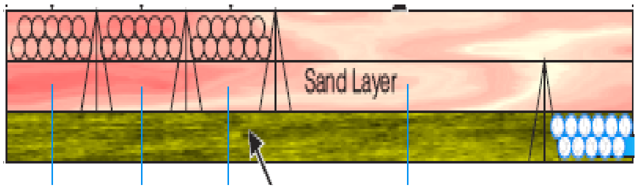
On-Site Sewage Treatment and Disposal Systems Evaluation for Nutrient Removal

FDEP Project # WM 928



Final Report
Submitted to Florida Department of Environmental Protection

By

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

Stormwater Management Academy
Civil, Environmental, and Construction Engineering Department
University of Central Florida

April 17, 2011

Acknowledgment

This project was funded by an Urban Nonpoint Source Research Grant from the Bureau of Watershed Restoration, Florida Department of Environmental Protection. The authors appreciate the assistance from the State of Florida Department of Environmental Protection. Technical assistance was also provided by the State of Florida Department of Health. The time provided to collect and analyze samples in addition to the construction supervision at the site by students from the stormwater management academy is also appreciated.

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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 water resource utilization has resulted, especially in spring areas. Elevated nitrate levels in groundwater may cause public health problems, such as blue baby syndrome, and may impair or destroy surface water ecosystems through algal blooms and other nuisance plants. Impaired water and loss of resource utilization have resulted in increased cost of protecting these resources and loss of recreational opportunities.

The major causes of nutrient problems are widely acknowledged to be nonpoint sources of pollution 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 et al. 2007). OSTDS systems are currently regulated by the Florida Department of Health (FDOH). In the Florida Keys, there is a nitrogen limitation level of 10 mg/L as set in Chapter 64E-6 (FDOH, 2009, pg 64). However, this level may be about one order of magnitude too high to protect springs and other water bodies from nutrient degradation if there is no removal of nitrogen in the soil systems after the OSTDS. Nitrogen compounds are not significantly reduced in the conventional OSTDS and thus nitrogen levels within groundwater 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 et al. (2010) 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 drainfield was measured at 19 mg/L. OSTDS are one likely source contributing to this increase.

Because of the concern for nitrate levels from OSTDS, scientists, engineers, regulators and manufacturers in the wastewater treatment industry have been developing 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 requiring performance-based OSTDS in the Florida Keys and other environmentally sensitive areas such as springsheds, but they are expensive to install and operate. In addition, there is a cost of energy and they may not always produce a consistent nutrient reduction. Among currently available OSTDS treatment technologies, passive OSTDS systems are relatively more appealing than their active counterpart because of their consistent nutrient reduction capabilities and relatively low initial and operating costs. Passive OSTDS is defined by the Florida Department of Health (FDOH) as a type of onsite sewage treatment and disposal system that excludes the use of aerator pumps and includes no more than one effluent dosing pump with mechanical and moving parts. These systems may use reactive media to assist in nitrogen removal. Reactive media are materials usually placed in a filter that effluent from a septic tank or pretreatment device passes through. Some technologies use one or more reactive media in a filter to assist in nitrogen removal.

Within this report are the results of a Florida Department of Environmental Protection sponsored research program comparing three passive OSTDS treatment trains to a control system – a conventional OSTDS with drainfield. The comparison is done with a full scale operating system at the University of Central Florida (UCF) Onsite Wastewater Treatment Test Center. To obtain better nutrient reduction from the conventional septic tank and drainfield, a recirculation sand filter was added to the conventional OSTDS at the Test Center. Thus, the first passive OSTDS treatment train includes a septic tank with a media recirculation sand filter. There are also two drainfields in parallel following the septic tank to compare the use of two types of sand. Astatula sand, a type of Florida sand, was used as an alternative to compare against washed builder's sand, which is an option to use in conventional drainfields in Orange County, FL. The second passive OSTDS treatment train is designed as a Bold & Gold^{TM} (B&G) media filter with green reactive sorption media in an underground tank. The third is designed as a subsurface upflow wetland (SUW) with innovative subsurface hydraulic flow patterns, green reactive sorption media and various plant species. The Bold & Gold^{TM} (B&G Filter) is used before the standard drainfield design and the subsurface upflow wetland (SUW) is used to replace the conventional drainfield and must have a seepage area for the effluent from the SUW if reuse of the water is not planned.

During the operation and testing period, two alternative passive OSTDSs, namely B&G Filter and SUW have proven to 1) be effective in nutrient reduction and 2) maintain operating reliability. Depending on site conditions, a pump may be needed, however for most site conditions, no pump should be needed. A dosing pump was used at the Test Center to maintain equal loadings to all the OSTDSs. The newly developed passive technologies, B&G Filter and SUW systems, installed at the UCF Test Center underwent intensive sampling for system performance, modeling of the processes, pollutant transport and fate measures, and an assessment for integration of the planning, design, installation, maintenance, and management functions for future implementation and certification testing. For the test conditions, average effluent concentrations of the B&G Filter and the SUW are compared in Table ES-1. The comparison illustrates that the nutrient removal effectiveness of the B&G Filter and SUW systems are greater compared to the conventional OSTDS with and without recirculation. Average effluent nitrates are less than 10 mg/L with the B&G Filter and SUW sorption systems. Alkalinity also is available in the effluent of the B&G Filter and SUW OSTDS to continue the process of nitrogen assimilation provided other conditions for assimilation are present. The Fecal and E. Coli data indicate that their removal is significant for all OSTDSs. Most likely there would be no violation of fecal standards in a receiving water body considering a standard for which less than 10% of samples are greater than 400 cfu/100mL.

Table ES-1 Average Effluent Concentrations for a Conventional OSTDS, an OSTDS with Recirculation, a B&G Filter OSTDS and a SUW OSTDS

	Conventional DF without recirculation Control case	Conventional DF with recirculation Design I	B&G Media filter	SUW – Sorption with Canna Plants
Alkalinity (mg/L)	54	203	221	379
CBOD5 (mg/L)	1	2	8	4
Nitrate-N (mg/L)	41.97	14.86	3.146	0.006
TKN (mg/L)	6.110	3.180	9.463	1.957
TN (mg/L)	48.09	18.21	12.902	1.964
SRP (mg/L)	4.58	3.07	1.00	0.018
TP (mg/L)	4.92	3.88	1.38	0.096

In addition, nutrients in the groundwater below the drainfields of the conventional OSTDS are measured and elevated nutrient levels were noted relative to the background. Nitrate nitrogen was as high as 29.9 mg/L. Elevated nutrient levels beneath drainfields of a conventional OSTDS were also noted in the Wakulla basin (Katz, 2010).

Using actual construction and operating cost data used at the UCF OSTDS Test Center, four OSTDS alternatives are compared as shown in Table ES-2. The cost data are based on a design flow rate of 500 gpd (for a 4 bedroom, 4050 square foot home as one example). All costs were verified with local construction companies who install OSTDS. The annual operating cost for the OSTDS with recirculation and the B&G Filter are based on inspection and hydraulic repair cost only, which in many situations is zero but assumed equal to $200 for this analyses. The operating cost of the SUW assumes a plant replacement cost in addition to inspection. Also, the cost for B&G Filter and SUW may be lower if drip irrigation is used; as the cost data in Table ES-2 assumed a drainfield designed to conventional design standards follows the B&G Filter. It should be noted that these costs are variable from one geographic region to another and also will change with site conditions in the State.

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

System Technology	Construction Cost in 2009 ($) except last entry	Annualized Construction Cost at 6% interest rate and 20 years ($)	Annual Operating cost ($)	Unit Cost $/1000 gallons
Conventional OSTDS	5,770	500	200	3.84
B&G filter media and DF	8,370	725	200	5.07
Conventional OSTS with RSF	6,920	600	390	5.42
SUW with sorption media and plants	9,070	785	400	6.49

On average, the B&G Filter and SUW passive OSTDS technologies designed and operated as reported here will result in lower TN effluent concentrations relative to a conventional OSTDS technology. These passive OSTDS have been shown to achieve concentrations of TN from near zero to 12 mg/L with nitrate concentrations below the 10 mg/L ground water quality standard. They are effective alternatives for reduction of nutrients in OSTDS, produce reliable operation, and may consume no energy (depending on site conditions). Furthermore, they have less construction and operation costs relative to other OSTDS that remove nutrients. Vendors and third party organizations have been contacted to further refine the design and operation of the B&G Filter and the SUW for extended applications. Based on full scale operation and measurement for the systems at the UCF OSTDS Test Center, it is recommended that the B&G Filter and the SUW be certified by third party organizations for use in the State of Florida.

Chapter 1: Introduction

1.1 Objectives

Aquifers 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 groundwater 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 drainfields. There are more than 2 million septic tanks and drainfields in the State of Florida (Briggs et al. 2007). 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 such residential communities, nitrates are contributed from fertilized landscaped areas and from septic tank effluents. The most common type of OSTDS is a septic tank followed by a drainfield system, A.K.A. “septic system” or “conventional system”. The most significant benefit of this OSTDS is their cost effectiveness and ease of operation and maintenance. To reduce the impacts of OSTDS on groundwater, 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, especially in meeting the groundwater standard of less than 10 mg/L nitrate-N. Passive

OSTDS with appropriate nutrient removal capacity 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 and performance-based designs.

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

3) Document the fate and transport of nutrients in vadose zone and groundwater aquifer from a conventional drainfield.

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 processes are studied, focusing on the use of a recycling system, a subsurface wetland, and an innovative passive media filter with soil substitution. To verify the cost-effectiveness and nutrient removal efficiencies, a septic tank with a conventional drainfield is used as a control for comparative basis.

Groundwater 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 OSTDSs are used widely. Accordingly, the general findings gained in this study are transferable to many communities statewide.

The objectives of this research concentrate on 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 drainfield?

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.

OSTDSs have been constructed, operated, and monitored at the UCF Test Center since spring 2008. There are three passive nutrient removal treatment technologies and a conventional system which serves as the control. The first treatment technology consists of a septic tank, a recirculation sand filter, and two types of conventional drainfields in parallel to allow testing of two differing types of sand to be arranged with the same influent. The first drainfield uses washed builder's sand as its filtering media while the second drainfield design uses Astatula (citrus grove sand). The second treatment technology has a septic tank followed by a lined media filter tank underground filled with Bold & Gold^{TM} sorption media (called "Bold & Gold Filter" or B&G Filter in our study). The third treatment technology consists of a septic tank and 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 flows are collected from the UCF presidential reception house to maintain daily inflow.

1.2 Nutrient Impact Resulting from Conventional On-site Wastewater Treatment

On-site sewage contains organic matter (i.e. 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, OSTDSs can represent a large fraction of nutrient loads to groundwater 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 impacts 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 OSTDSs" that are available instead of conventional septic tanks for homeowners. Section 64E-6.025(10), F.A.C, defines a Performance-based OSTDS as a "specialized onsite sewage treatment and disposal system designed by a professional engineer with a background in wastewater engineering, licensed in the state of Florida, using appropriate application of sound engineering principles to achieve specified levels of CBOD5 (carbonaceous biochemical oxygen demand), TSS (total suspended solids), TN (total nitrogen), TP (total phosphorus), and fecal coliform found in domestic sewage waste, to a specific and measurable established performance standard. The level of TN reduction varies from 20 mg/L to as low as 3 mg/L. However, performance-based OSTDSs are energy intensive and they are frequently expensive to install, operate, and maintain. In addition, while they are designed to achieve an effluent with 10 mg/L nitrate which will prevent blue-baby syndrome, this level of nitrate is much too high to protect springs and other water bodies. To effectively remove nutrients in OSTDS effluents, there is a need for improving the current OSTDS used in Florida. Additionally, a better understanding is needed of nutrient removal behavior as the effluent plume passes through the OSTDS and the soil to the groundwater and possibly a receiving water body. Today's focus on sustainability will drive the market toward energy-efficient systems in the near future. Passive nutrient removal OSTDSs are expected to be preferred choices for future generations. Pairing their excellent nutrient reduction and their energy-efficient operation with low-cost maintenance should stimulate demand for them in the future market place.

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). It is connected to the standard drainfield 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 expected that most of the residual nutrients may be assimilated. Several types of effluent distribution are applicable in standard drainfield systems. These include gravity systems, low pressure dosed systems, and drip irrigation systems. 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 groundwater 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 OSTDSs on ground and surface waters, scientists, engineers, and manufacturers in the wastewater treatment industry have developed a wide range of alternative active and 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

Given the above issues with conventional and performance-based OSTDSs, a new generation of passive on-site wastewater treatment technologies with nutrient removal capacity is needed to effectively remove nutrients and better protect public health and our ground and surface waters in a cost-effective manner. Reactive media are materials that effluent from a septic tank or pretreatment device passes through prior to reaching the groundwater. This may include but are not limited to soil, sawdust, zeolites, tire crumb, vegetative removal, sulfur, spodosols, or other media. This project evaluates three passive OSTDSs including two innovative designs, a newly developed filter media that is composed of soil amendments (B&G Filter with 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 as 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 µg/L nitrate. The Florida Department of Health (DOH) is charged with regulating OSTDSs through their authority in Chapter 381, F.S., and their implementing regulations in Chapter 64E-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 (Chapter 64E-6, F.A.C.).

1.5 NSF 245 Standard

National Sanitation Foundation and the American National Standards Institute (NSF/ANSI) Standard 245 was developed for residential wastewater treatment systems designed to provide for nitrogen reduction and published 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 1,500 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):

- $CBOD_5$: 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 Standard 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 OSTDS 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
- TN : less than 50% of average of all influent TN 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 main campus in 2008 which includes a conventional septic tank and drainfield (the control) and three passive nutrient reduction OSTDSs treatment technologies. The first OSTDS treatment technology consists of a septic tank with a sand-filter circulation tank, and two drainfields 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 approximately 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 drainfield. These lysimeters (S5-S7) collect wastewater infiltrate in the vadose zone as the effluent travels through the sand in the drainfield with Astatula sand whereas S8-S10 collect wastewater infiltrate in the vadose zone as the effluent travels through the sand in drainfield with washed builder's sand. During the research, we installed S11 and S12 for collecting more samples and they are at the depth of 108 inches beneath the surface of the infiltrating 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 effluent from the former septic tank goes to both the B&G Filter (Figure 1) and the SUW systems (Figure 1), the effluent of the latter one goes to both conventional drainfields. A dosing tank is connected to one septic tank for equal distribution of flow to the B&G Filter and the wetland treatment processes. The wetland is designed as a subsurface upflow wetland (SUW) with four media cells. Each conventional drainfield and the B&G Filter received about 200 gallons of wastewater daily, whereas each wetland cell received 50 gallons of wastewater daily.. Three different species of plants were installed into three separate wetland cells for testing. One wetland cell is set up as the control case, which has no plants. Both B&G Filter and SUW wetland systems are lined. All the effluents from the B&G Filter and the SUWs at the UCF experimental site were collected and returned to the main sewage line nearby.

There are two sets of monitoring wells at UCF Test Center, eight (8) drainfield monitoring wells and eight (8) groundwater monitoring wells (Figure 1). The eight (8) drainfield monitoring wells are located near the two standard drainfields to monitor the water quality of the groundwater up-gradient, immediate, and down-gradient of each standard drainfield. 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 drainfield monitoring wells were sampled on a biweekly basis.

