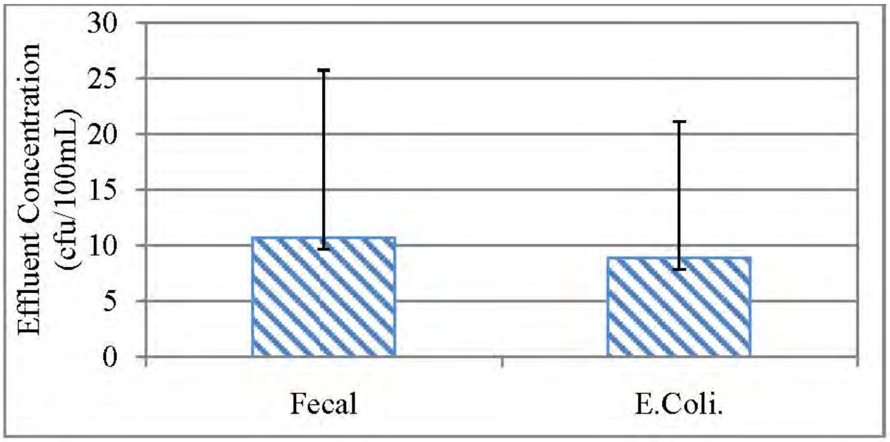


Figure 15 Effluent bacteria of B&G drain field.

Table 6 Summary of mean, minimum and maximum values of water quality parameters in the effluent of the B&G drain field

	B&G Effluent (Oct 08 - Apr 09)			
	Average	Min	Max	Median
Alkalinity (mg/L)	220.5	190.0	256.0	220.5
TSS (mg/L)	10.7	1.2	23.3	10.7
BOD_5 (mg/L)	11.2	4.4	29.7	9.0
$CBOD_5$ (mg/L)	7.7	2.0	21.0	5.2
Ammonia-N (µg/L)	6101.5	2617.0	8533.0	6439.5
NO_X-N* (µg/L)	3198.0	2.0	6851.0	3065
Nitrite-N (µg/L)	52.3	3.0	141.0	35.5
Nitrate-N (µg/L)	3145.7	-1.0	6820.0	2998.0
Org. N (µg/L)	3361.3	499.0	16401.0	760.5
TKN (µg/L)	9462.8	6513.0	19018.0	7607.5
TN (µg/L)	12902.3	6520.0	19020.0	13581.5
SRP (µg/L)	1003.8	3.0	2203.0	824.0
Org. P (µg/L)	258.3	0.0	669.0	153.5
TP (µg/L)	1386.8	33.0	2909.0	1384.0
Fecal (cfu/100mL)	242.0	1.0	1400.0	5.0
E.Coli. (cfu/100mL)	240.7	1.0	1400.0	4.5

*[NO_X-N] = [Nitrite-N]+[Nitrate-N]

Chapter 5 Passive On-Site Wastewater Treatment System with Subsurface Upflow Wetland (SUW) and Sorption Media

5.1 System design of subsurface upflow wetland (SUW) with sorption media

A subsurface upflow wetland (SUW) system receives septic tank effluent and is treating up to 454 m^3 (120 gallon) per day with each of the four SUW cells treating 50 gallons per day. The septic tank before the SUWs has a size of 1000 gallon per day providing 2-3 days hydraulic retention time (HRT). The septic tank effluent enters a gravel-filled gravity distribution system including header pipe, equalization distribution box, distribution pipe, and flow meter. The four SUW cells are packed with special green sorption media. Within the full scale field study, a new set of green sorption media is used for both nutrient and pathogen removal in the SUW. An innovative upflow operation is used. The operation includes a high porosity gravel as the substrate at the bottom, vertical piping to introduce oxygen to the bottom, and an outlet that is higher than inlet. The design fosters an upflow hydraulic pattern and an amenable nitrification-denitrification environment as well as minimizing clogging and flooding, which overcomes the main disadvantage of the conventional subsurface flow wetlands. Such a design reduces the effect of rainwater since most rainwater drains from the higher outlet directly instead of mixing with the wastewater, which provides more accurate evaluation of the performance of the SUW. Through various physical, chemical, and biological processes, most bacteria and viruses in wastewater, as well as nutrients, are consumed and intercepted as the wastewater effluent travels up through the pollution control layer (i.e., aerobic layer at the bottom) and growth media layer (i.e., anaerobic layer in the middle) before reaching the root zone. Combined with the gravel layer and the sand layer beneath the pollution control layer and the plant species on the top of the growth media, the SUW may promote pathogen, nitrogen and phosphorus removal via nitrification, denitrification adsorption, absorption, ion exchange, filtration, and precipitation collectively.

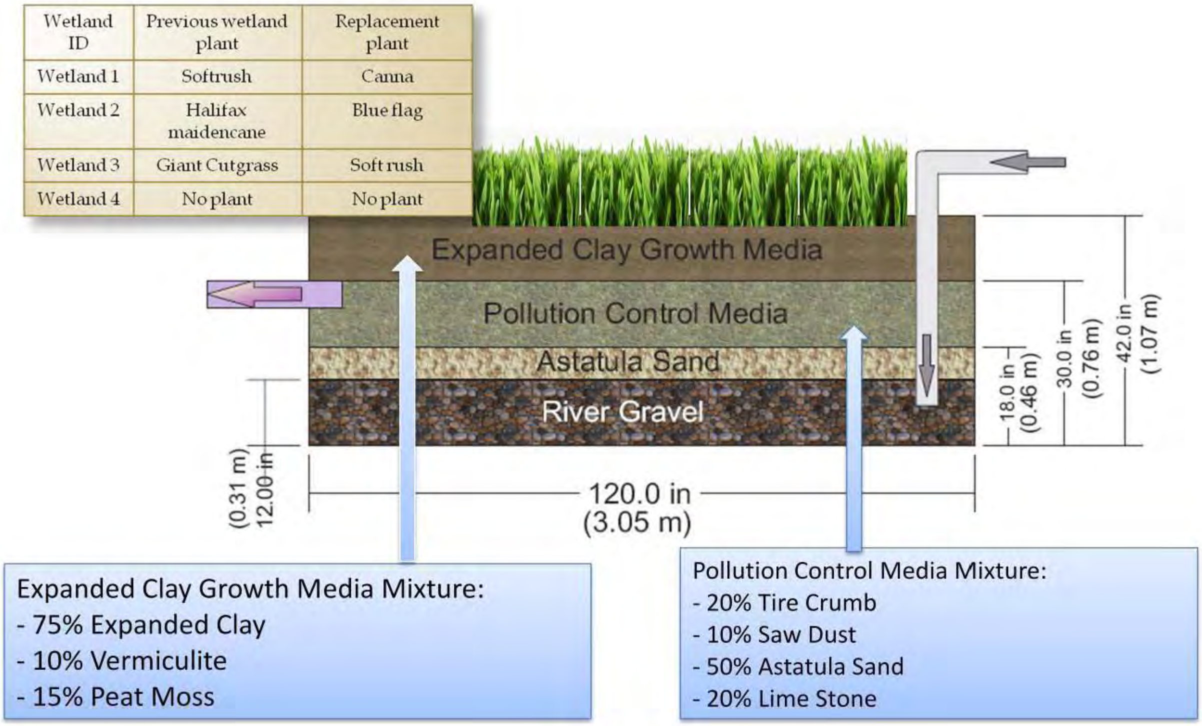
Three kinds of plant species are tested against the control case with no plant species. Using the criteria for screening plant species as described in previous study (Xuan et al, 2009), we selected three kinds of native vegetation with similar volumes and costs, Canna (*Canna*

Flaccida), Blue flag (*Iris versicolor L.*), and Bulrush (*Juncus effusus L.*) (Figure 16). These were evenly planted in SUW cells 1, 2 and 3, respectively as listed in Table 6. Wetland cell 4 is the control without any plant species but it does include the placement of the same layered green sorption media.

There are four parallel 1.52 m wide × 3.05 m long × 0.91 m deep (5 ft wide × 10 ft long × 3 ft deep) cells in each test bed. Each of four cells contains an impermeable liner at the bottom, a gravel substrate, fabric interlayer, sand, pollution control media (called PC media hereafter), growth media (called G media hereafter) and selected plants. An overall section is shown in Figure 17. G medium layer (75% Expanded Clay, 10% Vermiculite, and 15% Peat Moss) is used to support the root zone and PC medium layer (50% Citrus grove sand, 15% tire crumb, 15% sawdust and 20% lime stone) is used to help nutrient removal. Both are 30.48-cm (12-inch) deep. The gravel substrate at the bottom creates additional pore space allowing water to spread across the bottom of a SUW more freely while maintaining a desired flow rate. The purpose of the separation fabric liner on the top of the gravel layer is to keep the sand above the gravel layer. A 15.24-cm (6-in) sand layer is added beneath the PC medium to improve the removal of pathogen and total suspended solid (TSS). The 30.48-cm (12-inch) layer PC media was used to remove nutrients, TSS, and BOD. The main function of the G media layer is to support the root zone and to aid in further nitrogen removal. The HRT is about 6-7 days. Once the gravel layer is fully saturated, the water level would rise up gradually, passing through the sand and PC medium layer up to the outlet. In each SUW, two customized oxygenators were inserted on both sides of inlet into the gravel layer to enhance the nitrification at the bottom of the SUW cells so as to fulfill the design ideas configured for the SUW. The samplers were installed at the interface between different layers with three depths. Horizontally, the samplers in the four SUW cells are 33%, 67% and 100% along the length of the SUW and well as the control wetland (See Figure 17).

(a) (b) (c)

Figure 16 Plant species selected in the study: (a) Canna; (b) Blue flag; (c) Bulrush



Wetland ID	Previous wetland plant	Replacement plant
Wetland 1	Softrush	Canna
Wetland 2	Halifax maidencane	Blue flag
Wetland 3	Giant Cutgrass	Soft rush
Wetland 4	No plant	No plant

Expanded Clay Growth Media Mixture:
- 75% Expanded Clay
- 10% Vermiculite
- 15% Peat Moss

Pollution Control Media Mixture:
- 20% Tire Crumb
- 10% Saw Dust
- 50% Astatula Sand
- 20% Lime Stone

Figure 17 SUW with green sorption media design.

Table 7 Summary of wetland plant species

SUW ID	Plant Species
SUWcell 1	Canna
SUW cell 2	Blue Flag
SUW cell 3	Bullrush
Control Wetland	None

5.2 *SUW removal efficiency*

Figure 18 shows the overall removal efficiencies between the inlet of the septic tank and the outlet of the four SUW cells. The plant species in the SUW cells demonstrated higher nitrogen and phosphorus removal relative to the control without plants. Yet the TSS removal efficiency was less than expected. It must be noted that the sampling point at the effluent was not the most suitable one for the TSS measurements due to the fact that the sampling ports were buried in the media and fine particles collected in the sample.