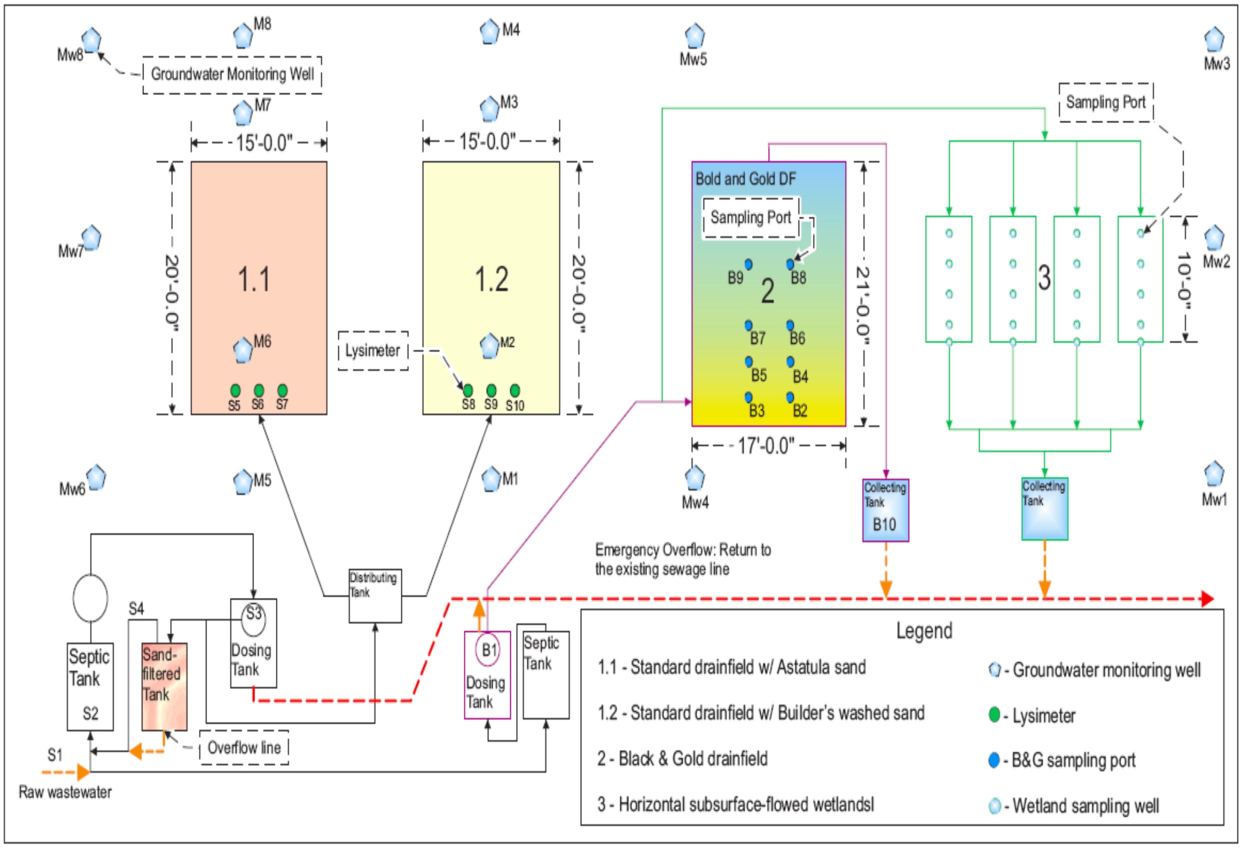


Figure 1 Schematic Layout of OSTDSs at UCF Test Center.

2.1.2 Influent conditions

Formal sampling campaign was launched on Oct. 13 2008 in the conventional drainfield and B&G Filter. The influent concentrations of sewerage for 2008 and 2009 are shown in Table 1. Data for all Sampling OSTDS Process Locations and Dates are listed in Appendix B.

Table 1 Influent Water Quality Condition

Year	Sample Date	Sample ID	ALK	TSS	BOD_5	$CBOD_5$	Ammonia-N	Nitrite-N	Nitrate-N	Diss. Org. N	TKN	TN	SRP	Diss. Org. P	TP
			mg/L	mg/L	mg/L	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
2008	10/14	S1	293	175	31.3	31.2	32,864	8	3	13,395	46,259	46,270	4,928	32	7,200
2008	11/4	S1	316	268	41.6	37.1	42,143	8	94	3,865	46,008	46,110	4,918	5,005	9,891
2008	11/19	S1	295	117	6.2	5.4	11,921	18	10	2,935	14,856	14,884	5,174	4,960	5,616
2009	2/10	S1	277	250	725	204	37,040	20	5	9,525	46,565	53,410	4,469	1,021	8,310
2009	2/24	S1	275	212	232	181	32,990	27	4	7,008	39,998	41,752	3,859	697	6,356
2009	3/10	S1	264	644	355	350	67,685	71	34	231	67,916	77,202	8,026	2,586	14,037
2009	3/18	S1	284	165	5.9	4.6	38,901	5	19	1,062	39,963	47,930	4,453	660	6,689
2009	3/2	S1	521	454	345	260	55,657	15	36	15,537	71,194	79,219	6,659	159	6,985
2009	3/30	S1	283	82	293	156	41,884	31	17	3,016	44,900	44,948	3,164	3,694	6,858
2009	4/8	S1	279	342	310	241	45,194	13	2	19,238	64,432	64,447	5,128	4,688	9,816
2009	4/13	S1	250	150	149	132	27,266	8	1	7,044	34,310	34,319	2,383	2,070	4,453
2009	4/22	S1	286	259	345	136	41,944	30	14	1,633	43,577	43,621	3,627	512	4,139
Avg. 2008		S1	301.3	186.7	26.4	24.6	28,976	11	36	6,732	35,708	35,755	5,007	3,332	7,569
Std. Dev. 2008			13	76	18	17	15,482	6	51	5,789	18,059	18,075	145	2,858	2,161
Avg. 2009		S1	302	284	307	185	43,173	24	15	7,144	50,317	54,094	4,641	1,787	7,516
Std. Dev. 2009			83	174	194	97	12,127	20	13	6,658	13,709	15,998	1,759	1,585	2,999

* TKN: Total Kjeldahl Nitrogen (= Organic N + Ammonia N)
* TSS: Total Suspended Solid
* SRP: Soluble Reactive Phosphorus
* $CBOD_5$: 5 day Carbonaceous Biochemical Oxygen Demand
* TN, TP: Total Nitrogen and Total Phosphorus
* Diss Org. N: Dissolved Organic Nitrogen
* Diss Org. P: Dissolved Organic Phosphorus
* ALK: Alkalinity
* BOD_5: 5 day Biochemical Oxygen Demand

2.2 Nutrient removal mechanism and sorption media

2.2.1 Nutrient removal mechanism

The adsorption, absorption, ion exchange, and precipitation processes are actually intertwined with the overall physicochemical process in the nutrient removal media filters or drainfields at UCF Test Center no matter whether 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.

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 natural systems or the built environments is well understood. Within the microbiological process, if there are organic sources in the wastewater streams, hydrolysis converts particulate organic nitrogen (PON) to soluble organic N (SON), 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 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, there are various forms of organic compounds in the wastewater that serve as electron donors. The relationships between the various nitrogen species are well defined and are shown by equations listed below. 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 Florida DOH (FDOH), (2009).

The two steps of nitrification 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 Filter and SUW systems.

2.2.2 Sorption media

As already described, passive OSTDSs can use a reactive media to assist in nitrogen removal. Reactive media used in OSTDS have normally included soil, sawdust, zeolites, tire crumb, sulfur, spodosols, or other media. Some passive OSTDS technologies use reactive media to assist in nitrogen removal including sawdust and other wood products, zeolites, vegetation, sulfur, spodosols, as electron donors also (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, groundwater remediation, and treatment of drinking water (Chang et al., 2008b). The use of these sorption media in the engineered processes and natural systems may remove not only the nutrients, but also some other pollutants, such as heavy metals, pathogens, pesticides, and toxins (TCE, PAH, etc.). Sorption is important for phosphorus removal because of the adsorption, absorption, and precipitation effects. With such functionality, a biofilm can be formed on the surface of soil or media particles to allow microbes to assimilate nitrogen species although nitrogen cannot be removed by sorption directly. It is indicative that sorption provides an amenable environment for subsequent nitrification and denitrification.

In this project, four types of green sorption media including Bold & Gold media, pollution control media, growth media, and recirculation media are used and evaluated. Sorption media previously used for wastewater treatment is summarized along with their corresponding references in Table 2. The media and their recipes being applied at UCF Test Center are also summarized in Table 3.

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%)	
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	Typical Recipe	Note
Bold & Gold (B&G)	68% Astatula sand 25% Tire crumb 7% Compost	This sorption media is used at the bottom layer in the B&G media filter.
Pollution Control Media	50% Astatula sand 20% Limestone 20% Tire crumb 10% Compost	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% Compost 5% Expanded clay	This sorption media is used in the top layer of recirculation sand filter in one of the three testing stage

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

Engineered, functionalized, and natural sorption media can be used to treat stormwater runoff, wastewater effluents, groundwater 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.

One of the main objectives of this study is to evaluate the basic functionality and effectiveness of the B&G Filter (a green sorption media filter) with its unique recipe to remove both nutrients and pathogens. This innovative passive underground media filter may fit in any landscape currently used for a conventional drainfield 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 Filter are used in a manner to foster a saturated anaerobic or anoxic environment sequentially. 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 such passive media filters (Wanielista et al., 2008). A lab-scaled study was conducted in which sorption isotherm and microcosm tests were used to prove the concept (Chang et al., 2008a, 2008b). The laboratory study is followed by a comparative full scale field study that is required to prove the advantageous features of passive treatment technologies within the treatment trains at the UCF Test Center.

The schematic of the B&G Filter filling the horizontal underground cells beneath a sand layer is shown in Figure 2. 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 media filter provides contiguous aerobic and anoxic environments to transform and remove nutrients and pathogens in wastewater. In the media filter, the hydraulic pattern is used in combination with a sequential reactor of aerobic and anoxic environments, which repeats the reaction mechanism of nitrification and denitrification in sequence, to remove nutrient content from the influent. Several vertical perforated pipes (i.e., oxygenators) for venting in the beginning of the media filter close to the header pipe are used to induce air into the initial portion of cell so that the aerobic environment can be promoted periodically when needed. At the Test Center, the B&G Filter 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 Filter which is designed as an open channel within the box that is 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) periodically occurs depending on the raw water flow. The B&G Filter and SUW do not require a dosing pump but such a pump is used because of the need to equally supply water to the conventional drainfields, SUW and the B&G Filter. In actual applications, the SUW and B&G Filter can be operated without a dosing pump. In the B&G Filter, the perforated pipes (i.e., oxygenators) at the front end are controlled to maintain the aerobic condition at the left part of channel (see Figure 2). Then the baffles guide the flow through the media filter. While the first part of the channel consumes air and alkalinity for nitrification, the dissolved oxygen would gradually decrease over space and time making the subsequent process anoxic before the riser where denitrification may occur. All zones before the riser baffle in the open channel must be filled with sorption media to promote the targeted reactions. In Figure 2, the four triangles between sampling locations 3, 4, 5, 6, and 7 are these baffles and the MPI-11 bundle is noted between locations 6 and 7 in the media filter portion. 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 is verified by a tracer study later on. The disposal chamber is for sampling purposes, which allows pumping back the effluent to a central sewer line that was required by the Florida DOH for this experimental site. The sample collected from disposal chamber (location 7 in Figure 2) was considered as the effluent hereinafter. The effluent may be directed to a drainfield if there is no need to pump the effluent back to a central sewer line.

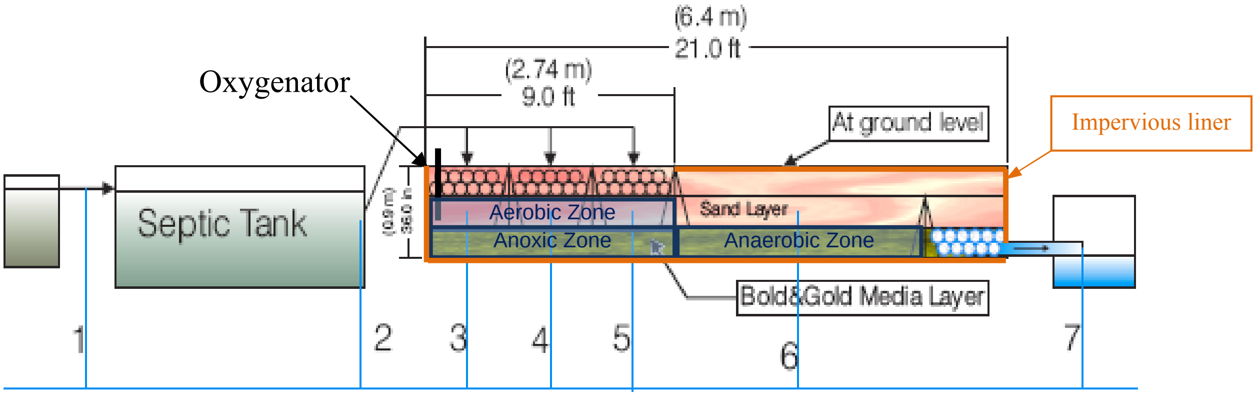


Figure 2 Schematic of the B&G Sorption Media Filter (Wanielista et al., 2008). Numbers refer to Sampling Locations in the Treatment System

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 are important mechanisms also.

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 type 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 importance to developing specific wetland media instead of conventional soil, sand and gravel to gain better pollutants removal capacity is widely recognized. Mann (1993) conducted the pioneer trial 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 was 25.8 to 47.5 μg P/g, blast furnace slag was 160 to 420 μg P/g and fly ash was 260 μg P/g, which warranted 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.

The potential of a constructed wetland for treating wastewater, both onsite and otherwise, 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 a 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 (TSS) 56 ± 53%, biochemical oxygen demand (BOD) 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% (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 in wetland studies. One of the main objectives of this study is to provide the cost-effectiveness of a newly developed subsurface upflow wetland (SUW) system with sorption media and selected plant species. In our initial pilot testing without the inclusion of oxygenator, it is showed that green sorption media consisting of recycled and natural materials provide a favorable environment for nutrient removal (Xuan et al., 2009). The data discussed in this chapter include the results after the retrofit of the SUW wetland with the oxygenator. However, all data are included in Appendix B.

2.4.2 Wetland plant species

Plants are an extremely important component of a wetland system both in terms of nutrient uptake and the provision of 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 anaerobic-anoxic-aerobic 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 also 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 summarized as a foundation for the SUW design. In 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 UCF SUW OSTDS consists of four parallel 1.52 m wide × 3.05 m long × 1.07 m deep (each 5 ft wide × 10 ft long × 3.5 ft deep) cells. Each of four cells contains a gravel-filled gravity distribution system including header pipe, distribution pipe, collection pipe, flow meter, and a planted bed of special green sorption media with an underdrain collection system. With the aid of a suite of selected plant species, this SUW is configured to handle 189 liters per day (50 gpd) influent. 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.

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)

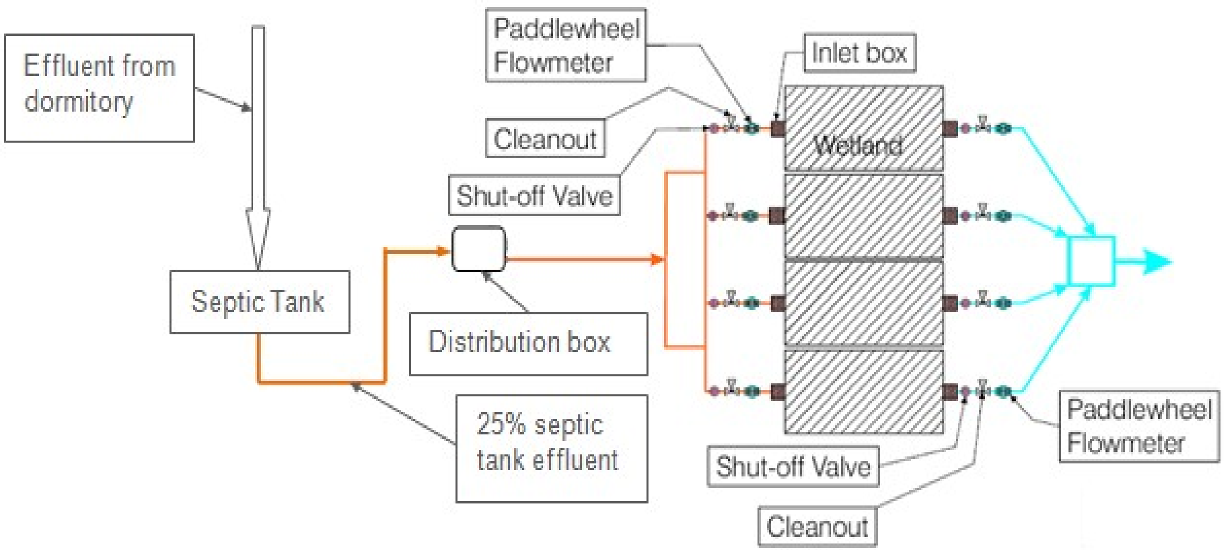


Figure 3 Configuration of a Septic Tank Followed by a 4-Cell Wetland System Including Shut-Off Valve, Cleanout, and Flow Meter

2.5 *Conventional septic system with RSF*

The Florida Keys On-site Wastewater Nutrient Reduction Systems (OWNRS) Demonstration Project was initiated in 1995 to demonstrate the use of an 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 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) evaluated 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). Although the previous literature gives a range of 47.6% to 83% TN removal in the passive treatment process with the inclusion of RSF, most of results count on very long HRT (e.g., 6.6 days) that are not cost effective.

In Figure 4(a) is a schematic of an OSTDS in which the nitrification can be promoted with a RSF while denitrification mainly occurs in septic tank and drainfield. What are shown in Figure 4(b) are the sampling locations at the UCF Test Center for this treatment train. Detailed results are presented in Appendix B corresponding to these locations while summarized discussion is provided in the main body of text.

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

- Nitrification:

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

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \tag{5}$$

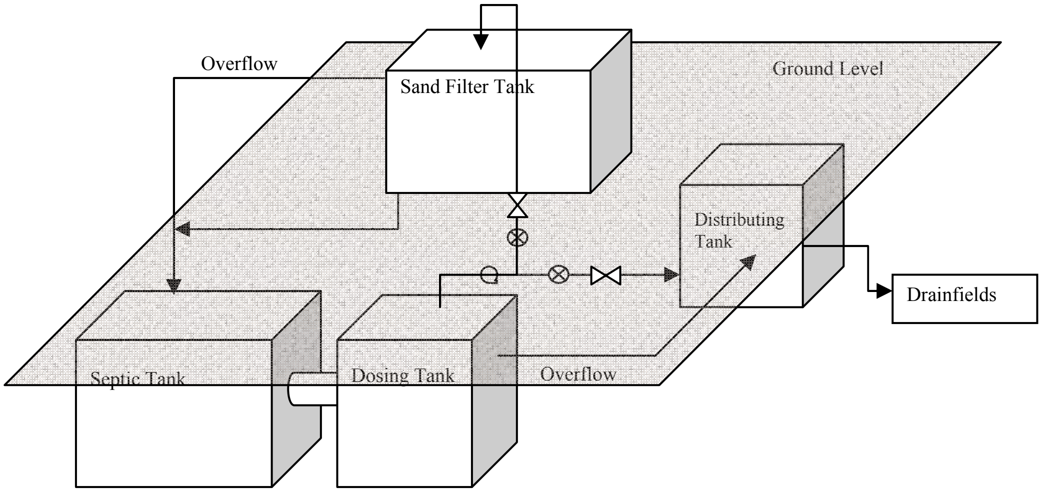
$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \tag{6}$$

- Denitrification:

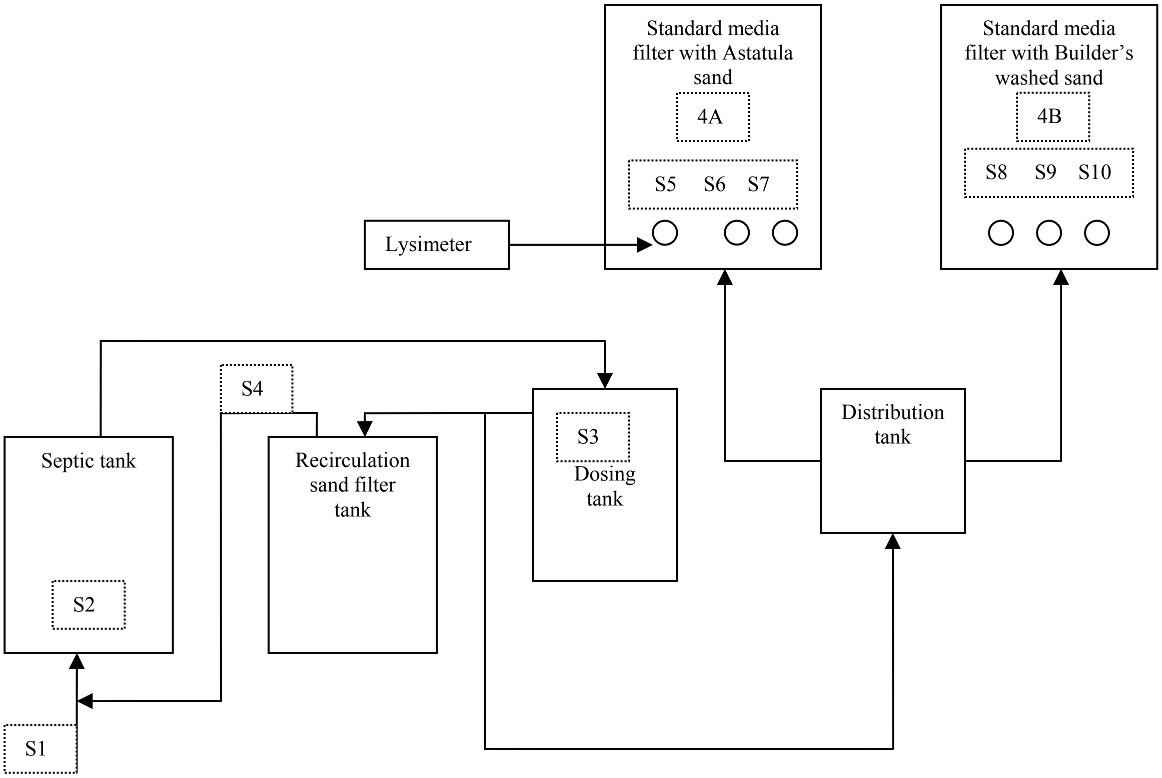
$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10OH^- \tag{7}$$

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, little has been known about the required size that may sustain both nitrification and denitrification in a RSF and how the performance could be improved by using different sorption media with a smaller size of RSF. Accordingly, the replacement of sand in the recirculation sand filter with sorption media may have value in nutrient reduction. The use of a smaller RSF with only half day HRT filled with coarse sand, fine sand, or sorption media was tested in our study. It became part of the UCF Test Center operation as described below.

The conventional drainfield with washed builder's sand was observed over a one month sampling period without recirculation. The influent and effluent water quality serve as base line numbers for comparing the water quality effectiveness with that of the other OSTDS options.



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



(b): Sampling locations at UCF OSTDS with RSF

Figure 4 Schematic Flow and Sampling Diagrams of the UCF OSTDS with RSF

The start-up procedure before sampling (e.g. time of loading before the first water quality sample) was of sufficient length for the following reasons: 1) to avoid creating turbulence in the pumping station water, 2) to fill up the containers for sampling during and after the sampling event, and 3) to follow the sampling protocol to pick up, measure, and/or store composite samples for delivery. In parallel with this project, a detailed study conducted by the United States Geological Survey (USGS) and Florida State University (FSU) has been geared toward investigating the fate and transport process of pollutants in the vadose zone of drainfield and groundwater (Katz et al., 2010).

Chapter 3 Conventional On-Site Sewage Treatment and Disposal System

3.1 Conventional OSTDS

The conventional OSTDS is defined as one that includes a septic tank followed by a drainfield. At the experimental site, there is an option for the use of a recirculation filter and two drainfields, each with different type of sand. The first drainfield has washed builder's sand as the media, while the second has Astatula sand (A.K.A. Citrus Grove sand). The performance of the OSTDS with respect to water quality improvement is measured over the study period. Also groundwater quality is measured to assess the concentration differences under and near the drainfields to those upstream of the drainfields.

3.2 Conventional drainfield impacts on groundwater quality

There are 16 monitoring wells at the UCF OSTDS site. Eight are used to monitor the groundwater around the perimeter of the test site, whereas the other eight wells concentrate on monitoring the groundwater aquifer at and around the two conventional drainfields. There is no need to monitor the groundwater beneath the B&G Filter and the SUWs because they are lined with impermeable material. In Figure 5 the site groundwater elevations are shown. The groundwater levels are highest in the northeast part of the site and drops toward the west, northwest, and southwest direction. The SUWs are located upstream, the B&G Filter are in the middle, and the two conventional drainfields are downstream (Astatula or citrus grove sand is furthest downstream). The direction of flow at each ground location can be determined from the groundwater elevation contours and knowing that flow is perpendicular to the contours. Additional monitoring wells are also located inside the conventional drainfields. Figures 5- 8 present the groundwater conditions, in which the groundwater nutrient maps were generated based on the average values of three datasets measured between March and April, 2009. The linear spline interpolation method was used to estimate the values between points. All cases had the impact of differing recirculation designs considered.

Figure 6 shows the ammonia-N concentration in the groundwater with high levels of ammonia-N concentration located downstream from the conventional drainfields (slightly higher downstream of the washed builder’s sand). The SUW and B&G Filter should not release any nutrients into the groundwater due to the use of impermeable material to prevent any leakage. Figure 7 shows the nitrate-N concentrations in the groundwater. It was observed that peak values appeared downstream of the Astatula sand drainfield 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 drainfield (most downstream rectangular in Figure 7). Second, the ammonia released from the conventional sand drainfields was converted to nitrate and is transported 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 conventional sand drainfields, it was highly likely that the drainfields released nitrogen into the groundwater. The nitrate-N concentration gradient shown in Figure 7a indicates the source of nitrate-N is from the washed builder’s sand drainfield. Figure 7b confirms that the high level of TN was released from the washed builder’s sand drainfield. Figure 8a shows the soluble reactive phosphorus (SRP) in the groundwater downstream was released from the Astatula sand drainfield. It is unknown which conventional drainfield contributes most of the SRP to the groundwater. Nevertheless, there is a higher concentration of SRP in the groundwater downstream of the conventional drainfields. However, Figure 8b shows the TP concentration that came from both conventional drainfields.

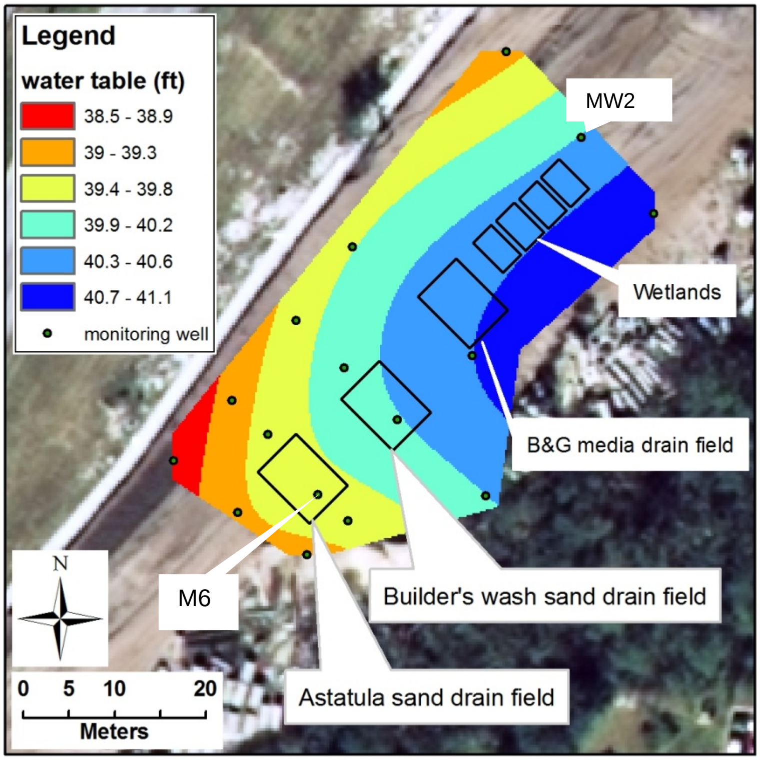


Figure 5 Groundwater Monitoring Wells and Groundwater Elevation

Additional monitoring wells are also located inside the conventional drainfields. Groundwater flows in the southwest direction as indicated with the arrow. A summary to show the groundwater concentrations can be seen in Table 5. A detailed data record of groundwater concentrations monitored throughout the study period is listed in Appendix A. By comparing the two datasets in Table 5, it shows that the groundwater impacts made by the conventional drainfield were evident.

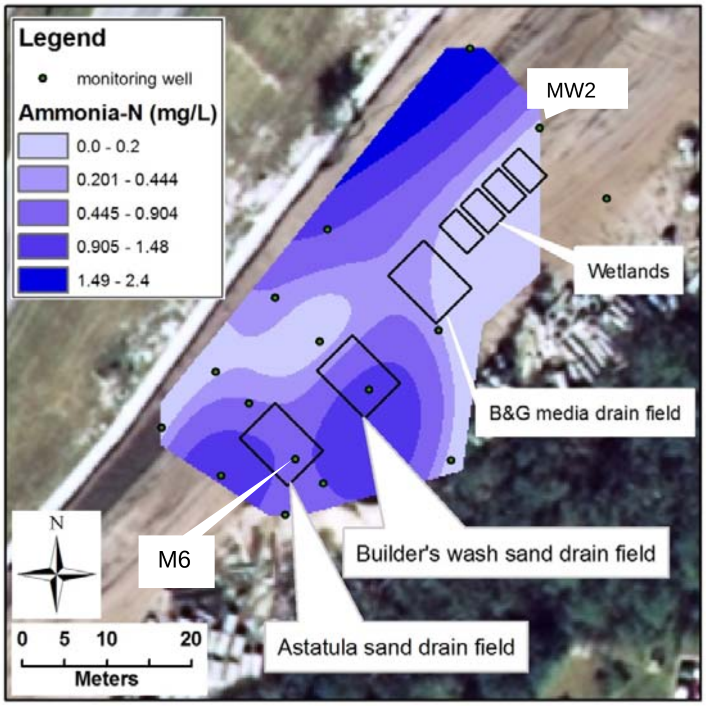
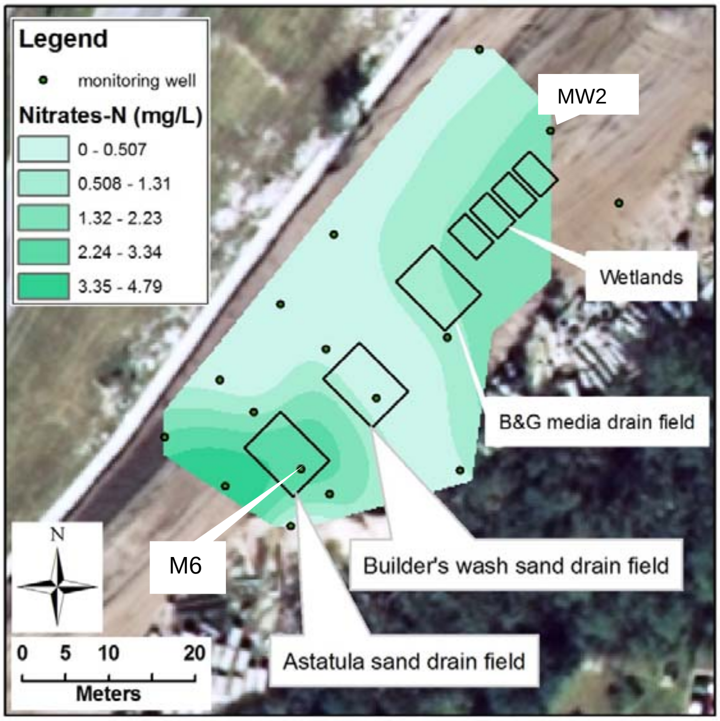


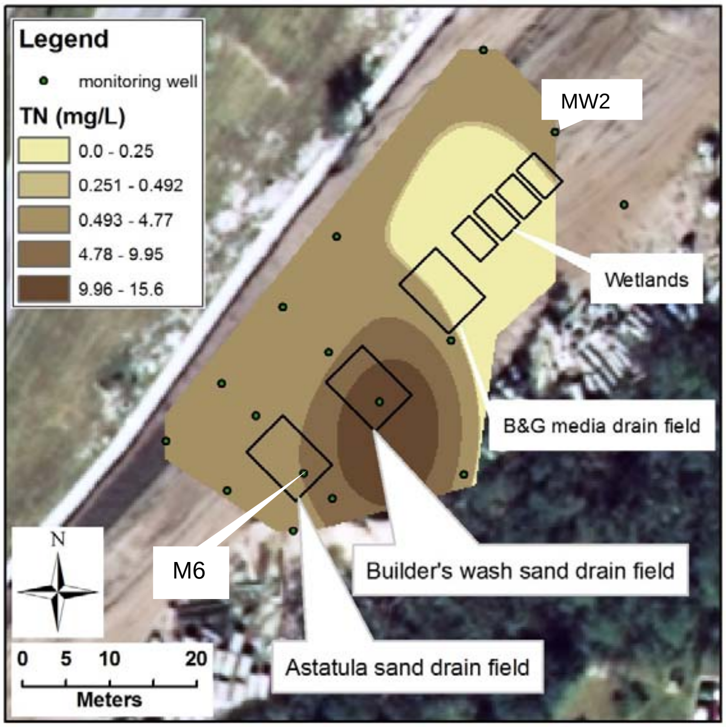
Figure 6 Average Ammonia Concentrations in the Groundwater under UCF Test Site.