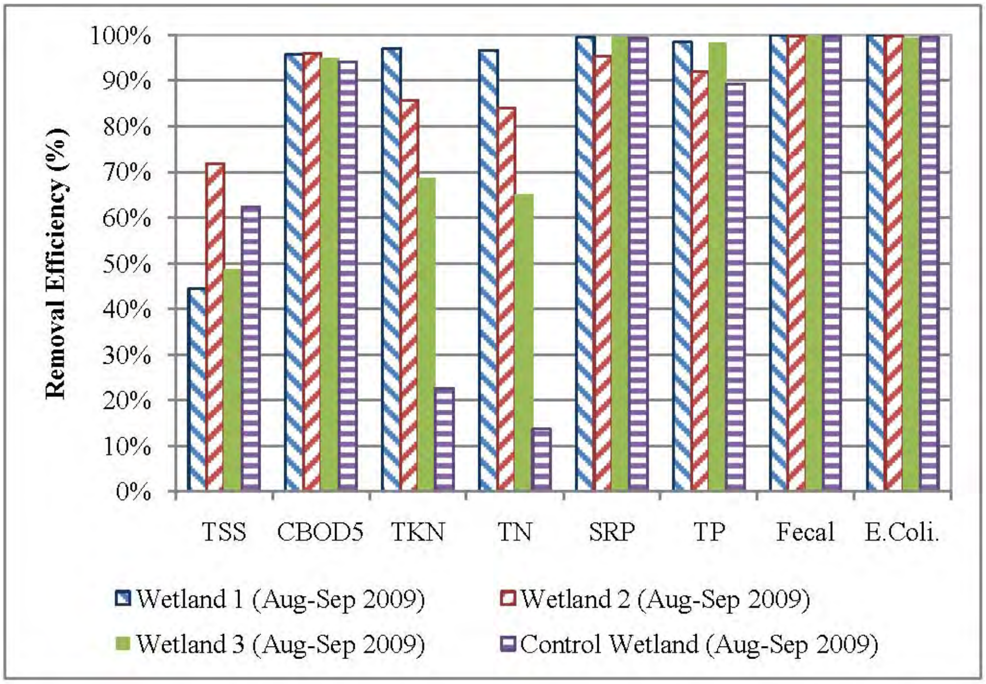


Figure 18 A summary of overall removal efficiencies of septic tank and SUW.

5.3 *SUW effluent concentrations*

In Figure 19 and 20, TSS and $CBOD_5$ concentrations of the SUWs' effluents are shown. The TSS concentrations were near 30 mg/L with an average below 30 mg/L, which is the NSF 245 requirement for effluent TSS. TSS removal is expected to be lower with a simple modification at the SUW sampling outlet. $CBOD_5$ concentrations average below 5 mg/L (the NSF 245 requirement is 25mg/L). Figures 21 and 22 show a set of effluent concentrations for nitrogen- and phosphorus-species. The effluent TKN and TN of the four SUW cells were different, depending on the plant species. Overall, SUW cells 1 and 2 performed best in removing nitrogen with the nitrate, nitrite, and total nitrogen concentrations below the measured values in cell 3 and the control cell. In fact, nitrogen concentrations in the effluent of SUW cells 1 and 2 were below the USEPA MCL of nitrate (10 mg/L) and nitrite (1 mg/L) for drinking water. Bacteria counts in all SUW effluents were high, even though the removal efficiencies were more than 99.9%. However, it must be taken into account that once the effluent was released into the underground vadose zone, most bacteria would be consumed or filtered out by the soil. Table 8 summarizes the mean, maximal, and minimal values of all water quality parameters.

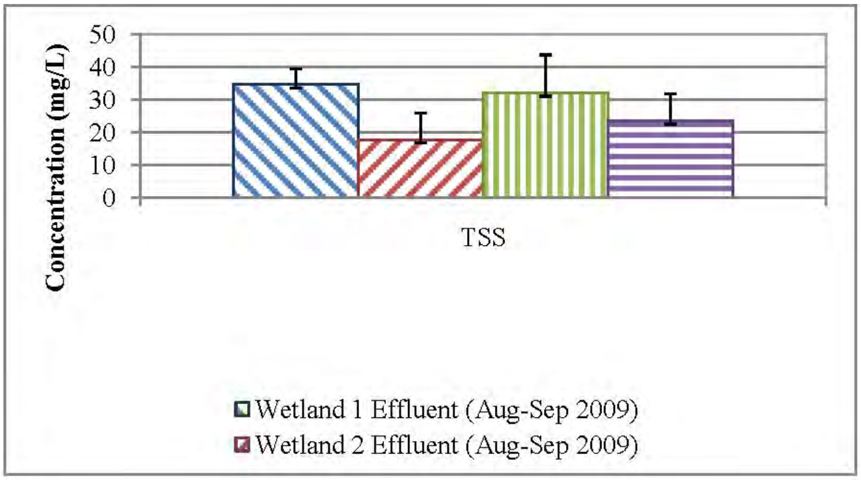


Figure 19 Effluent TSS of SUW.

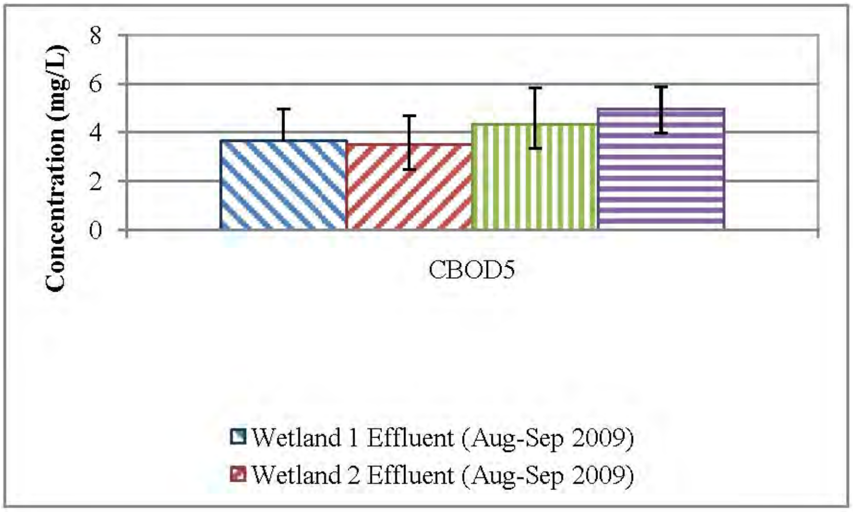


Figure 20 Effluent $CBOD_5$ of SUW.

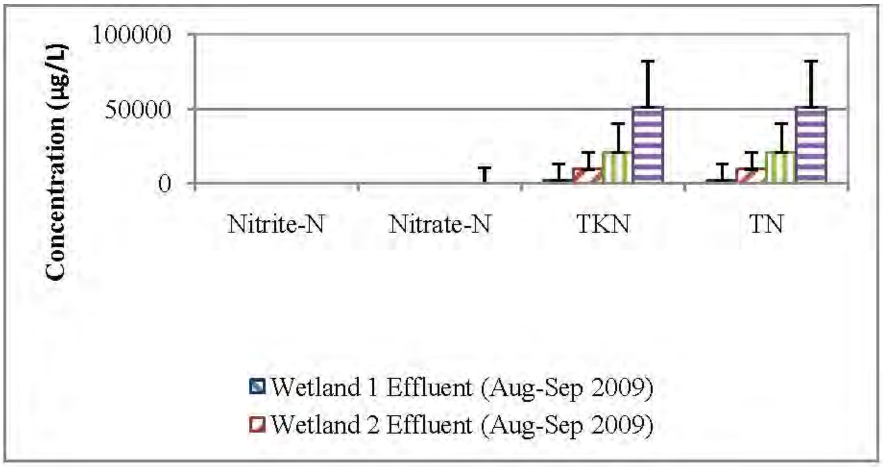


Figure 21 Effluent nitrogen concentration in SUW.

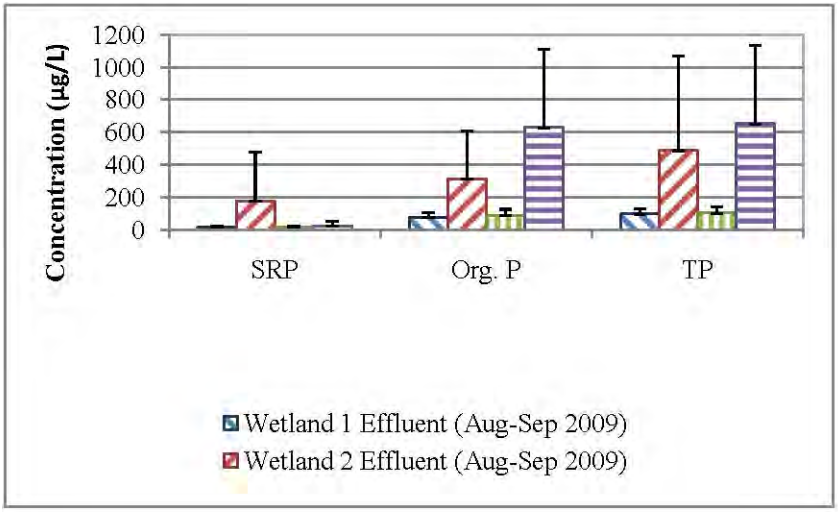


Figure 22 Effluent phosphorus concentration in SUW.

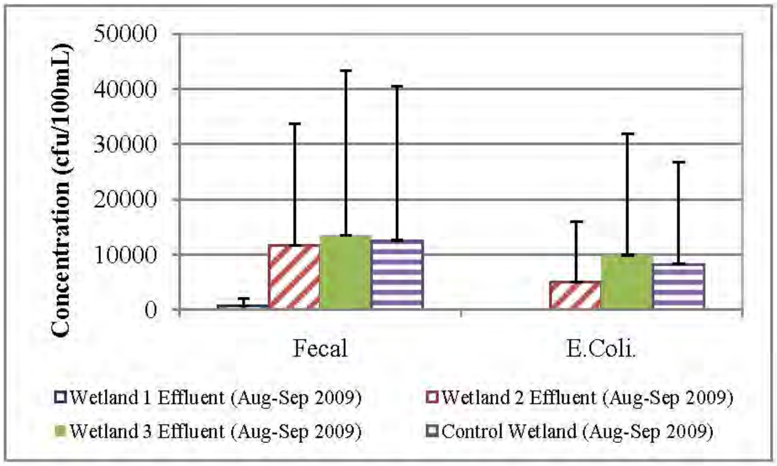


Figure 23 Bacteria counts in SUW effluent.