Table 5 Summary of the Ground Water Impacts beneath the Traditional Drainfield

	Background Concentration Average of 5 samples at MW2 Between (9/29/09 – 11/18/09)	Beneath the conventional drainfields Average of 5 samples at M6 Between (9/29/09 – 11/18/09)
TN (µg/L)	615	6,616
Nitrate-N (µg/L)	171	781
Ammonia-N (µg/L)	54	2,275
TP (µg/L)	70	611
SRP (µg/L)	41	370

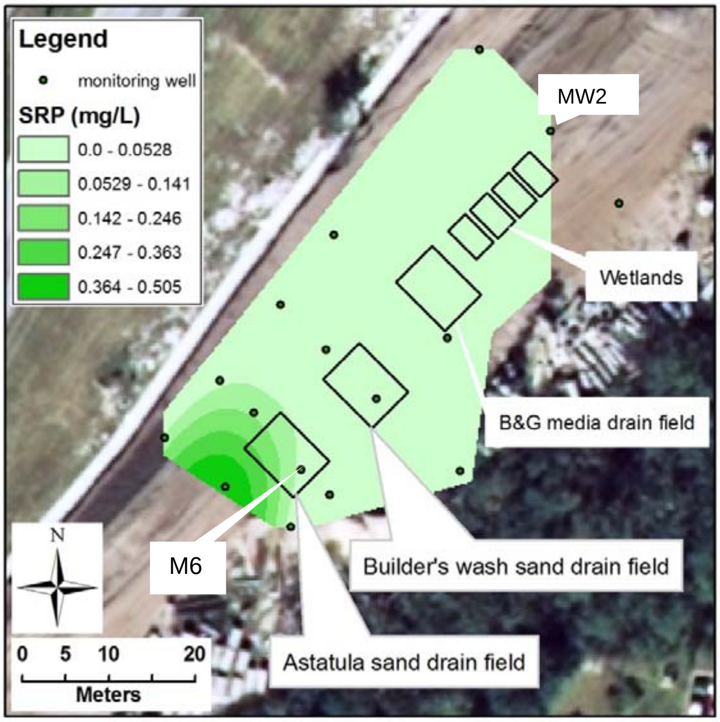


(a) Average Nitrate-N Concentrations

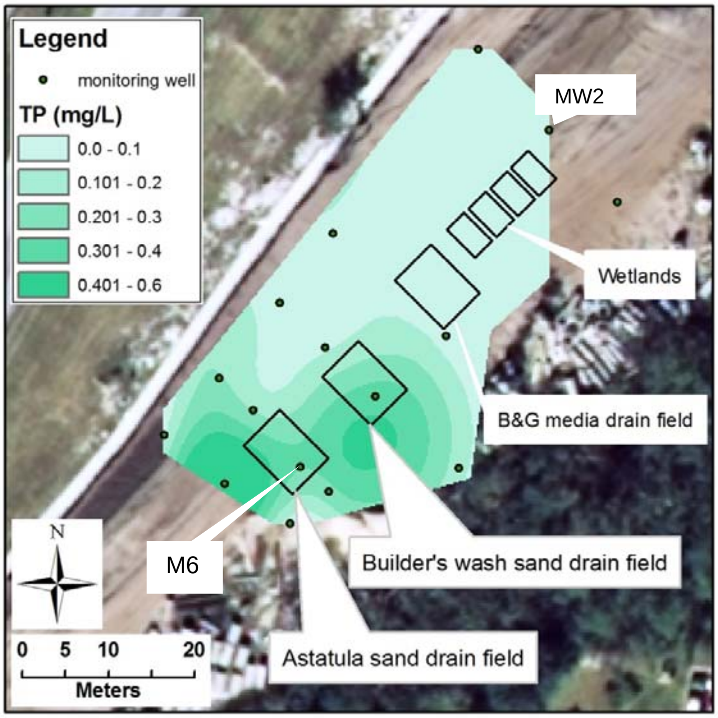


(b) Average Total Nitrogen Concentrations (TN)

Figure 7 Nitrogen-Species Concentrations in the Groundwater Under UCF Test Site.



(a) Average Soluble Reactive Phosphorus (SRP) Concentrations



(b) Average Total Phosphorus (TP) Concentrations

Figure 8 Phosphorus-species Concentrations in the Groundwater Under UCF Test Site.

3.3 Performance of conventional OSTDS with washed builder's sand in the drainfield

Although it was assumed the recirculation sand filter would improve the nutrient removal capability of the conventional OSTDS; operation without recirculation is the more common option among conventional systems. Thus the OSTDS without recirculation was monitored for one month and is called the control case for comparison reasons. The average effluent nutrient concentrations are shown in Figure 9 and TSS, CBOD, Fecal coliforms and E. Coli concentrations in Figure 10. Influent ammonia nitrogen concentration was 40.5 mg/L (40,500 ug/L), and as expected there was a conversion to the nitrate form. However there was no decrease in total nitrogen and also no decrease in total phosphorus concentration. Shown in Figure 11 is the overall removal effectiveness for conventional OSTDS or the control case. Location S10 that is 24 inches beneath the surface of the infiltration sand, shows a slight increase in TN, TP and SRP. All exhibit similar increases. These values will be compared with the performance of the other systems in the next Chapter.

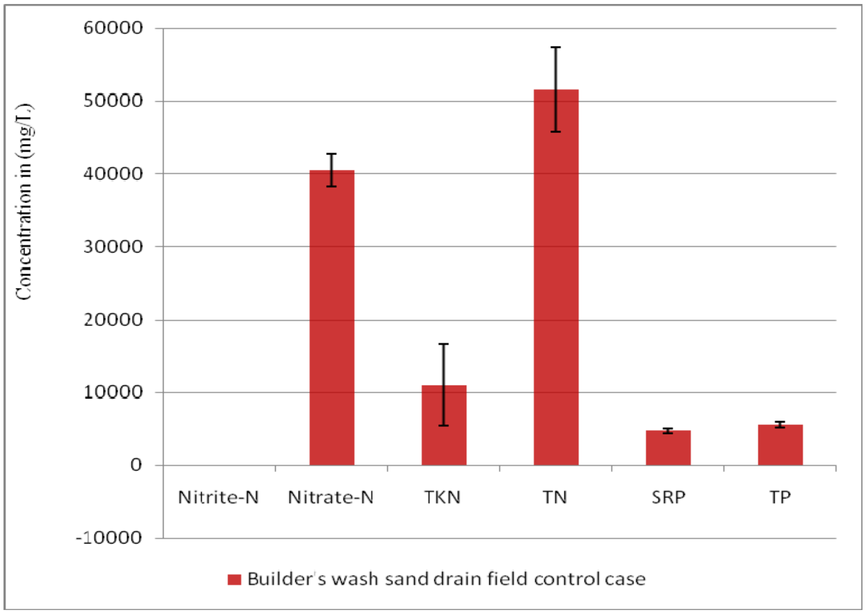


Figure 9 Effluent Nutrient Concentrations for Conventional OSTDS at S10 that Shows High Level of Nitrogen (Control Case)

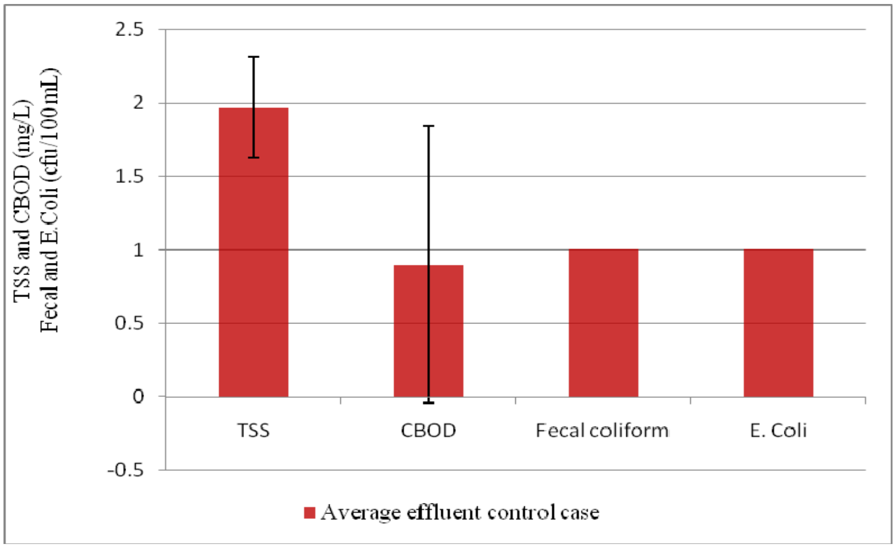


Figure 10 Effluent TSS, CBOD and Coliform Concentrations for Conventional OSTDS at S10 that Shows Low TSS, CBOD$_5$, and Bacteria Levels (Control Case)

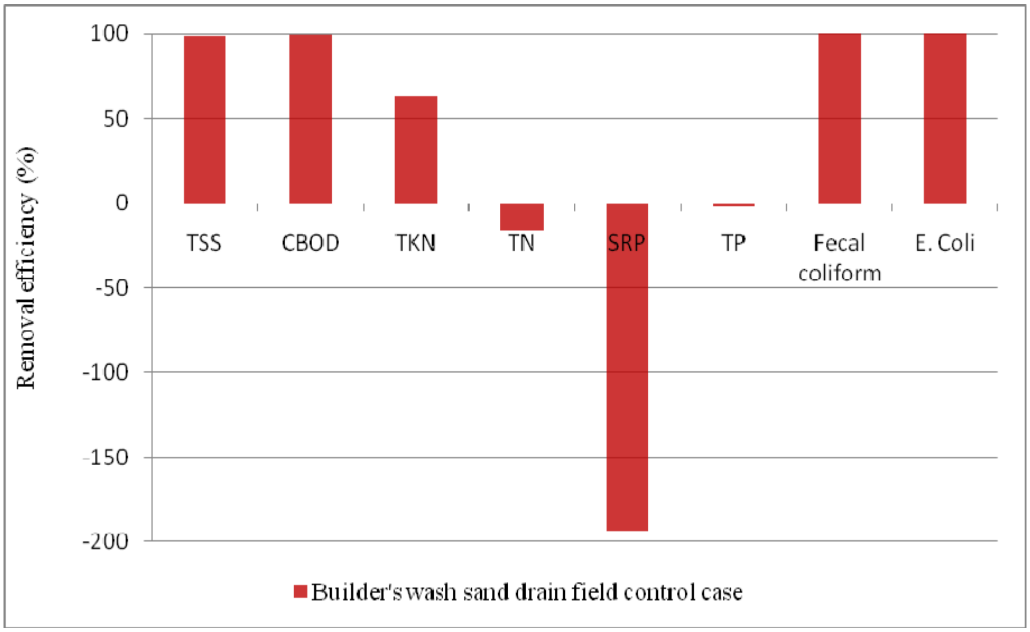


Figure 11 Removal Effectiveness of the Conventional OSTDS at S10 (Control Case)

Chapter 4 Passive On-Site Sewage Treatment and Disposal System with Sorption Media-Based Recirculation Sand Filter

4.1 The system design of recirculation sand filter with sorption media

The system design of recirculation sand filter with sorption media explores the feasibility of using sorption media to replace the traditional 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 between Sep – Oct 2009. The experimental settings of these three designs within a four-week time period are summarized in Table 6.

Table 6 Summary of the Experimental Settings for OSTDS with Recirculation

ID	Date	Number of Dataset	Experimental Settings All Septic Tank-Recirculation-Drainfield
Recirculation Design I	Oct – Nov 2008	3	• 3:1 Return to Forward Recirculation RTF ratio • Astatula sand used as the filtrating media in the recirculation sand filter
Recirculation Design II	Mar – Apr 2009	4	• 3:1 RTF ratio • Very coarse sand media in the recirculation sand filter
Recirculation Design III	Sep – Oct 2009	3	• 3:1 RTF ratio • Green Sorption Media in recirculation sand filter

Design improvements have been made to the recirculation sand filter based on our evaluation of the three different media used inside it and their resulting differences in performance. Replacement of sand with green sorption media together with a unique hydraulic design in the recirculation sand filter eventually improves the overall system performance. The basic design (Recirculation Design I) started out with a recirculation sand filter filled with Astatula sand. However, the major goal in Recirculation Design I is to measure the removal efficiency of two types of sand, including Astatula sand and washed builder's sand, associated with these two conventional drainfields 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 sand filter. The initial run caused clogging in the Astatula sand, increasing the HRT in the recirculation sand filter and sometimes made it overflow. With this experience, Recirculation Design II in the second set of tests used very coarse 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 Design 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. The cross-sectional area of the recirculation sand filter is 50 sq.ft. There was an overflow weir at the outlet of the recirculation sand filter 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 12 shows the novel design of this recirculation sand filter with green sorption media and coarse sand. In principle, the coarse sand would allow more 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 in a drainfield or in a media filter.

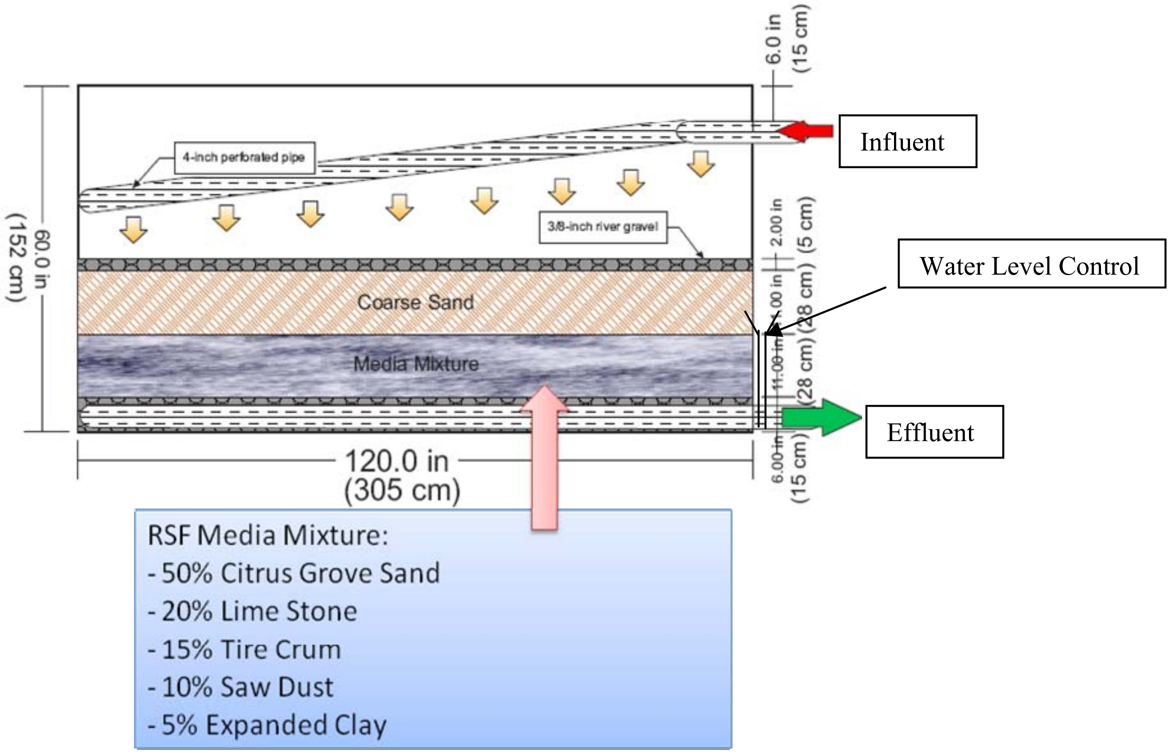


Figure 12 Schematic and Design of Green Sorption Media inside the Recirculation Filter Tank

4.2 Performance of OSTDS with recirculation sand filter and Citrus sand (Recirculation Design I)

In this option, the recirculation sand filter was filled with Astatula sand. The Design I showed average nitrogen and phosphorus removal at about 50 %. 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 complete. TSS, $CBOD_5$, and bacteria removals were excellent. Figure 13 presents the overall removal efficiencies of the passive OSTDS Recirculation Design I while the sampling locations are identified in Table 7. Figures 14 and 15 summarize the differences in effluent concentrations of Recirculation Design I (Astatula sand drainfield) and Recirculation Design II (Washed Builder's sand drainfield). Note these removals are calculated 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 7 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 filtering sand (S7)
Conventional DF with Wash Builder's sand	Inlet of septic tank (S1)	At 24 inches below filtering sand (S10)
Septic tank with B&G Filter	Inlet of septic tank (S1)	At the outlet of the B&G Filter
Septic tank with SUW 1	Inlet of septic tank (S1)	At the outlet of the SUW 1
Septic tank with SUW 2	Inlet of septic tank (S1)	At the outlet of the SUW 2
Septic tank with SUW 3	Inlet of septic tank (S1)	At the outlet of the SUW 3
Septic tank with Control Wetland	Inlet of septic tank (S1)	At the outlet of the control wetland

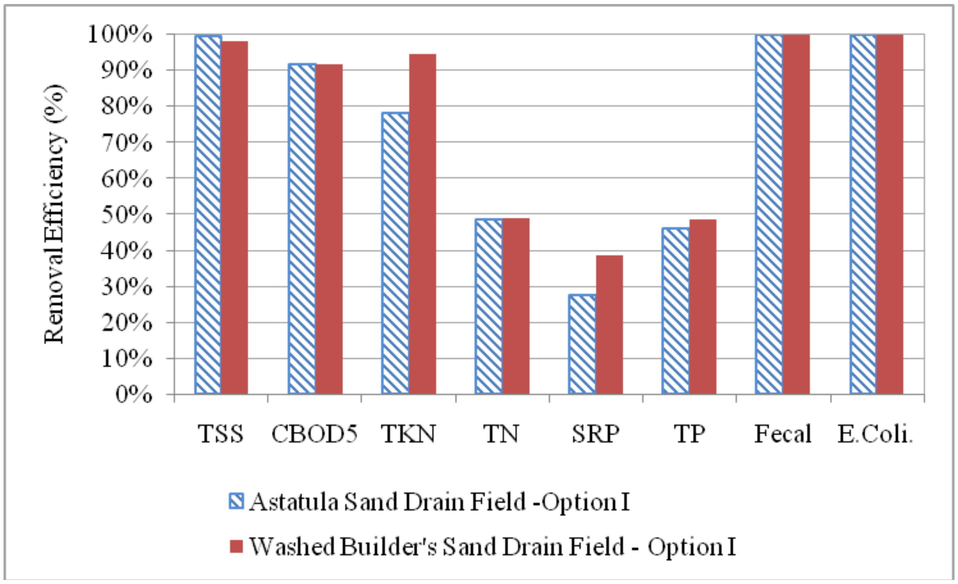


Figure 13 Removal efficiency of the OSTDS Recirculation Design I with Astatula Sand in the Recirculation Sand Filter and Comparisons of Two Drainfield Systems. The Hatched Bars Represent the OSTDS with Astatula Sand Drainfield. The Solid Bars Represent the OSTDS with Washed Builder's Sand Drainfield

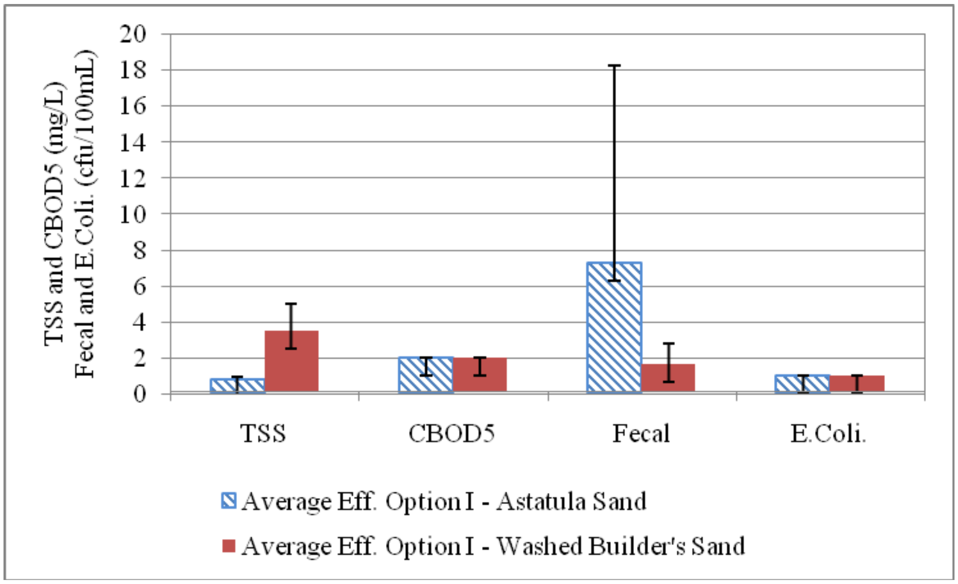


Figure 14 OSTDS Effluent Concentrations of Recirculation Design I at S7 in Astatula Sand Drainfield and S10 in Washed Builder's Sand Drainfield Showing Low TSS, $CBOD_5$, and Bacteria Levels

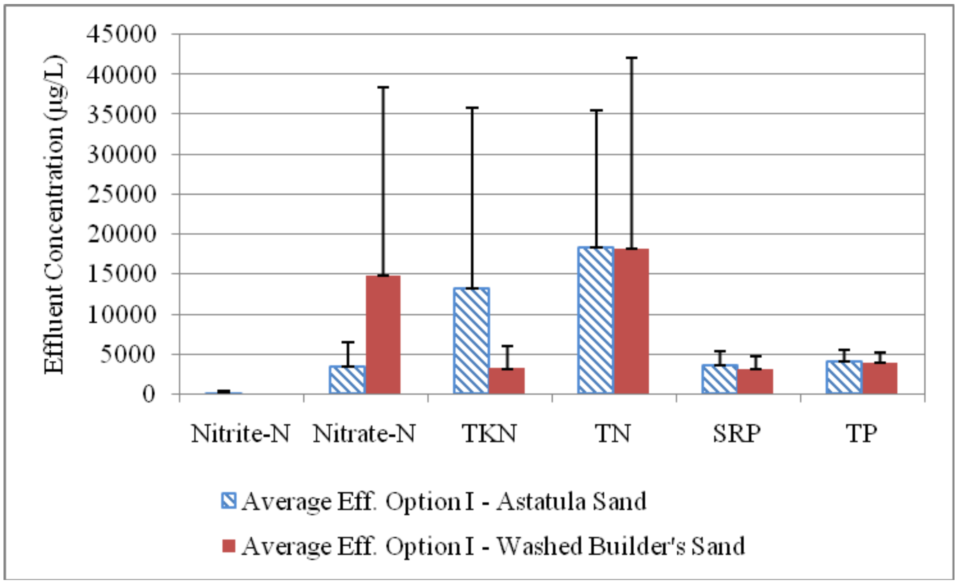


Figure 15 OSTDS Effluent Concentrations of Nitrogen and Phosphorus in Recirculation Design I at S7 in Astatula Sand Drainfield and S10 in Washed Builder's Sand Drainfield

4.3 Performance of passive OSTDS with recirculation and filter and coarse sand (Recirculation Design II)

In Recirculation Design II the media in the recirculation sand filter was replaced with very coarse sand to reduce the clogging experienced in Recirculation Design I. Removal efficiency of total nitrogen in Recirculation Design II was similar to that in Recirculation Design 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 both designs. Soluble Reactive Phosphorus (SRP) removal was negative or phosphorus may be resident in the very coarse sand. Figure 16 shows the overall removal efficiencies of the OSTDS and recirculation sand filter with coarse sand. For TN and TP, the system achieved moderate TN removal, and meager TP removal. Bacteria removal however was excellent. Figures 17 and 18 collectively present the effluent concentrations for TSS, CBOD5, bacteria and nutrients, respectively. Again they were measured at S7 in the Astatula sand drainfield and at S10 in the Washed Builder's sand drainfield.

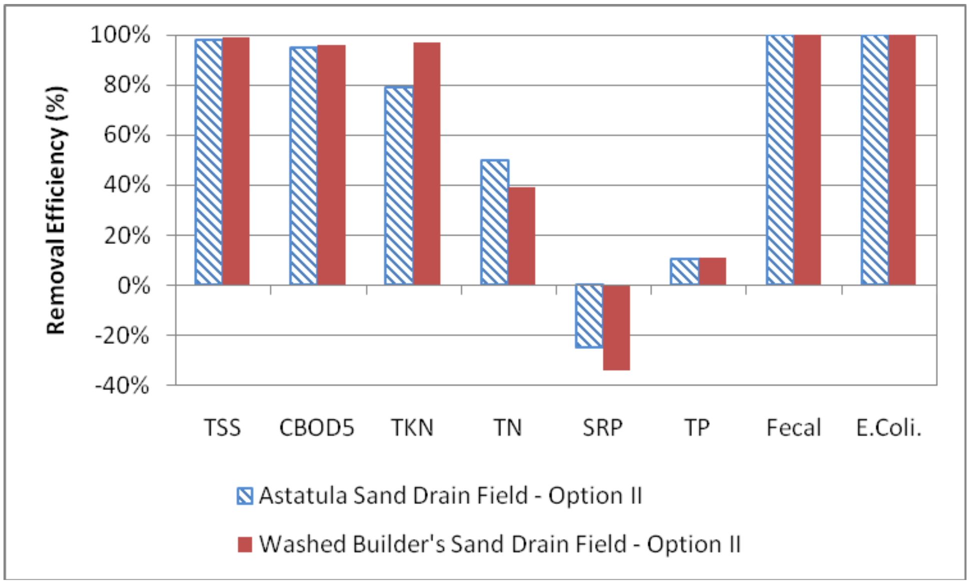


Figure 16 Overall Removal Efficiency of the OSTDS Recirculation Design II with Very Coarse Sand in the Recirculation Sand Filter Showing Comparisons of Two Drainfield Systems. The Hatched Bars Represent the OSTDS with Astatula Sand Drainfield and the Solid Bars Represent the OSTDS with Washed Builder's Sand in the Drainfield

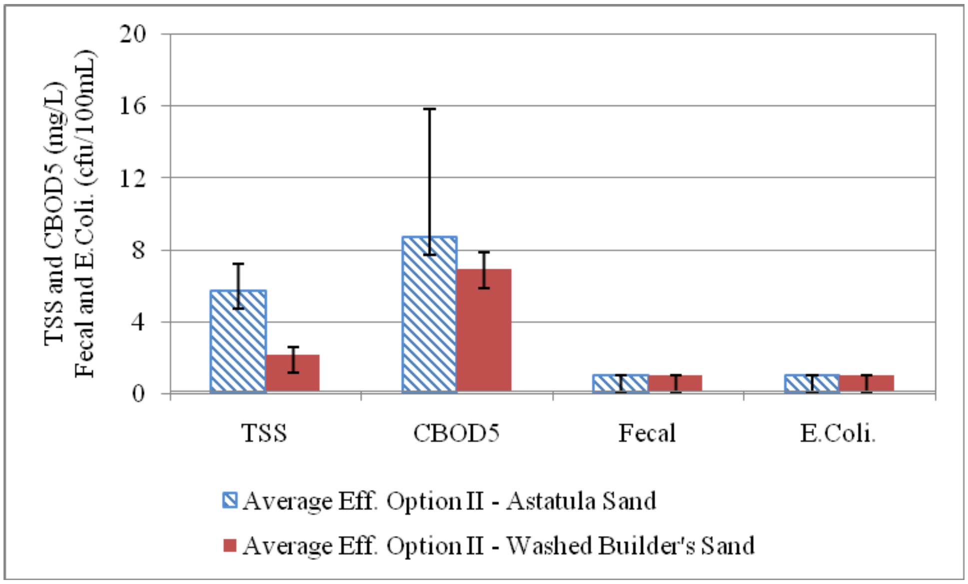


Figure 17 OSTDS Effluent Concentrations of Recirculation Design II Showing Low TSS, $CBOD_5$, and Bacteria Levels

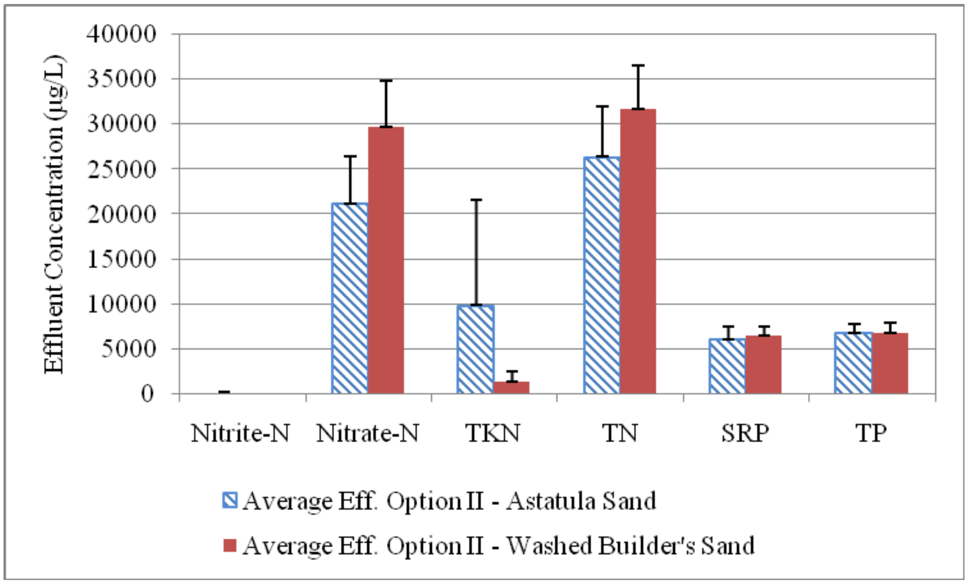


Figure 18 OSTDS Effluent Nitrogen and Phosphorus Concentrations of Recirculation Design II

4.4 Performance of OSTDS with recirculation sand filter and coarse sand and green media blend (Recirculation Design III)

Recirculation Design III with the recirculation sand filter 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 designed to improve denitrification process. Figure 12 indicates the media layers in the recirculation sand filter of this Recirculation Design III.