Table 8 A summary of the mean, maximum, and minimum values of all water quality parameters

(a) From wetlands (1) and (2)

	Wetland 1 Effluent (Aug-Sep 2009)				Wetland 2 Effluent (Aug-Sep 2009)			
	Average	Min	Max	Median	Average	Min	Max	Median
Alkalinity (mg/L)	378.8	277.0	465.0	38.01	312.6	112.0	423.0	369.0
TSS (mg/L)	34.6	29.0	42.0	34.0	17.6	12.5	32.0	14.0
BOD_5 (mg/L)	5.22	2.9	8.7	3.7	7.8	2.3	21.9	3.6
$CBOD_5$ (mg/L)	3.6	2.3	5.5	3.1	3.5	2.2	5.5	3.2
Ammonia-N (μg/L)	859.6	304.0	1437.0	972.0	6461.2	987.0	27566.0	1313.0
NO_X-N* (μg/L)	7.8	4.0	16.0	5.0	9.0	5.0	20.0	5.0
Nitrite-N (μg/L)	1.6	1.0	3.0	1.0	4.8	1.0	15.0	3.0
Nitrate-N (μg/L)	6.2	2.0	14.0	4.0	4.2	2.0	7.0	4.0
Org. N (μg/L)	1097.4	337.0	2030.0	1139.0	3037.6	760.0	9689.0	1888.0
TKN (μg/L)	1957.0	1536.0	2576.0	1711.0	9498.8	2227.0	28326.0	2924.0
TN (μg/L)	1964.2	1540.0	2578.0	1727.0	9507.2	2232.0	28336.0	2929.0
SRP (μg/L)	18.0	11.0	27.0	17.0	174.6	12.0	717.0	28.0
Org. P (μg/L)	78.0	38.0	101.0	79.0	313.0	95.0	753.0	122.0
TP (μg/L)	96.0	51.0	125.0	96.0	487.6	123.0	1470.0	134.0
Fecal (cfu/100mL)	657.0	1.0	3000.0	20.0	11590.6	120.0	51000.0	3000.0
E.Coli. (cfu/100mL)	6.8	1.0	30.0	1.0	4933.8	1.0	24600.0	1.0

*[NO_X-N] = [Nitrite-N]+[Nitrate-N]

(b) From wetlands (3) and (4)

	Wetland 3 Effluent (Aug-Sep 2009)				Wetland 4 Effluent (Aug-Sep 2009)			
	Average	Min	Max	Median	Average	Min	Max	Median
Alkalinity (mg/L)	364.8	141.0	486.0	459.0	217.8	82.0	375.0	217.0
TSS (mg/L)	32.0	18.5	50.5	30.0	23.5	16.0	36.8	22.0
BOD_5 (mg/L)	7.2	3.2	13.2	6.1	11.5	5.8	19.2	8.5
$CBOD_5$ (mg/L)	4.3	2.5	5.7	4.7	5.0	3.9	6.0	4.9
Ammonia-N (μg/L)	17327.6	805.0	46645.0	14441.0	42376.4	4582.0	71220.0	56233.0
NO_X-N* (μg/L)	6.0	5.0	10.0	5.0	4.4	1.0	6.0	5.0
Nitrite-N (μg/L)	2.2	1.0	3.0	2.0	1.6	1.0	3.0	1.0
Nitrate-N (μg/L)	3.8	2.0	8.0	3.0	2.8	0.0	5.0	3.0
Org. N (μg/L)	3458.8	333.0	7835.0	3129.0	8847.2	476.0	25355.0	3169.0
TKN (μg/L)	20786.4	1138.0	49774.0	19498.0	51223.6	5058.0	83966.0	59402.0
TN (μg/L)	20790.6	1148.0	49779.0	19500.0	51227.4	5059.0	83971.0	59407.0
SRP (μg/L)	15.2	9.0	23.0	16.0	24.2	9.0	74.0	12.0
Org. P (μg/L)	87.6	50.0	137.0	79.0	628.4	53.0	1392.0	571.0
TP (μg/L)	102.8	64.0	147.0	102.0	652.6	65.0	1401.0	594.0
Fecal (cfu/100mL)	13422.2	1.0	66800.0	20.0	12544.6	1.0	62400.0	8.0
E.Coli. (cfu/100mL)	9890.6	1.0	49200.0	16.0	8242.0	1.0	4120.00	4.0

*[NO_X-N] = [Nitrite-N]+[Nitrate-N]

Chapter 6 Passive On-Site Wastewater Treatment System with Sorption Media-Based Recirculation Tank

6.1 System design of recirculation tank with sorption media

Design improvements have been made to the recirculation tank based on our evaluation of the three different media used inside the recirculation tank and their resulting differences in performance. Replacement of sand with green sorption media together with a unique hydraulic design in the recirculation tank eventually improves the overall system performance. The basic design (Recirculation I) started out with a recirculation tank filled with Astatula sand. However, the major goal in Recirculation I is to discern the removal efficiency of two types of sand, including Astatula sand and wash builder's sand, associated with these two conventional drain field to examine whether or not they have significantly different performance for final wastewater disposal. Once the better choice may be determined, we started altering the sand materials within the recirculation tank. The initial run caused clogging in the Astatula sand, increasing the hydraulic retention time in the recirculation tank and sometimes overflows. With this experience, the design (Recirculation II) in the second set of tests stage used very course sand (washed builder's sand) instead of Astatula sand. The coarse sand did not get clogged, but made marginal if any improvement on treating wastewater.

The last and most up-to-date design (Recirculation III) incorporated two layers of media. The top layer was 27.94 cm (11-inch) coarse sand. The bottom layer was 27.94 cm (11-inch) green sorption media. There was an overflow weir at the outlet of the recirculation tank to maintain the standing water level inside the tank at the transition between the sand and the media. This standing water inside the tank would cause a saturation condition in the sorption media layer and maintain an anaerobic condition promoting denitrification whereas the coarse sand layer may perform the nitrification process as usual. Figure 24 shows the novel design of this recirculation tank with green sorption media and coarse sand. In principle, the coarse sand would allow more dissolved oxygen to dissolve in the wastewater streams, which should improve the nitrification process. After the nitrification process, the denitrification process is expected to occur in the submerged media layer and drain field as shown in Figure 24.

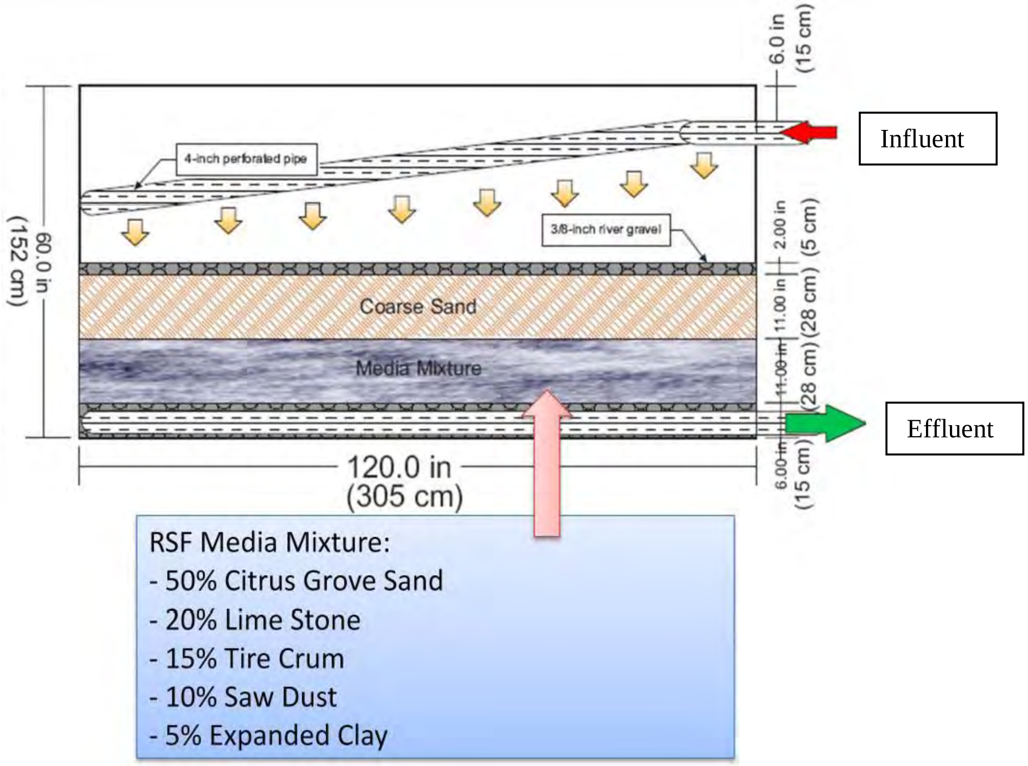


Figure 24 Schematic and design of green sorption media inside the recirculation filter tank.

6.2 Performance of conventional OSTDS and recirculation tank with Citrus sand (Recirculation I)

In this recirculation option, the recirculation tank was filled with Astatula sand. The conventional OSTDS showed average nitrogen and phosphorus removal at about 50 percent. TKN conversion was high. The evidence of low TN and high TKN conversion indicates that nitrification process probably occurred effectively, but the denitrification process was not significant. TSS, $CBOD_5$, and bacteria removals were excellent. Figure 25 presents the overall removal efficiencies of the Recirculation I conventional OSTDS while the sampling locations are identified in Table 9. Figures 26 and 27 summarize the differences in effluent concentrations of Recirculation I (Astatula sand drain field) and Recirculation II (Washed Builder's sand drain field). Note these removals are with respect to influent conditions and as such the nitrate concentrations increased as expected in the effluent and were near zero in the influent. A large negative number would have to be presented in the comparison tables and thus was not added.

Table 9 A summary of sampling locations used to calculate overall removal efficiencies for each OSTDS.

ID	Influent Point	Effluent Point
Conventional DF with Astatula Sand	Inlet of septic tank (S1)	At 24 inches below filtrating sand (S7)
Conventional DF with Wash Builder's sand	Inlet of septic tank (S1)	At 24 inches below filtrating sand (S10)
Septic tank with B&G DF	Inlet of septic tank (S1)	At the outlet of the B&G drain field
Septic tank with SUW 1	Inlet of septic tank (S1)	At the outlet of the SUW
Septic tank with SUW 2	Inlet of septic tank (S1)	At the outlet of the SUW
Septic tank with SUW 3	Inlet of septic tank (S1)	At the outlet of the SUW
Septic tank with Control Wetland	Inlet of septic tank (S1)	At the outlet of the control wetland

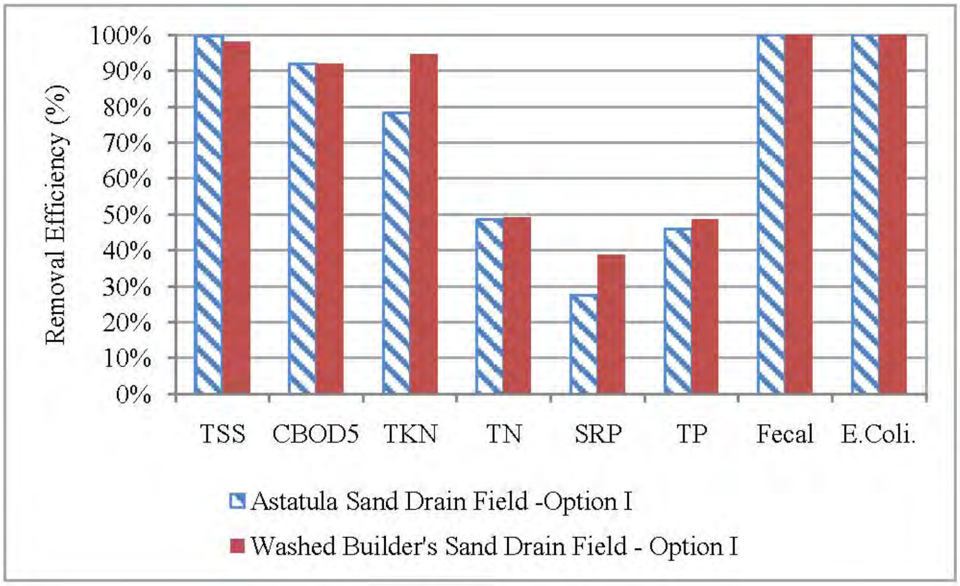


Figure 25 A summary of removal efficiency of the conventional OSTDS Recirculation I with Astatula sand in the recirculation tank shows comparisons of two drain field systems. The hatched bars represent the OSTDS with Astatula sand drain field. The solid bars represent the OSTDS with Wash Builder's sand drain field.