Figure 19 presents the overall removal efficiencies of the OSTDS Recirculation Design III. TSS and $CBOD_5$ removal efficiencies were better than the earlier designs. Figures 20 and 21 show the effluent concentrations at S10 for conventional and nutrient measurements respectively. TKN conversion was about equal to the other design recirculation options. It can be seen that phosphorus removal efficiency in this Design was similar to that in Recirculation Design II. However, the nitrogen removal efficiency in Recirculation Design III was not as good as in the two earlier designs. Further observational evidence may be gained in Figure 22. It shows only nitrification process was observed in the system, but the denitrification process was missing. This is why good TKN removal efficiency was observed while TN removal efficiency was poor. Also, SRP is most likely in the recirculation filter media. There was a relatively short retention time (less than a half hour) in the recirculation sand filter. The finding herein confirms that without sufficient hydraulic retention time, green sorption media may not be able to perform well as expected.

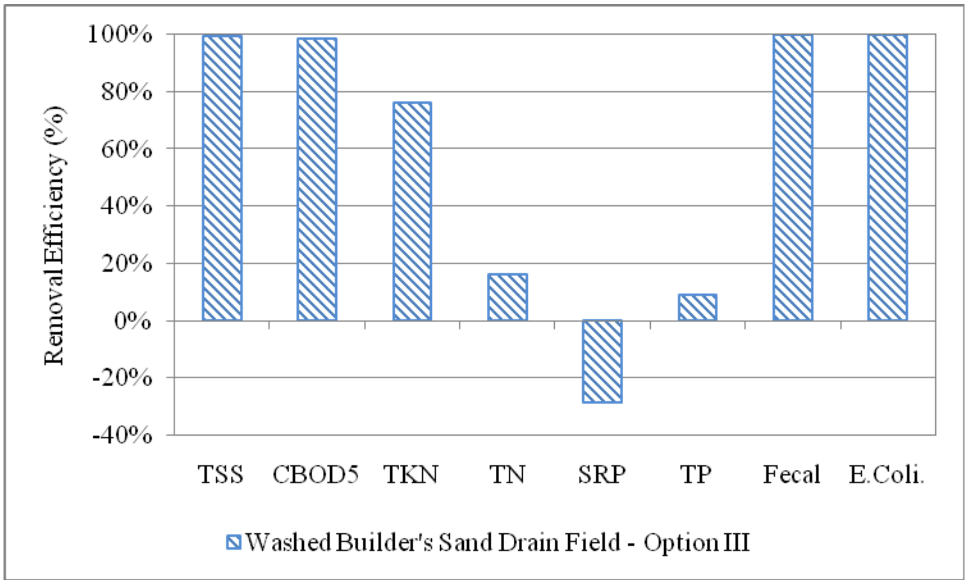


Figure 19 Overall Removal Efficiencies of the OSTDS Recirculation Design III with Sorption Media in the Recirculation Sand Filter with the Washed Builder's Sand Drainfield

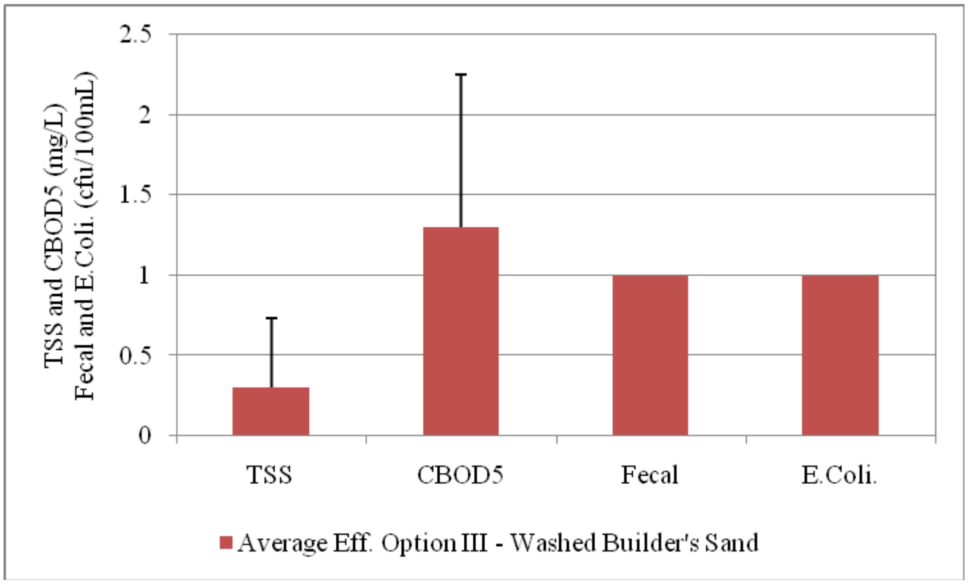


Figure 20 OSTDS Effluent Concentrations of Recirculation Design III at S10 Shows Low TSS, $CBOD_5$, and Bacteria Levels

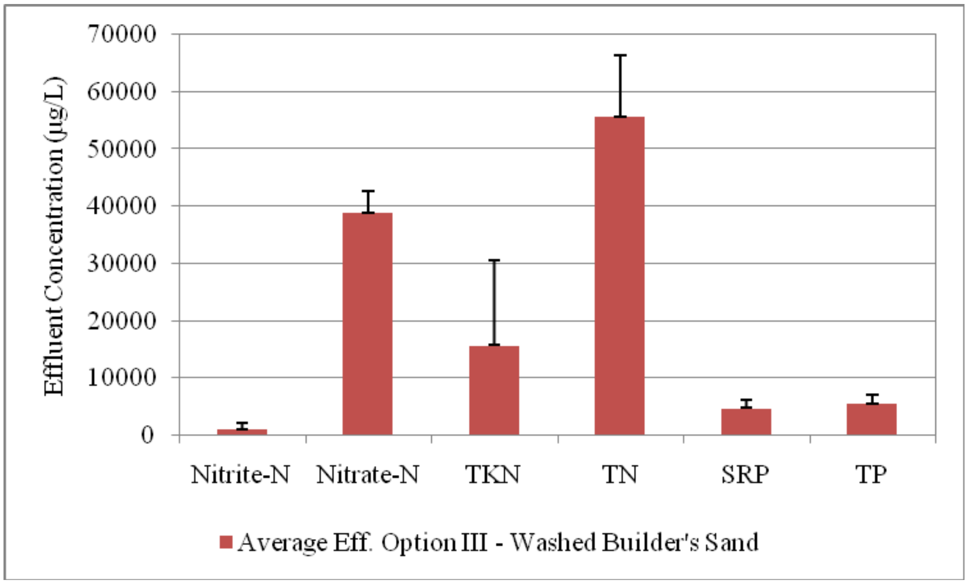


Figure 21 OSTDS Effluent Concentrations of Recirculation Design III at S10 Showing High Level of Nitrogen

To further view the systematic trend, Figure 22 shows traces of nitrogen species and alkalinity at various sampling locations from the beginning to the end of the Recirculation Design I OSTDS process, where S1 is the starting point (raw wastewater) and S12 is the ending point (8-foot below the washed builder's sand drainfield). Such a single-day event may clearly reveal the mechanisms as explained. The average values do not clearly reflect changes. It strongly suggests that most of the nitrification happened between S4 (outlet of the recirculation sand filter) and S8 (inlet of the drainfield), 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 drainfield) that most of the total nitrogen was in nitrate form. This condition supports that the nitrification process was obvious while the denitrification process was almost nonexistent in the recirculation sand filter. This evidence agrees with the spike of nitrate in the groundwater as shown in Figure 7. Overall, traditional drainfield did not provide obvious assimilative capacity to diminish the nutrient as evidenced by these measurements at S10 and S12. Recirculation Design I had the best removal efficiencies in terms of nitrogen and phosphorus when compared against Design II and Design III. But the fine sand was clogged easily making the maintenance become an issue. As a consequence, Recirculation

Design III performs relatively better than Recirculation Design II in terms of TN and TP removal efficiencies.

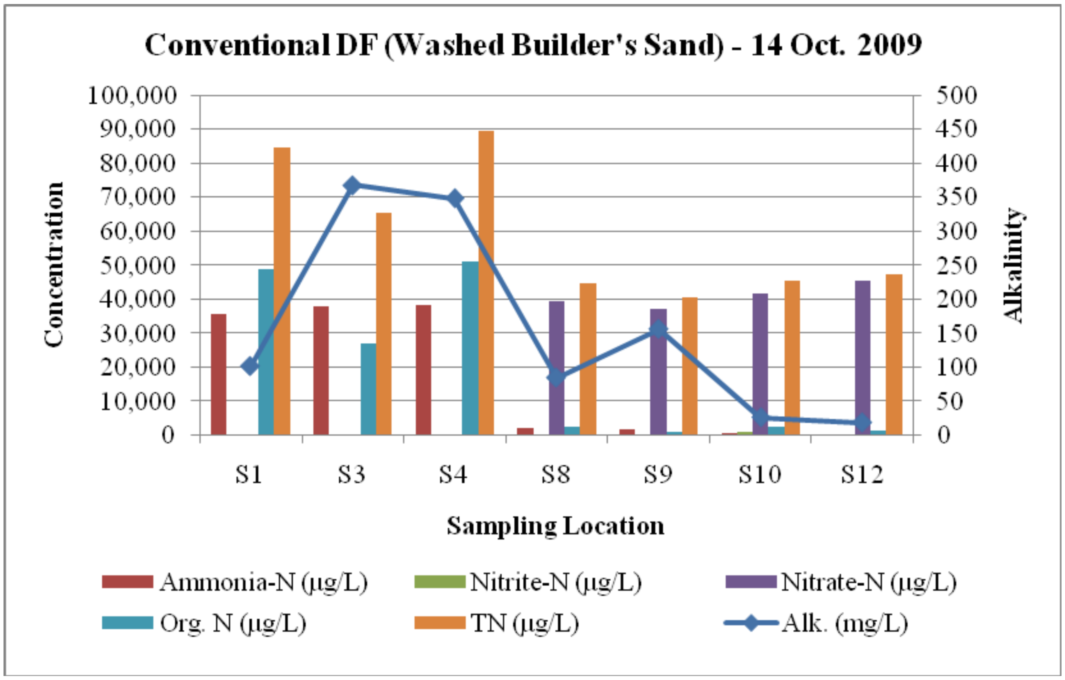


Figure 22 Tracking of Nitrogen Species in the OSTDS with Sorption Media-Based Recirculation Sand Filter

Chapter 5 Passive On-Site Sewage Treatment System with Bold & Gold^{TM} Media Filter

5.1 System design of Bold & Gold^{TM} media filter

The B&G Filter is designed to remove nitrogen by providing an aerobic zone for nitrification and an anaerobic zone for denitrification in series. The ammonification process is able to convert the organic nitrogen to ammonia and nitrification further converts the ammonia to nitrite and nitrate while the denitrification process is the biological reduction process of 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. For the purpose of demonstration, Figure 23 presents a representative result from one sampling date for nitrogen species, dissolved oxygen, and alkalinity in the septic tank and B&G Filter system. It supports expected relationships among the nitrogen species for nitrification and denitrification conditions. Detailed data for other B&G Filter tests can be found in Appendix B.

It was observed that both nitrification and denitrification processes occurred in the B&G Filter. The transition from septic effluents to B&G Filter aerobic zone shows significant reductions of ammonia and alkalinity while nitrate concentrations were increased due to the nitrification process (see Figure 23). The dataset shown in Figure 23 was collected on April 1st, 2009, which was the latest dataset of the experiment on B&G Filter. There was a trend of high organic nitrogen concentrations in septic tank; thus, ammonia concentration increased when the wastewater traveled through the B&G Filter (see Figure 23). The baffles did smooth out horizontal flows triggering the right flow patterns. 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 Filter 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. There are two ways for improvements. One is to install oxygenators to induce more air into the aerobic zone. The other is to add some limestone powder in aerobic zone to sustain high alkalinity. Both were implemented in this study and reported later in this report.

Denitrification process was observed in the anaerobic zone where nitrate concentrations were reduced considerably (see Figure 23). The fact that nitrate almost completely disappeared in the anoxic zone, but then reappeared at the B&G Filter effluent reveals that a secondary nitrification occurred again between the anoxic zone and the B&G Filter effluent point. In this project, we redirect all effluents back to a sewer line. This does not mean that it is necessary for all future applications. 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 dissolved oxygen in aerobic zone and effluent nitrate concentration was found. Obviously, the higher the DO in B&G Filter aerobic zone, the lower the nitrate-N concentration in the effluent (see Figure 24).

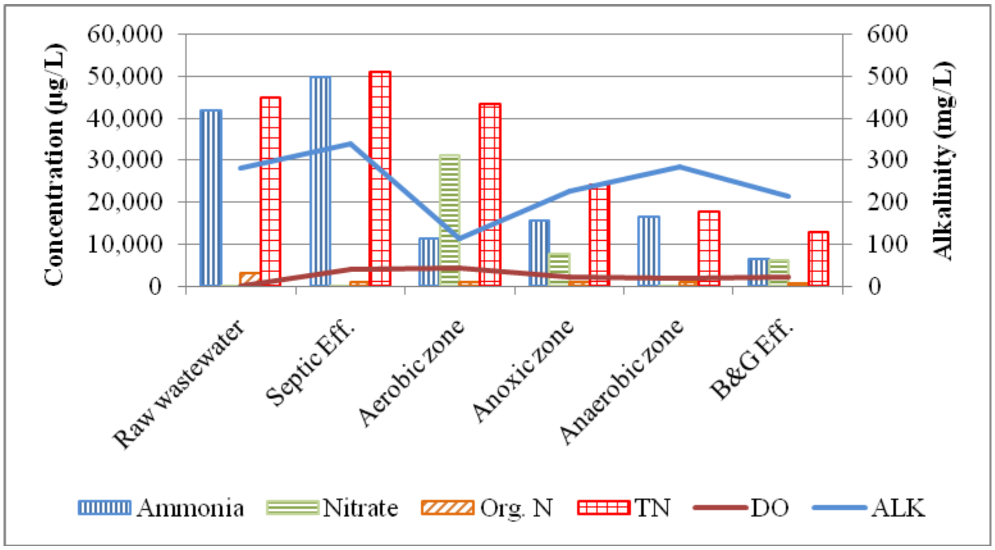


Figure 23 Tracking of Nitrogen Species in the B&G Filter Shows Nitrification Process in Aerobic Layer, and Denitrification Process in the Anaerobic Layer

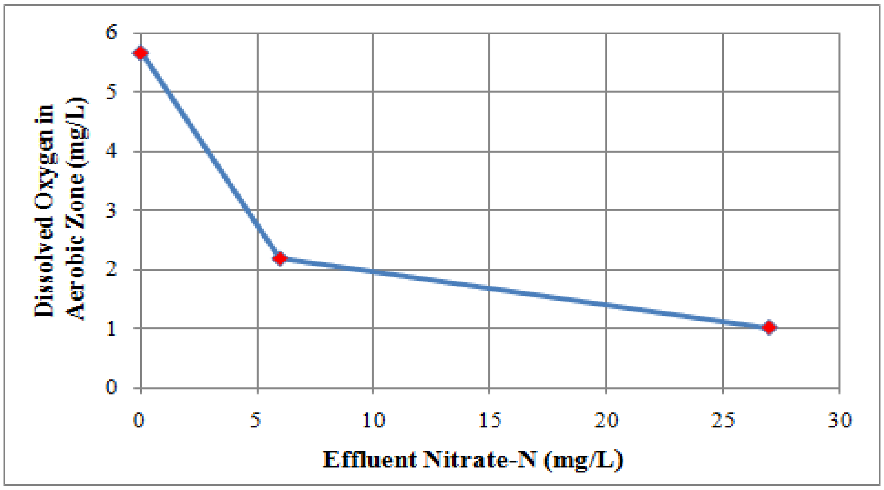


Figure 24 Relationship between Influent DO and Effluent Nitrate-N

5.2 *B&G Filter removal efficiency*

The B&G Filter 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 25 summarizes the removal efficiencies between the inlet of septic tank and the outlet of B&G Filter 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. One way to add alkalinity would be to add limestone to the front end of the B&G Filter.