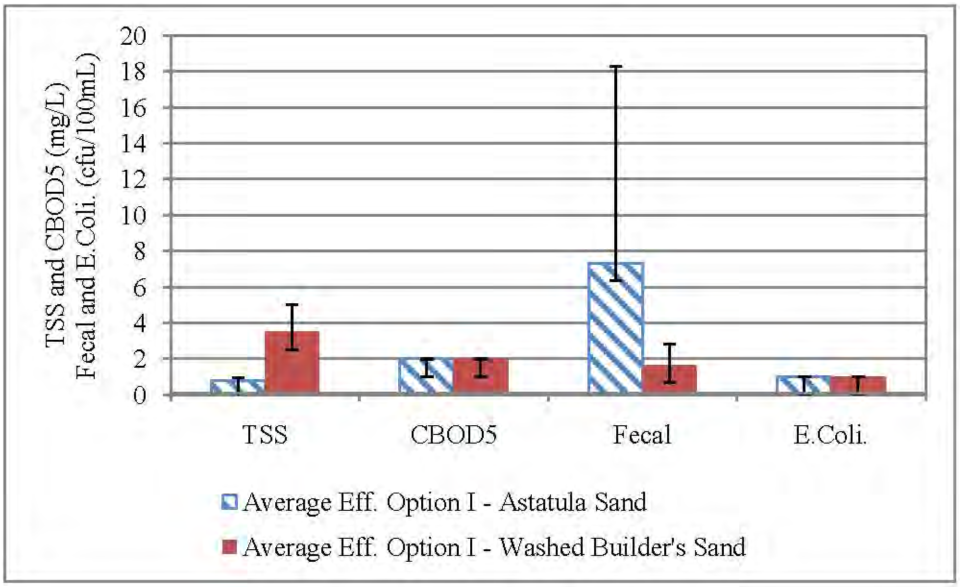


Figure 26 Conventional OSTDS effluent concentration of Recirculation I at S7 in Astatula sand drain field and S10 in Washed Builder's sand drain field shows low TSS, $CBOD_5$, and bacteria levels.

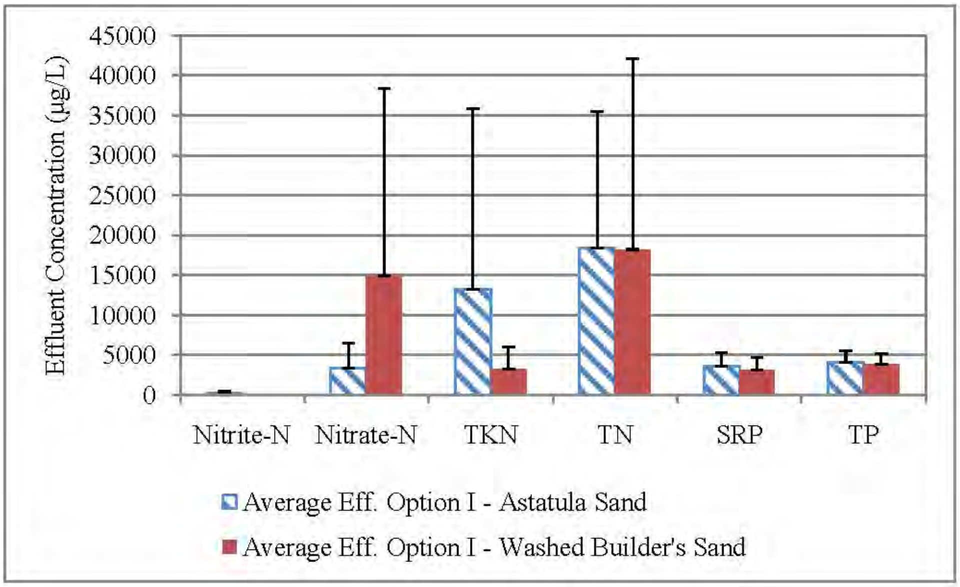


Figure 27 Conventional OSTDS effluent concentration of Recirculation I at S7 in Astatula sand drain field and S10 in Washed Builder's sand drain field of Recirculation I shows moderate levels of nitrogen and phosphorus.

6.3 Performance of Conventional OSTDS and recirculation tank with coarse sand (Recirculation II)

In Recirculation II the media in the recirculation tank was replaced with very coarse sand (Washed Builders Sand) to improve the clogging situation in Recirculation I. Removal efficiency of total nitrogen in Recirculation II was similar to that in Recirculation I. Both are close to about 50%. There was an improvement of TKN conversion efficiency (75% to 85%). TSS, $CBOD_5$, and bacteria removal efficiencies were also similar in Recirculation I and Recirculation II. Phosphorus removal was not promising in both cases. In fact, Recirculation II was even worse than the Recirculation I. Figure 28 shows the overall removal efficiencies of the conventional OSTDS and recirculation tank with coarse sand. This system achieved moderate TN removal, and poor phosphorus removal. Bacteria removal was excellent. Figures 29 and 30 collectively present the effluent concentrations for TSS, CBOD5, and bacteria and for nutrients (nitrogen and phosphorus), respectively. Again they were measured at S7 in the Astatula sand drain field and at S10 in the Washed Builder’s sand drain field.

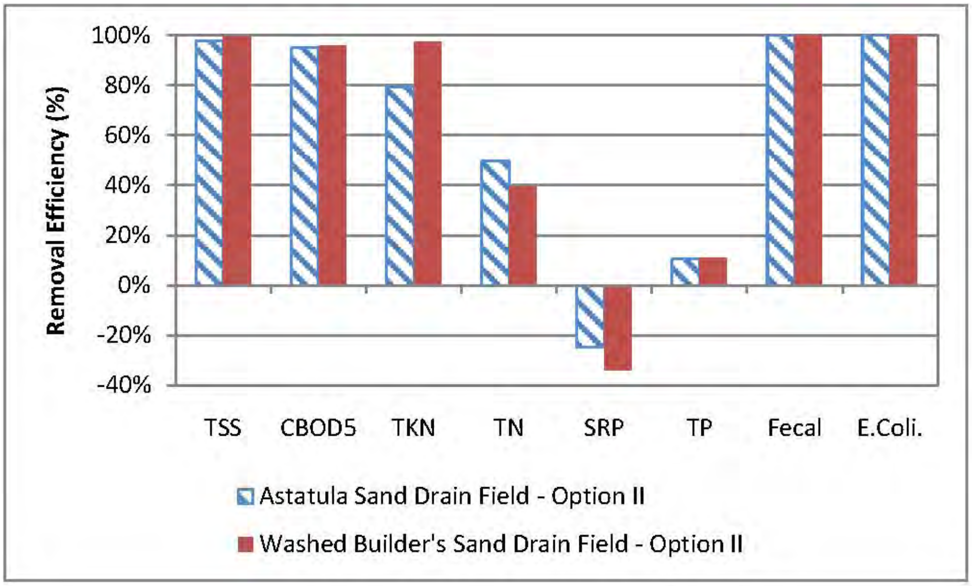


Figure 28 A summary of overall removal efficiency of the conventional OSTDS Recirculation II with very coarse sand in the recirculation tank shows comparisons of two drain field systems. The hatched bars represent the OSTDS with Astatula sand drain field. The solid bars represent the OSTDS with Wash Builder’s sand drain field.

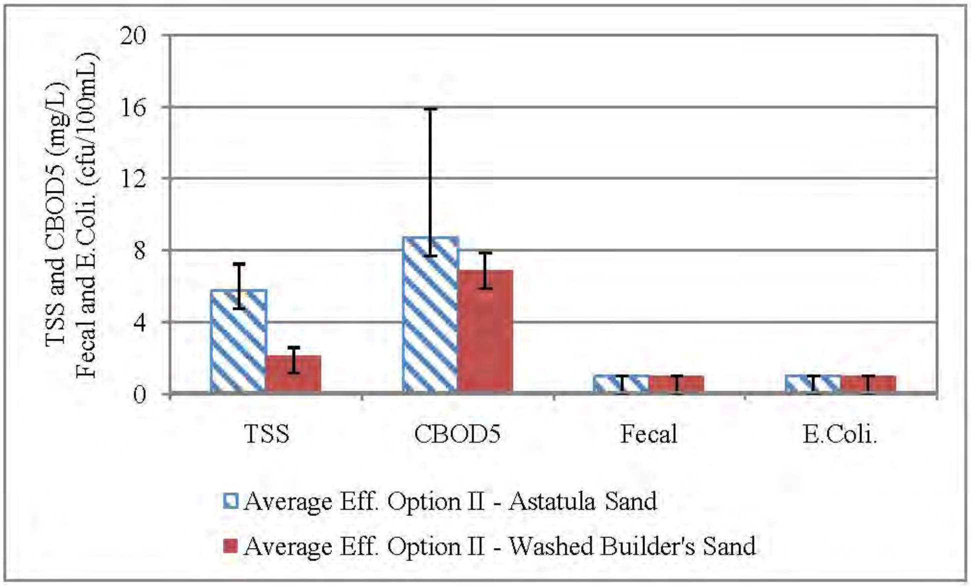


Figure 29 Conventional OSTDS effluent concentration of Recirculation II shows very low TSS, CBOD$_5$, and bacteria levels.

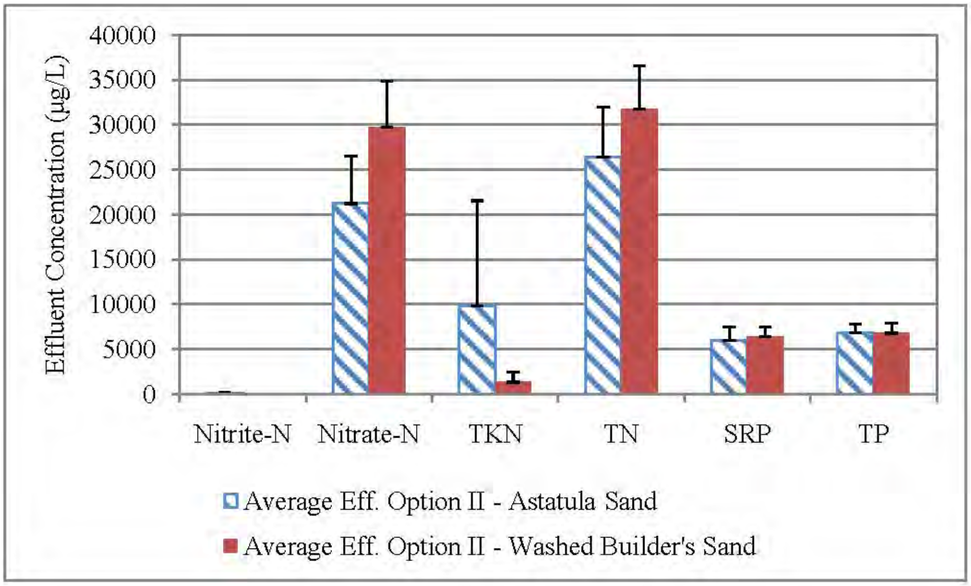


Figure 30 Conventional OSTDS effluent concentration of Recirculation II shows moderate levels of nitrogen and phosphorus.

6.4 Performance of conventional OSTDS and recirculation tank with coarse sand (Recirculation III)

Recirculation III with the recirculation tank uses an innovative modification by incorporating unsaturated and saturated zones. The tank is constructed mainly into two layers. The top layer is 11-inch of coarse sand, which is designed to be the unsaturated zone to increase dissolved oxygen, accommodating better nitrification process. The bottom layer is made of a mixture of sorption media, specifically design to improve denitrification process. Figure 24 indicates the media layers in the recirculation tank of Recirculation option III.

Figure 31 presents the overall removal efficiencies of the Recirculation III conventional OSTDS. TSS and $CBOD_5$ removal efficiencies were better than the earlier designs. Figures 32 and 33 show the effluent concentrations at S10 for conventional and nutrient pollutants respectively. TKN conversion was about equal to the other design recirculation options. It can be seen that phosphorus removal efficiency in Recirculation III was similar to that in Recirculation II. However, the nitrogen removal efficiency in Recirculation III was not as good as in the two earlier designs. Further observational evidence may be gained in Figure 34. It shows only nitrification process was observed in the conventional OSTDS, but the denitrification process was missing. This is why good TKN removal efficiency was observed while TN removal efficiency was poor. There was relatively low retention time (less than one hour) in the recirculation tank. The finding herein confirms that without sufficient hydraulic retention time, green sorption media may not be able to perform well as expected.

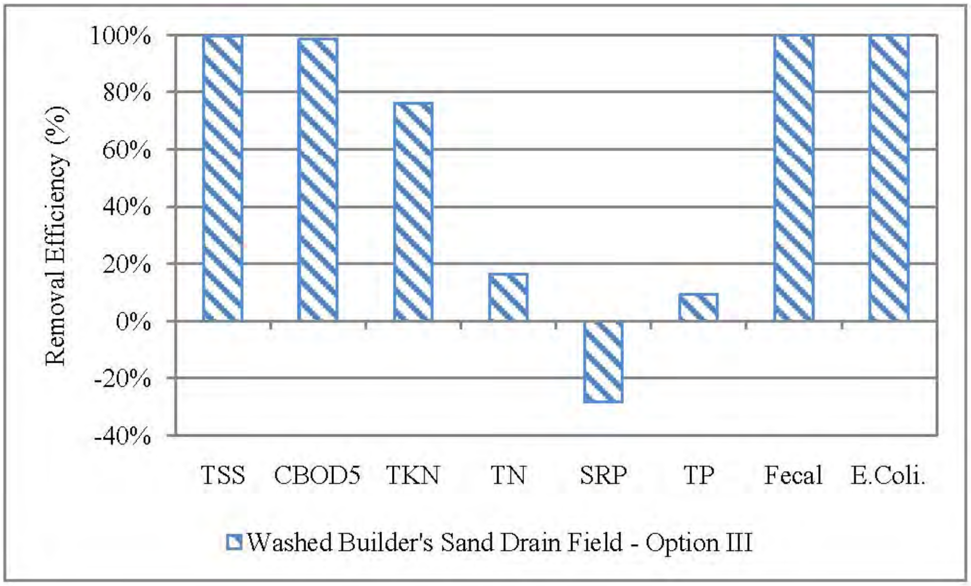


Figure 31 A summary of overall removal efficiencies of the conventional OSTDS Recirculation III with sorption media in the recirculation tank associated with the wash builder's sand drain field.

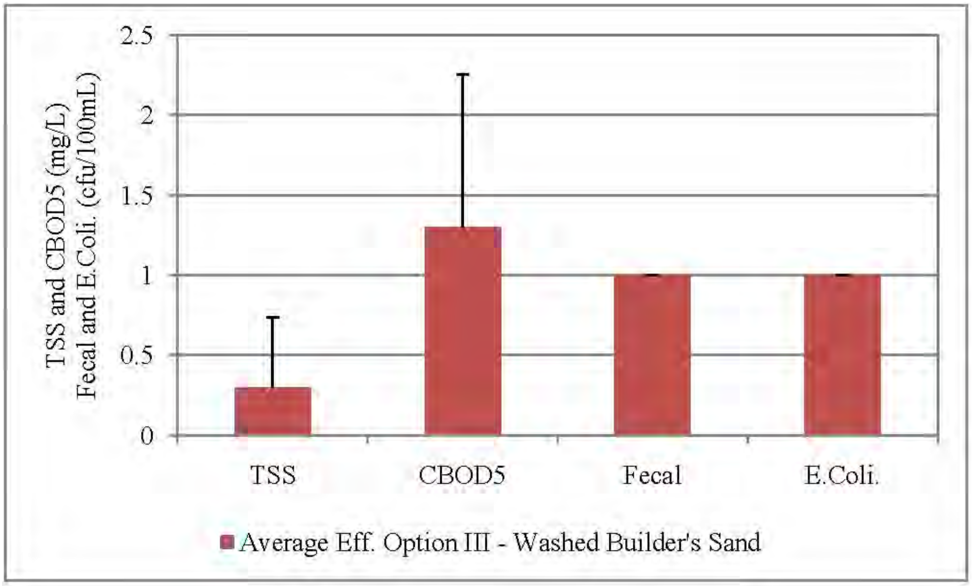


Figure 32 Conventional OSTDS effluent concentration of Recirculation III at S10 shows low TSS, $CBOD_5$, and bacteria levels.

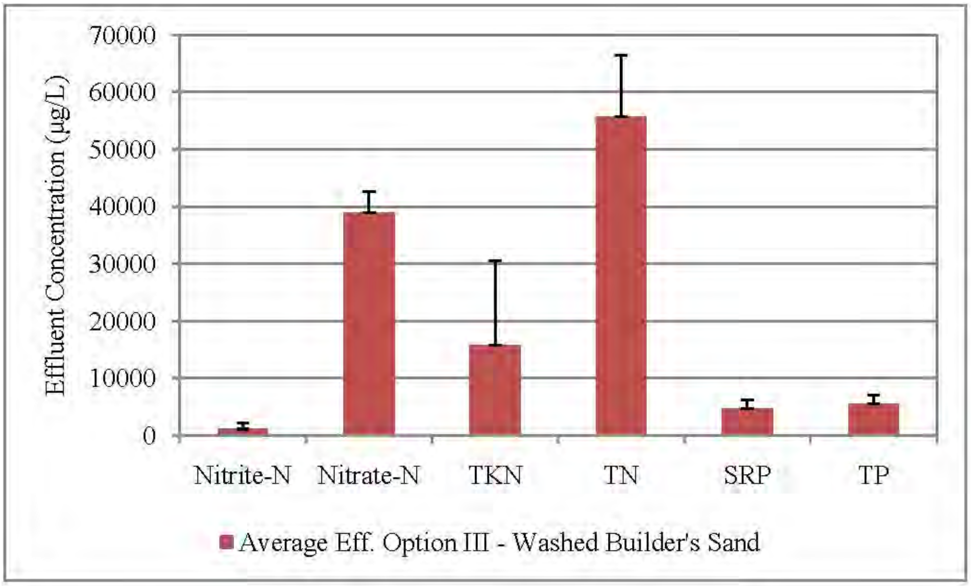


Figure 33 Conventional OSTDS effluent concentration of Recirculation III at S10 shows high level of nitrogen, but low level of phosphorus.

To further view the systematic trend, Figure 34 shows traces of nitrogen species and alkalinity at various sampling locations from the beginning to the end of the Recirculation I conventional OSTDS process, where S1 is the starting point (raw wastewater) and S12 is the ending point (8-foot below the washed builder's sand drain field). It strongly suggests that most of the nitrification happened between S4 (outlet of the recirculation tank) and S8 (inlet of the drain field), as evidenced by the disappearance of organic nitrogen and ammonia in parallel with the spike of nitrate at S8 whereas alkalinity dropped dramatically. It was observed at S12 (8-foot below the drain field) that most of the total nitrogen was in nitrate form. This condition support that the nitrification process was obvious while the denitrification process was almost nonexistent in the recirculation tank. This evidence agrees with the spike of nitrate in the ground water as shown in Figure 7. Overall, Recirculation option I had the best removal efficiencies in terms of nitrogen and phosphorus removal when compared against option II and option III. But the fine sand was clogged easily making the maintenance become an issue. As a consequence, Recirculation option II performs relatively better than Recirculation option III in terms of TN and TP removal.