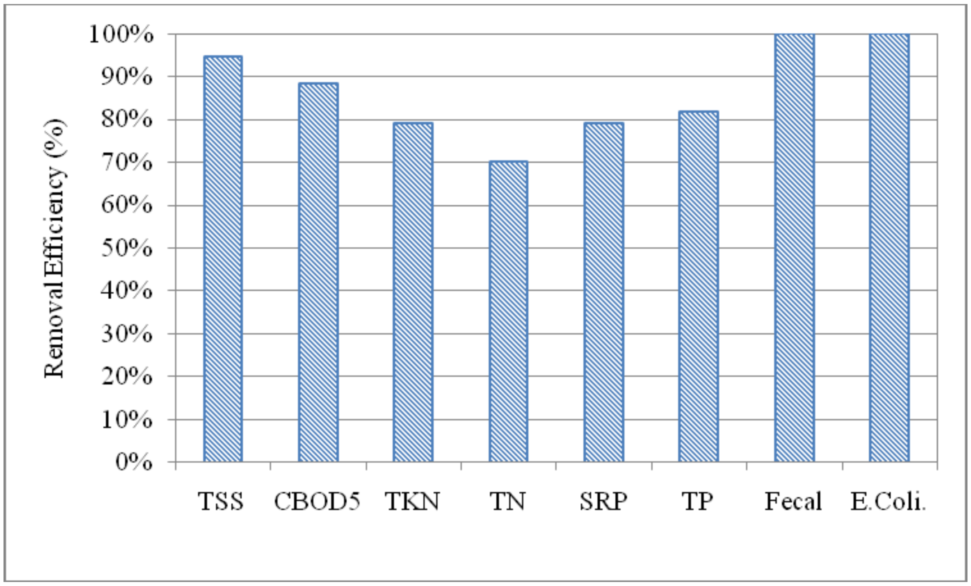


Figure 25 Overall Septic Tank and B&G Filter Removal Efficiency

5.3 B&G Filter effluent concentrations

It is also important to examine concentrations of the effluent leaving the B&G Filter. Average TSS and $CBOD_5$ concentrations were less than 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. Phosphorus concentration in effluent was very low. The median bacteria concentration in the B&G Filter effluent was about 5 cfu /100 mL. Figures 26-29 collectively present the results. Table 8 summarizes median, minimal, and maximal values of water quality parameters in the effluent of the B&G Filter.

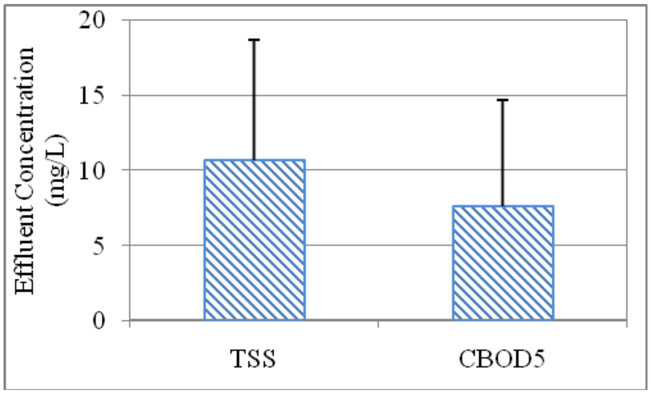


Figure 26 Effluent TSS and $CBOD_5$ of B&G Filter

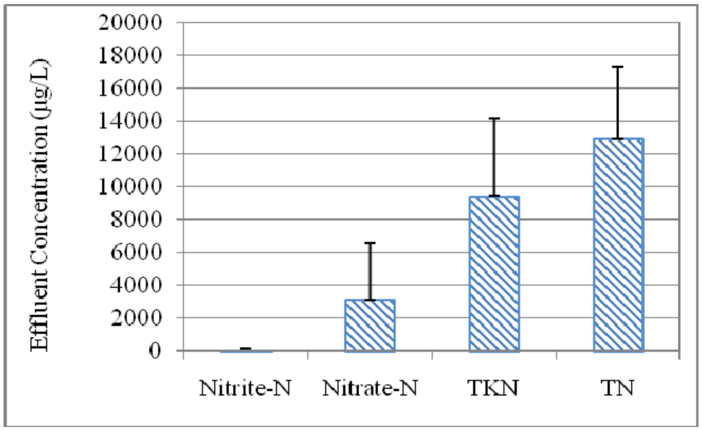


Figure 27 Effluent Nitrogen of B&G Filter

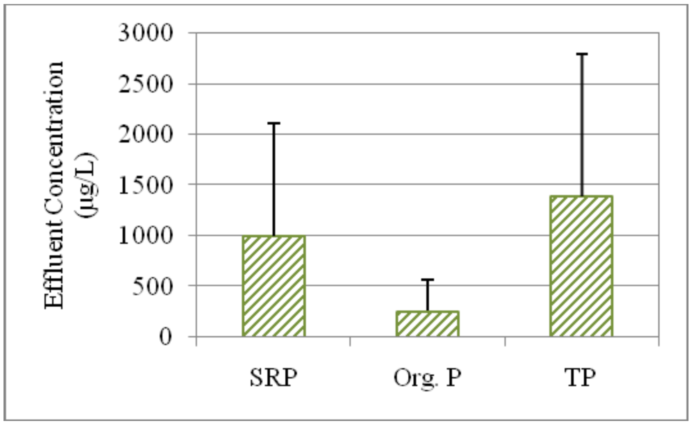


Figure 28 Effluent Phosphorus of B&G Filter

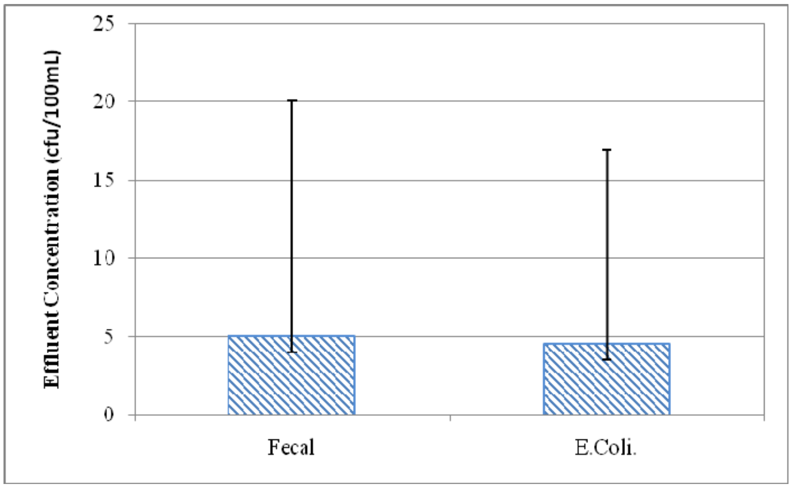


Figure 29 Effluent Bacteria of B&G Filter

Table 8 Summary of Mean, Median, Minimum and Maximum Values of Water Quality Parameters in the Effluent of the B&G Filter

	Raw Influent (S1) (Oct 08 – Apr 09)	B&G Filter Effluent (B10) Average 6 samples (Oct 08 - Apr 09)			
	Mean (12 samples)	Median	Mean	Min	Max
Alkalinity (mg/L)	298	220.5	221	190	256
TSS (mg/L)	244	10.65	11	1.2	23.3
BOD_5 (mg/L)	259	9	11	4.4	29.7
$CBOD_5$ (mg/L)	141	5.2	8	2	21
Ammonia-N (μg/L)	36689	6439.5	6102	2617	8533
NO_X-N* (μg/L)	423	3065	3198	2	6851
Nitrite-N (μg/L)	75	35.5	52	3	141
Nitrate-N (μg/L)	348	2998	3146	-1	6820
Org. N (μg/L)	13619	760.5	3361	499	16401
TKN (μg/L)	50308	7607.5	9463	6513	19018
TN (μg/L)	48827	13581.5	12902	6520	19020
SRP (μg/L)	4847	824	1004	3	2203
Org. P (μg/L)	2297	153.5	258	0	669
TP (μg/L)	7608	1384	1387	33	2909
Fecal (cfu/100mL)	2286143	5	242	1	1400
E.Coli. (cfu/100mL)	1190786	4.5	241	1	1400

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

Chapter 6 Passive On-Site Sewage Treatment System with Subsurface Upflow Wetland (SUW) and Sorption Media

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

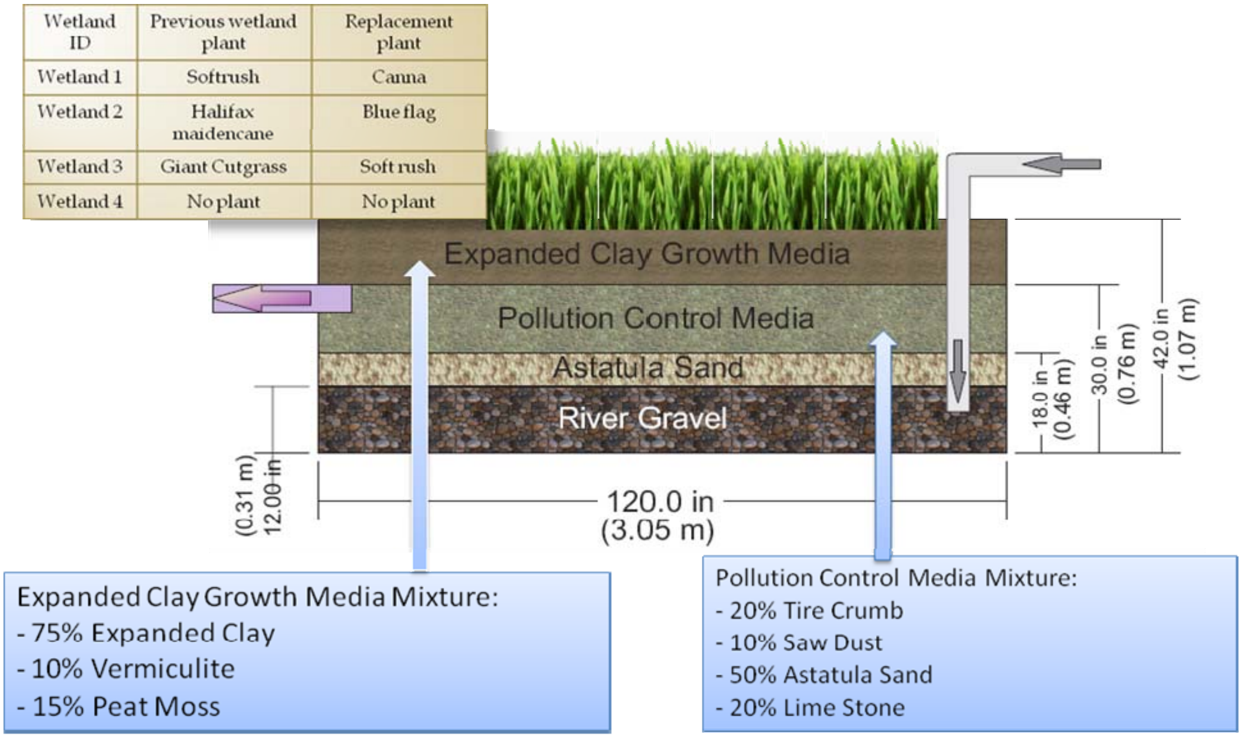
A subsurface upflow wetland (SUW) system receives septic tank effluent and can treat up to 0.75 m^3 (200 gallons) per day with each of the four SUW cells treating 50 gallons per day by design. The septic tank before the SUWs has a size of 1000 gallon per day providing 2-3 days HRT. The septic tank effluent 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 to the surface, 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. No sampling was conducted within 24 hours of a rainfall event. This protocol may or may not have an effect on effluent concentrations. After the first sampling event, we used an impervious membrane to cover the cells to improve the data integrity. 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, 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 30). These were evenly planted (7-8 plants per m^2) in SUW cells 1, 2 and 3, respectively as listed in Table 9. Seedlings of three kinds of plant were purchased from a local nursery and planted two months before the experiment period. Wetland cell 4 is the control without any plant species but it does include the placement of the same layered green sorption media. Based on our previous experience (Xuan et al, 2009), we improved the oxygen supply via the installation of two oxygenators per cell. An additional sand layer also was installed between the gravel and pollution control media to reduce the E-Coli.

There are four parallel 1.52 m wide × 3.05 m long × 1.07 m deep (5 ft wide × 10 ft long × 3.5 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 31. 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 (50% Citrus grove sand, 15% tire crumb, 15% sawdust and 20% lime stone) is used to remove nutrients, TSS, and BOD. The main function of the 15.24 cm (6 in) G media layer (75% Expanded Clay, 10% Vermiculite, and 15% Peat Moss) is to support the root zone and to aid in further nitrogen removal. 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. Sample IDs here were defined for following discussion as below: 1) “port B”: mixture of bottom three samples, 2) “port M”: mixture of middle three samples, 3) “port T1”: top sample at 1/3 length, 4) “port T2”: top sample at 2/3 length, and 5) “port T3”: top sample at 3/3 length.

(a) (b) (c)

Figure 30 Plant Species Selected: (a) Canna; (b) Blue flag; (c) Bulrush

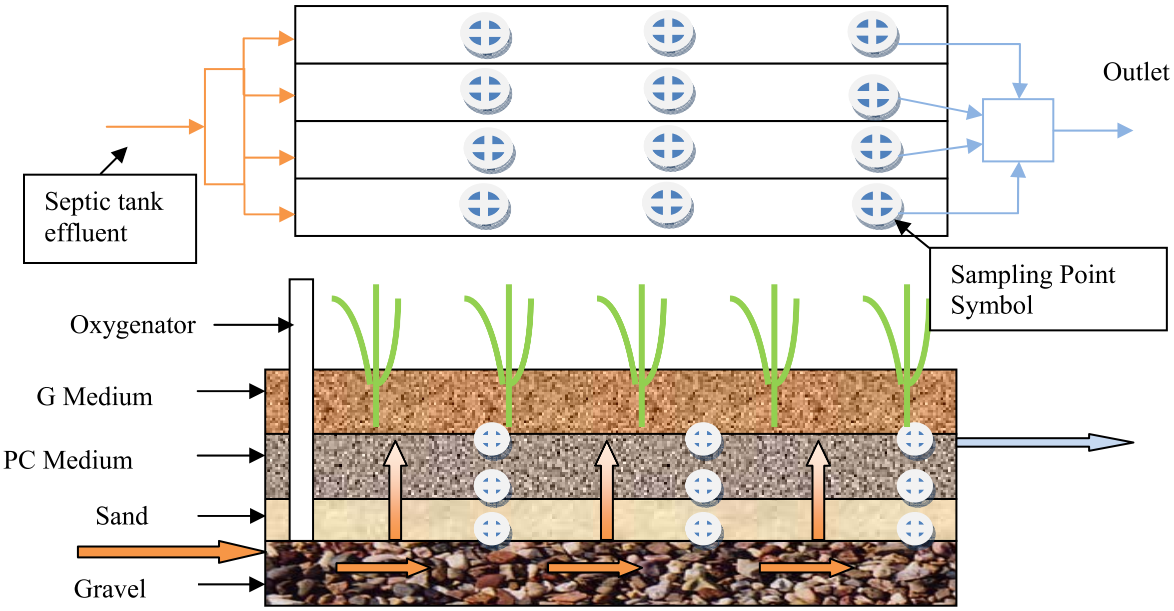


Wetland ID	Previous wetland plant	Replacement plant
Wetland 1	Softrush	Canna
Wetland 2	Halifax maidencane	Blue flag
Wetland 3	Giant Cutgrass	Soft rush
Wetland 4	No plant	No plant

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

(a) Profile View



(b) Sampler deployment

Figure 31 SUW with Green Sorption Media Design

Table 9 Summary of Wetland Plant Species

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

6.2 SUW effluent concentrations

In Figures 32 and 33, 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 within 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 34 and 35 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 10 mg/L of nitrate concentration. Bacteria counts in all SUW effluents were relatively higher than the other OSTDS at the UCF Test Center, even though the removal efficiencies were more than 99.9%. However, it must be understood that once the effluent is released downward into the underground vadose zone, most bacteria would be consumed or filtered out by the soil. Table 10 summarizes the mean, maximal, and minimal values of all water quality parameters.