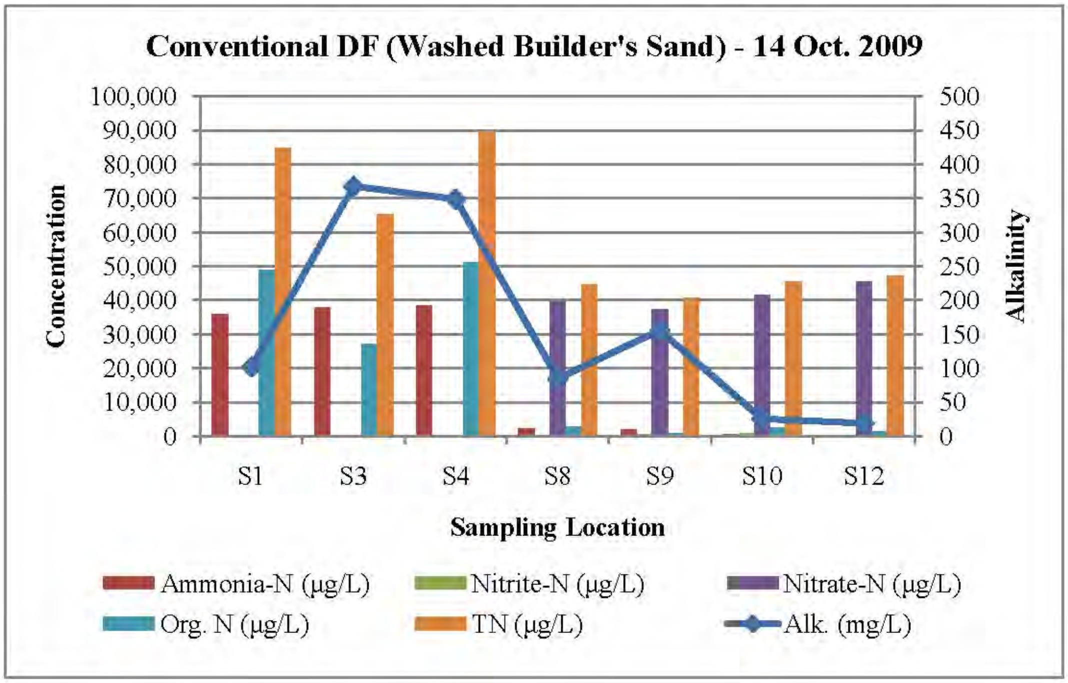


Figure 34 Tracking of nitrogen species in the conventional OSTDS with sorption media-based recirculation tank.

Chapter 7 Performance-based Evaluation of Three Conventional OSTDS with B&G and SUW Designs

7.1 Comparison of removal efficiencies

In this chapter, the average removal efficiencies for the conventional septic tank and drain field system with two recirculation designs, one without recirculation, the B&G drain field system, and the SUW (with Canna) are compared against each other. When recirculation is added, there is a high probability that additional conversion to nitrate can be accomplished and possibly denitrification. If this is the case, additional removal of nitrogen is possible. As shown in Figure 35 there is negligible differences in the measures of TSS, $CBOD_5$, and bacteria among the five systems. It should again be noted that TSS as measured in the SUW had additional solids added because of the sampling method. $CBOD_5$ removal efficiencies of all systems exhibit slightly different results but meet current standards. Bacteria removal efficiencies of all systems were over 99.9%. Figure 36 shows that the SUW with Canna and B&G had higher removal effectiveness of total nitrogen and phosphorus. All five systems converted the influent raw waste ammonia nitrogen (see TKN values) to nitrates. There were near zero nitrates in the raw wastewater. The conventional septic tank drain field designs, even with recirculation, did not perform well in removing total nitrogen. In two conventional system designs, the soluble phosphorus increased relative to the influent.

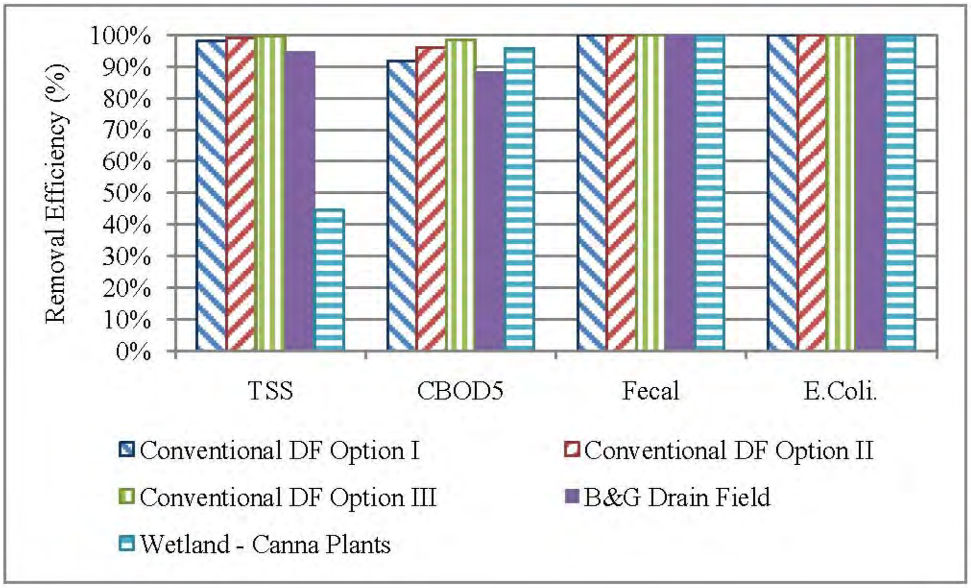


Figure 35 Comparative evaluation of removal efficiencies between conventional OSTDS, B&G system, and SUW with Canna in terms of TSS, CBOD$_5$, and bacteria.

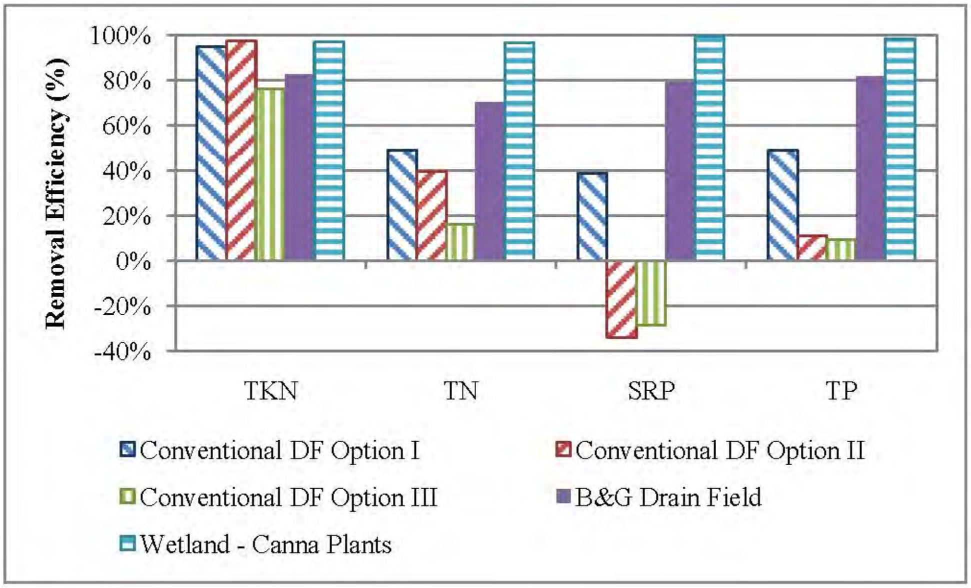


Figure 36 Nutrient removal efficiencies of the conventional OSTDS using the washed builder's sand drain field, B&G drain field and SUW with Canna plants.

7.2 Removing rate per unit area of drain field

To evaluate the relative importance of the surface area of the drain field with respect to pollutant removal we calculated the removal rates per unit area of drain field. The use of surface area reflects the relative importance in land and is an important cost consideration of each system. The SUW with Canna plants and B&G showed the best total nitrogen unit area removal efficiency as shown in Figure 37. Since there is minimal nitrate in the raw waste, a removal should not be significant if no nitrate appears in the effluent, however if nitrate appears in the effluent (as it does in conventional designs) then a negative removal or addition and be expected. In regard to the phosphorus removal per unit area, the SUW with Canna plants and the B&G present the best performance (see Figure 38). For TSS unit area removal, the B&G drain field was the best, while for BOD_5, the conventional system with recirculation and the B&G drain field were the best (see Figure 39).

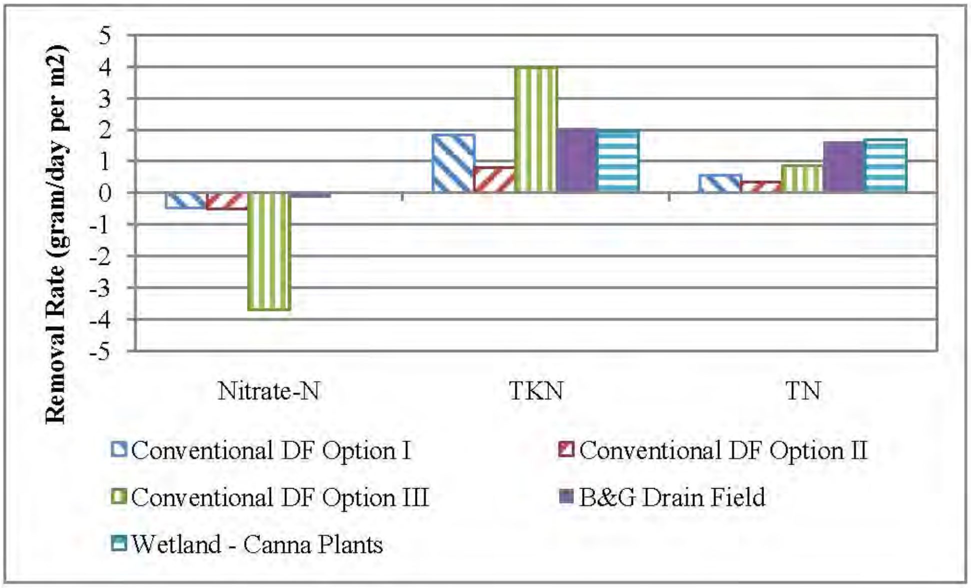


Figure 37 Nitrogen Species removal rate per unit area for five treatment trains

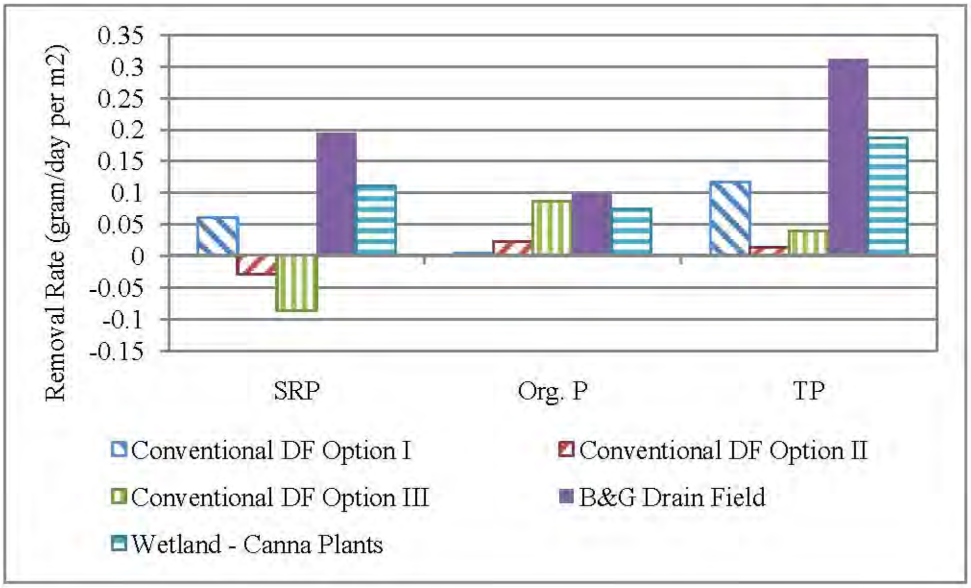


Figure 38 Phosphorus Species removal rate per unit area for five treatment trains

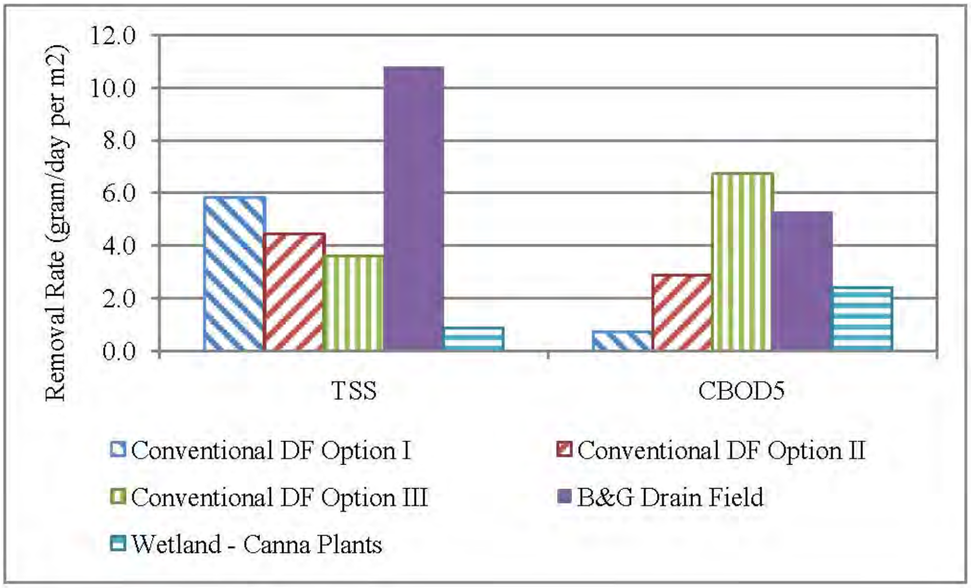


Figure 39 TSS and $CBOD_5$ removal rate per unit area for five treatment trains

7.3 Comparison of effluent concentrations

In the effluent measurements, the SUW had the lowest nitrogen concentration with the B&G drain field having the second lowest total nitrogen concentration and the conventional drain field systems having the highest nitrogen levels (see Figure 40). Similarly, the phosphorus level in the SUW with Canna cell (#1) was the lowest. B&G drain field had the second lowest level of phosphorus. The conventional drain field systems had the highest level of phosphorus in the effluent (see Figure 41). The bacteria level in the SUW effluent was the highest (see Figure 42). There were single measures where the fecal coliform counts exceeded the wastewater standard of 800 cfu/100mL. Average counts of fecal and E. Coli were less than the wastewater standard of 200 cfu/100mL. The effluent concentration of $CBOD_5$ in all systems was low as shown in Figure 43. The conventional OWST designs of this work are expected to have the greatest removal of nutrients, organics, and bacteria among all conventional systems because of the recirculation tank. Without recirculation tank, the removals are expected to be lower. In summary, the effluent data are reorganized in Tables 10 and 11 to ease the understanding of the variations versus averages with Table 10 reporting the standard deviation and Table 11 listing the overall average effluent concentrations.

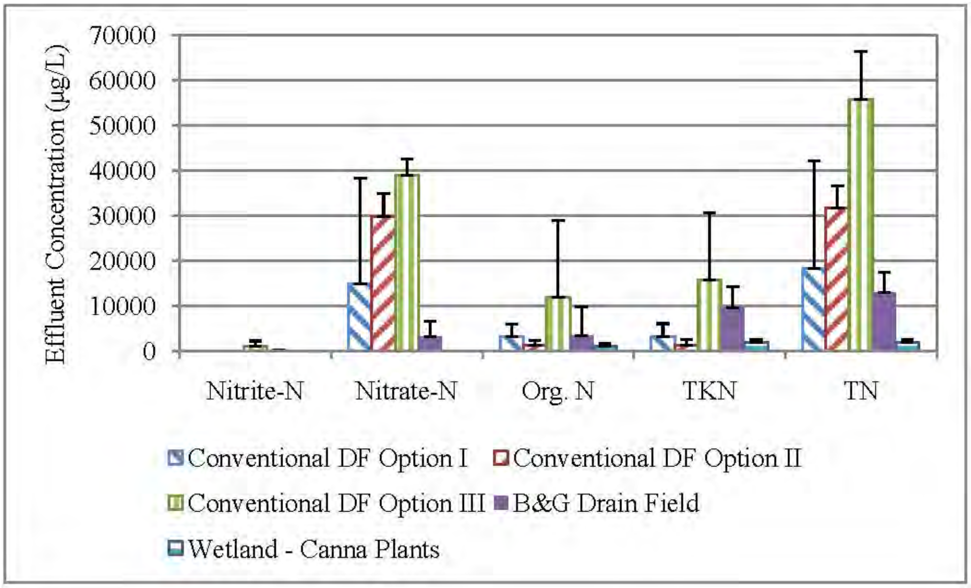


Figure 40 Effluent concentrations of nitrogen species in all OSTDS are compared. SUW with Canna plants and B&G performed the best.

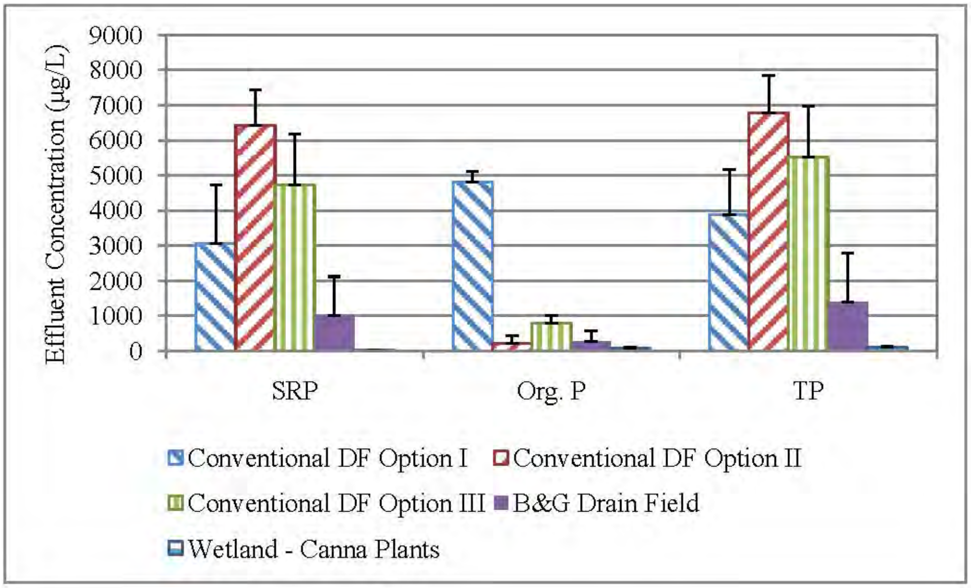


Figure 41 Phosphorus level in effluents where SUW with Canna plants and B&G performed the best.

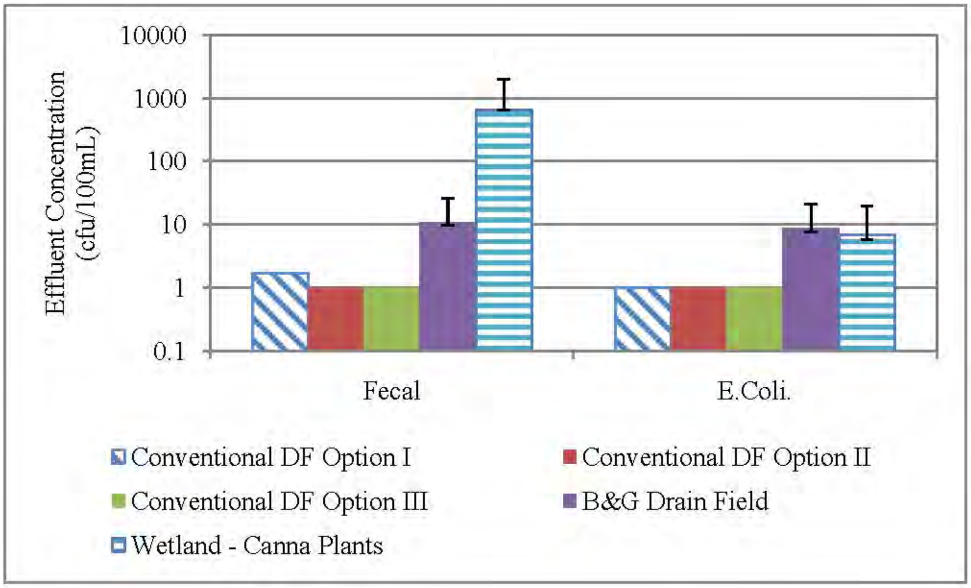


Figure 42 Summary of 1-year average effluent bacteria concentration in all systems.

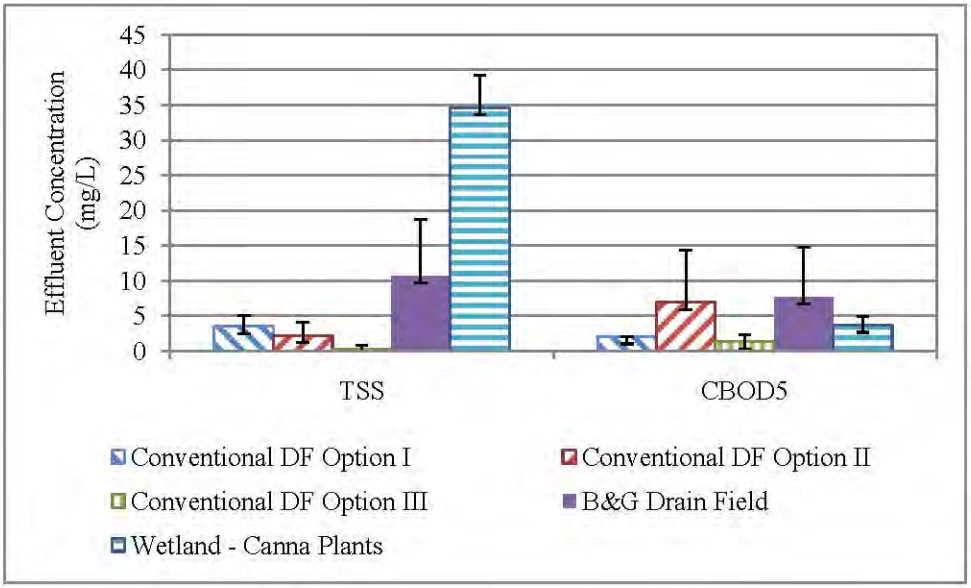


Figure 43 Effluent concentrations of TSS and CBOD$_5$ of all systems are compared.

Table 10 A summary of standard deviation of effluents at UCF Test Center.

Standard Deviation of Effluent					
	Conventional DF Recirculation I	Conventional DF Recirculation II	Conventional DF Recirculation III	B&G Drain Field	SUW - Canna Plants
Alk. (mg/L)	54.4	2.1	18.9	22.2	70.1
TSS (mg/L)	1.5	1.9	0.4	8.0	4.7
BOD5 (mg/L)	0.8	8.4	0.9	9.4	2.7
CBOD5 (mg/L)	0.0	7.5	1.0	7.1	1.3
Ammonia-N (µg/L)	29	24	5,578	1,928	499
NOX-N (µg/L)	23,490	5,149	4,495	3,454	5
Nitrite-N (µg/L)	2.3	3.9	1,137	55	0.9
Nitrate-N (µg/L)	23,488	5,146	3,657	3,417	4.9
Org. N (µg/L)	26,229	1,074	16,940	7,647	632
TKN (µg/L)	26,205	1,093	14,857	7,769	500
TN (µg/L)	23,881	15,394	10,698	4,431	499
SRP (µg/L)	1,647	1,013	1,445	1,111	6.6
Org. P (µg/L)	285	229	224	304	25.2
TP (µg/L)	1,289	1,077	1,439	1,405	30.5
Fecal (cfu/100mL)	1.2	0.1	0.1	15.0	1315
E.Coli. (cfu/100mL)	0.1	0.1	0.1	12.3	13.0

Table 11. A summary of effluent conditions at UCF Test Center.

Average Effluent Concentration					
	Conventional DF Recirculation I	Conventional DF Recirculation II	Conventional DF Recirculation III	B&G Drain Field	SUW - Canna Plants
Alk. (mg/L)	203	96	30	221	379
TSS (mg/L)	4	2	0	11	35
BOD5 (mg/L)	3	13	1	11	5
CBOD5 (mg/L)	2	7	1	8	4
Ammonia-N (µg/L)	47	44	3,829	6,102	860
Nitrite-N (µg/L)	6	7	1,062	52	2
Nitrate-N (µg/L)	14,860	29,749	38,923	3,146	6
Org. N (µg/L)	15,143	1,283	11,898	3,361	1,097
TKN (µg/L)	15,191	1,327	15,727	9,463	1,957
TN (µg/L)	40,057	31,103	55,711	12,902	1,964
SRP (µg/L)	3,071	6,436	4,729	1,004	18
Org. P (µg/L)	4,815	208	795	258	78
TP (µg/L)	3,883	6,780	5,524	1,387	96
Fecal (cfu/100mL)	2	1	1	11	657
E.Coli. (cfu/100mL)	1	1	1	9	7

Chapter 8 Conclusions

8.1 *Summary and remarks*

Passive nutrient removal OSTDS technologies, including the B&G and the subsurface upflow wetland (SUW), were evaluated in a full scale operational mode. The B&G and SUW systems have an advantage over conventional and performance-based OSTDS due to their higher nutrient removal efficiency, system reliability, no energy needed, and low maintenance requirement. Three tables present data to summarize and compare water quality results. Table 12 shows a summary of concentration changes of the three conventional OSTDS designs, the B&G drain field, and from the SUW with Cana as the plant species. For non-nutrient pollutants, the performance for the B&G drain field and the SUW is similar to the conventional septic tank systems. For nutrients, the B&G and the SUW perform much better. This table is developed based on the average raw water (inflow) and outflow conditions in a year.

Table 12 A summary of concentration changes for OSTDS at UCF Test Center.

Concentration Changes (- indicates an increase)#					
	Conventional DF Recirculation I	Conventional DF Recirculation II	Conventional DF Recirculation III	B&G Drain Field	SUW - Canna Plants
Alk. (mg/L)	32.63%	67.88%	88.02%	26.33%	-46.76%
TSS (mg/L)	98.13%	99.17%	99.53%	94.73%	44.56% *
BOD5 (mg/L)	90.14%	95.91%	98.51%	85.15%	94.79%
CBOD5 (mg/L)	91.86%	96.01%	98.45%	88.35%	95.74%
Ammonia-N (µg/L)	99.84%	99.89%	91.33%	81.78%	98.13%
Org. N (µg/L)	52.01%	85.30%	45.42%	85.83%	94.55%
TKN (µg/L)	74.91%	97.21%	76.16%	82.71%	97.04%
TN (µg/L)	49.07%	52.29%	16.21%	70.21%	96.69%
SRP (µg/L)	38.66%	-33.98%	-28.44%	79.11%	99.51%
Org. P (µg/L)	3.21%	86.73%	66.91%	83.56%	96.68%
TP (µg/L)	48.70%	11.01%	9.21%	81.79%	98.41%
Fecal (cfu/100mL)	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%
E.Coli. (cfu/100mL)	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%

* Includes additional particulate matter or measurement error. The resulting % removal (change) should be higher.
# Change or removal is based on influent or raw sewage concentration values and the effluent from the drain fields. Nitrate is not included because in raw sewage the nitrogen form typically is not nitrates or near zero.

8.2 Ground water impacts from conventional drain field

For the soil conditions at the UCF OSTDS Test Center, which are primarily well drained sand with low water table (greater than 10 feet below the surface), nitrogen and phosphorus concentrations in the ground water were measured based on full scale operation of the conventional septic tank and drain field designs. The average measured data from 16 groundwater sampling wells (2 beneath the conventional OSTDS drain field) as shown in Figures 6,7, and 8 indicate that the nutrient levels are greater under the conventional drain field relative to the background average nutrient values. Maximum levels of nutrients under the drain field are also noted and compared to the lowest background levels in 5 up-gradient wells as shown in Table 13. In particular, the highest level of nitrate nitrogen measured under the conventional OSTDS was 29.9 mg/L and the background levels were frequently below detection. The measured data under the conventional drain field are similar to those data reported in the Wakulla springs drain field study (Katz, 2009). These water quality data show the potential impact of increasing nutrients on ground water if nutrients are not controlled.

Table 13. Highest measured concentrations from two sampling wells beneath the conventional OSTDS compared to the lowest background levels.

Parameter/Location	Background concentration	Highest beneath the conventional drain fields
TN (mg/L)	.426	46.4
Nitrate-N (mg/L)	BDL*	29.9
Ammonia-N (mg/L)	.034	42.6
TP (mg/L)	.032	6.53
SRP (mg/L)	.004	2.89

* BDL – below detection level

8.3 Cost analyses

Cost data are developed using both operation and construction data. The cost of operating the B&G and the SUW is no more than the cost of operating a conventional system without recirculation, except for the replacement of plants. Plant replacement cost was estimated on a yearly basis and assumes that 25% of the plants will be replaced. The B&G and SUW require no energy. If a recirculation tank is added to a conventional system, an energy cost must be assigned because of the pump operation. A one-half horse power pump is assumed for recycle.

Construction cost estimates are based on the designs and materials used for the B&G and SUW as built at the UCF OSTDS Test Center. The B&G and SUW cost estimates are based on a flow rate of 500 gpd. Additional flow rates and cost estimates with details are provided by Wanielista (2008). It is recognized that other systems may be designed to incorporate the concepts and will have a different construction cost. The construction cost increase for the B&G is approximately $2,400 more than the conventional system and the construction cost increase for the SUW is about $3,300 more than the conventional system. Cost data are from actual purchased prices for materials and labor for installation and includes a 20% contingency margin.

Cost comparison data are provided for construction, annual operating and cost per thousand gallons of sewage treated. The flow rate base for design is 500 gallons per day. The cost for the conventional, B&G, and SUW systems were calculated based on the actual cost at the time of installation and are considered to be on a 2009 cost basis. The cost data for the other nutrient reduction OSTDS are based on published data from construction and operation in Florida (Mayer and Sherman, 1998). The cost data for these systems were calculated in 1998 dollars, thus construction and operating costs were inflated to mid-year 2009 using a 60% increase in construction cost and a 40% increase in operating cost to adjust the 1998 numbers to a mid-year 2009 estimate. The increases are based on a building construction cost index and the estimate does take into account a construction cost decrease of 8.4% from mid-year 2008 through 2009 (Turner, 2009). For nutrient reduction, the B&G and the SUW are the more cost effective options as seen in Table 14. The conventional system is the least costly but does not meet nutrient reduction standards.

From a report for the Wekiva area and an interest rate of 7%, Anderson (2006) concluded that for a performance based technology, the life cycle cost per year would be about $2232.71. The passive sorption options within this report range from $1010 to $1230 per year. A Savings to each home owner of over $1000 per year relative to the Wekiva site performance based technology. The most expensive performance based technology from Table 14 is $4270 per year. It should be noted that the cost in Table 14 are highly variable from region to region in our State, but the relative cost of each should not change.

Table 14 Cost comparison between a conventional OSTDS and advanced new passive OSTDS for nutrient removal including B&G and SUW designed at 500 gpd (mid-year 2009 basis).

	Construction Cost with 20% contingency ($)	Annualized Construction Cost at 6% interest rate and 20 years ($)	Annual Operating cost ($)	Unit Cost $/1000 gallons
Conventional OSTDS	6,920	600	200	4.38
B&G with sorption media	9,320	810	200	5.53
SUW with sorption media and plants	10,200	890	400	7.07
Conventional OSTDS with Drip Irrigation	12,600	1,100	1,460	8.00
Continuous Feed Cyclic Reactor & Drip Irrigation*	18,200	1,590	1,800	18.58
Rotating Biological Contactor & Drip Irrigation*	18,800	1,640	1,740	18.58
Fixed Activated Sludge & Drip Irrigation*	18,800	1,640	2,110	20.55
Recirculation Tank & Drip Irrigation*	27,800	2,420	1,850	23.40

* from Mayer and Sherman, 1998.

8.4 *Certification and commercialization*

Two US patents had been filed in 2008 and 2009 associated with the B&G drain field and the subsurface upflow wetland system, respectively. UCF is now seeking the industrial partnership to promote the outreach relationships and implement the technology transfer. During the pathway, we are eager to pursue any certification should our future industrial partners are interested in this route for final commercialization.

8.5 *Future work*

Continuing efforts will be directed toward more system reliability testing such as the stress test reflecting the situation that the B&G drain field and the subsurface upflow wetland system could be overloaded during abnormal conditions. Tracer test is required to track down if the flow pathway has any shortcut in the innovative passive OSTDS so as to provide ideas in regard to how to improve the hydraulic design as part of the final design criteria. Operational manuals have to be prepared based on long-term operational experience in addition to the design manuals. During the commercialization, some additional tests to customize these passive technologies in order to fit in a variety of needs in real world systems are inevitable. We are also preparing several modeling packages to characterize these three types of drain fields. For example, the computer code, HYDROGEOCHEM, has been developed by Dr. George Yeh (i.e., a faculty with UCF) to characterize the conventional drain field, the Subwet 2.0 developed by the United Nations Environment Program (UNEP) will be applied to characterize the B&G drain field and the wetland system to compare against the system dynamics model that had already been applied to characterize the SUW system.

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