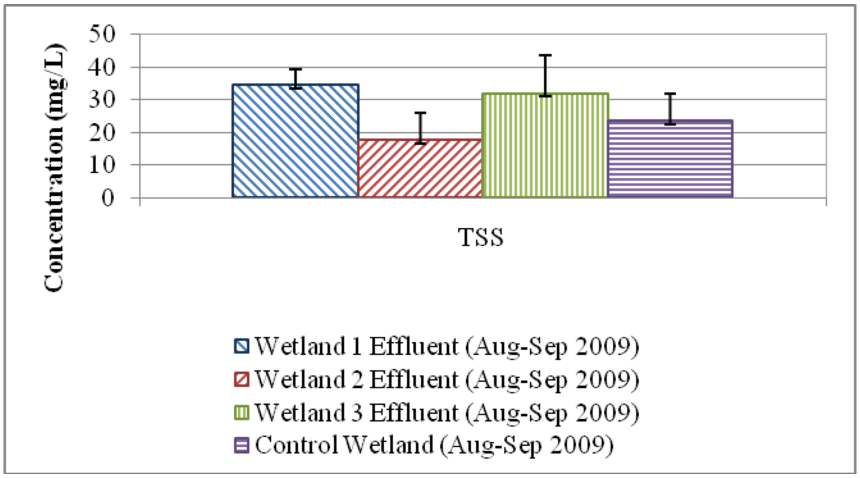


Figure 32 Effluent TSS from SUWs

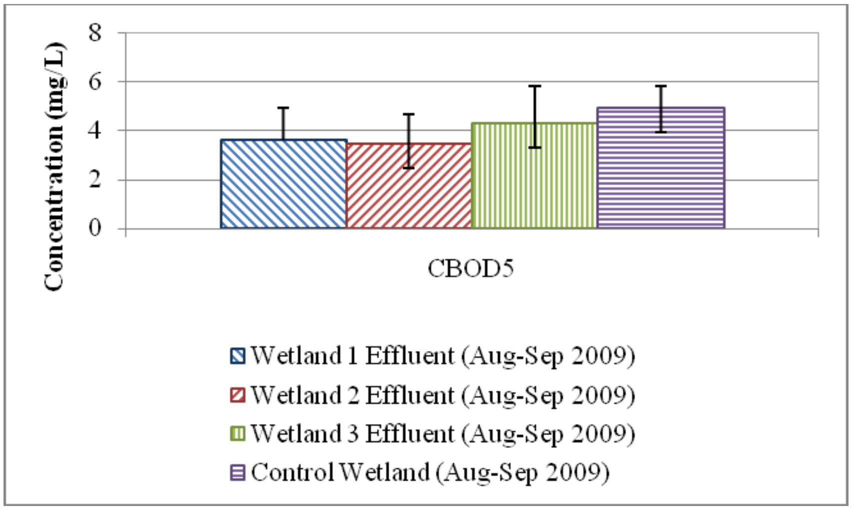


Figure 33 Effluent $CBOD_5$ from SUWs

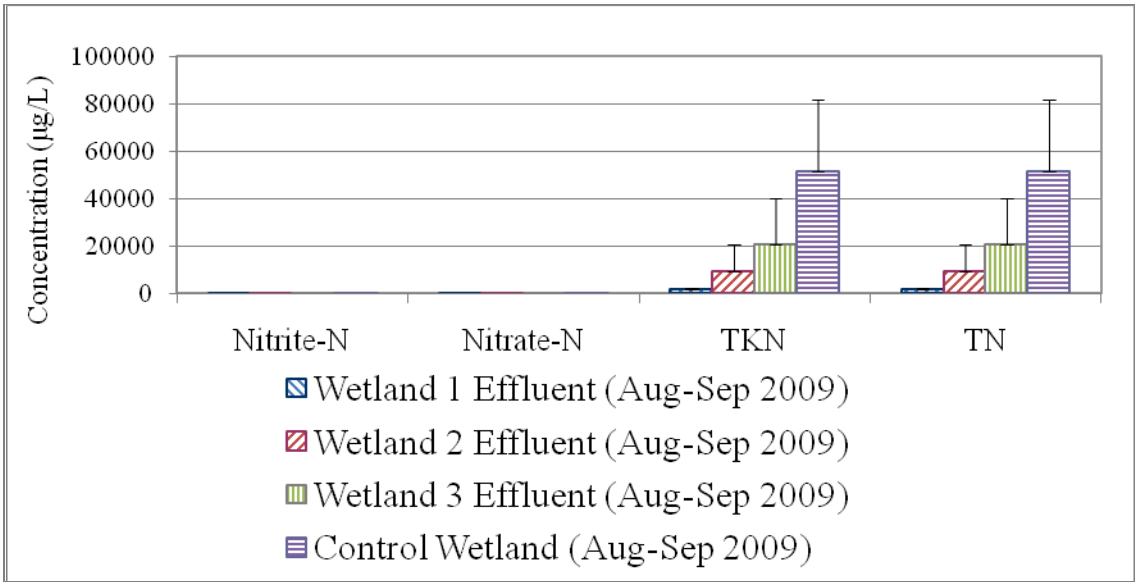


Figure 34 Effluent Nitrogen Concentration from SUWs

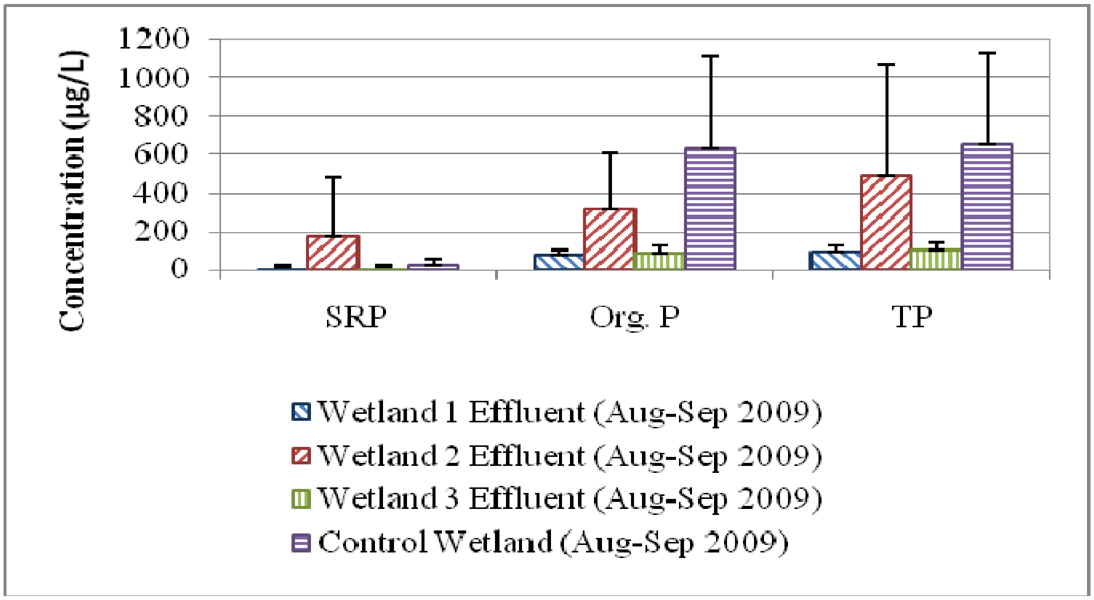


Figure 35 Effluent Phosphorus Concentration from SUWs

Table 10 Summary of Mean, Maximum, and Minimum Values of All Water Quality Parameters
(a) From SUW Canna Wetland Plants (1) and SUW Blue Flag Wetland Plants(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 SUW Bulrush Wetland Plants (3) and SUW No Plants (Control) (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]

6.3 SUW removal efficiency

Figure 36 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 additional fine particles collected in the sample.

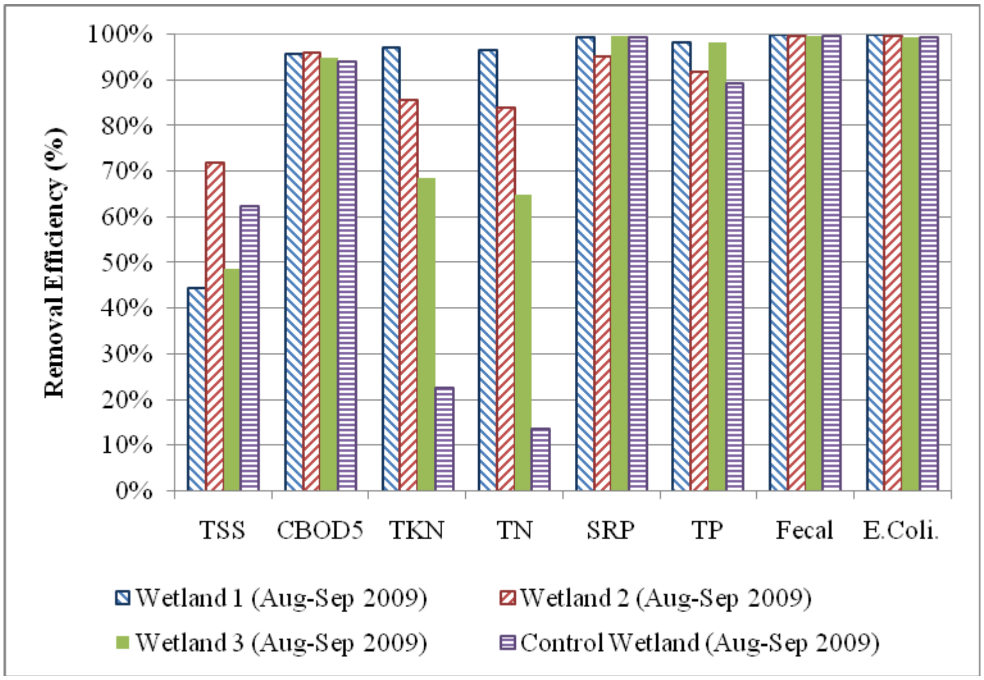


Figure 36 Overall Removal Efficiencies of Septic Tank and SUW

6.4 Cold Weather Stress test

For non cold weather, the nutrients removal ability of the SUW planted with Canna has been documented and reported in the previous section of this report, or results of one month of sampling indicated that it achieved a removal efficiency of 97.1 % and 98.3 % in total nitrogen (TN) and total phosphorus (TP), respectively. Yet Canna is known as a seasonal plant, and it will wither in cold temperatures. Besides, the winter of 2009-2010 was reported as one of the coldest winters since records began (Figure 37). To answer the following two questions: 1) “Can Canna keep functioning without its attractive foliage?” and 2) "What is the nutrient removal efficiency of SUW planted with Canna in cold weather?” Samples collected from the effluent of the Canna SUW were compared with the control cell in the end of February, 2010.

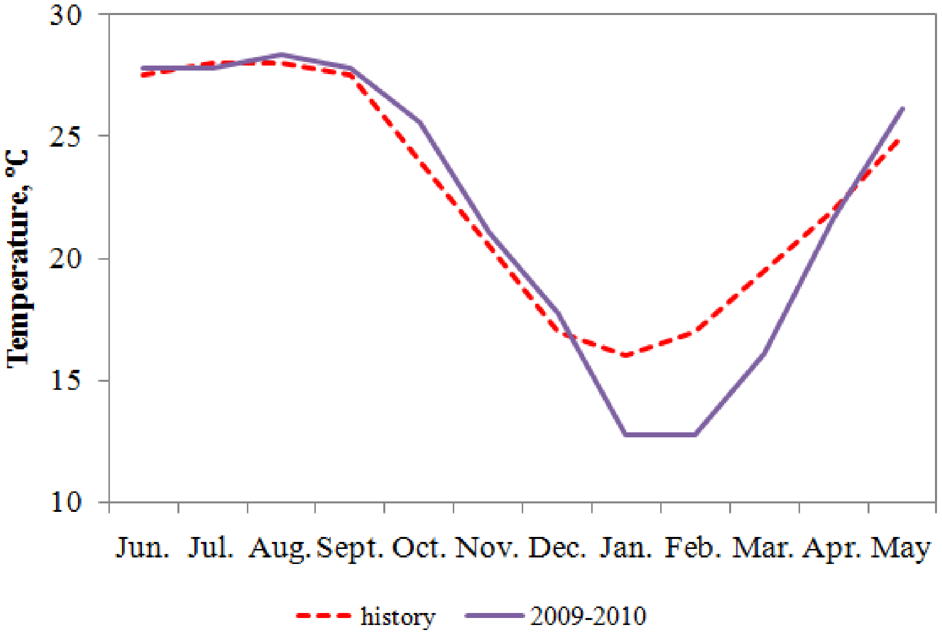


Figure 37 Monthly Average Temperature Comparison in 2009-10 and History in Orlando

Using the concentration data from the cold period of 2009-2010 as recorded in Figure 38, a comparison of the nitrogen removal in the cell with Canna to the control cell shows 87.4% of TN was removed in the Canna cell compared with the 41.0% TN removal in the control cell. The higher nitrate concentration in the control cell effluent shows that the SUW promoted the conversion from organic nitrogen to nitrate through ammonification and nitrification. In contrast, the less than 5 μg/L nitrate concentration in Canna cell effluent illustrated that the root system of Canna still played an important role in the denitrification effect even during the severe weather condition. Since denitrification is an alkalinity producing process, the higher alkalinity in the Canna cell also can be considered as a proof of successful denitrification.

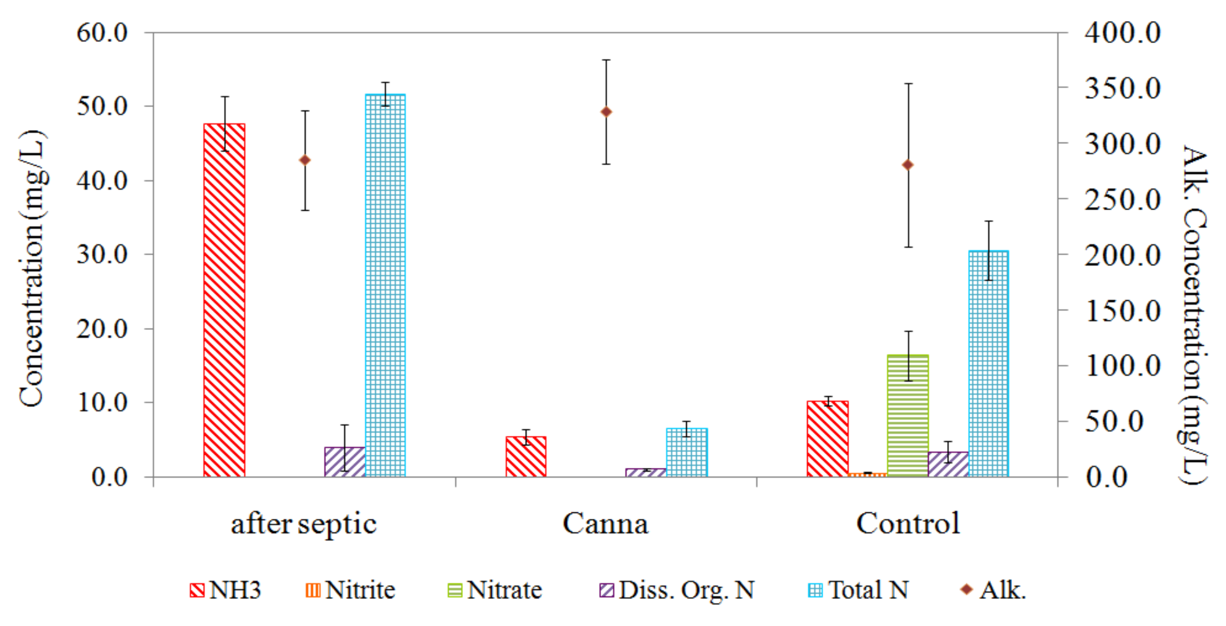


Figure 38 Nitrogen Concentrations in Cold Weather Stress Test

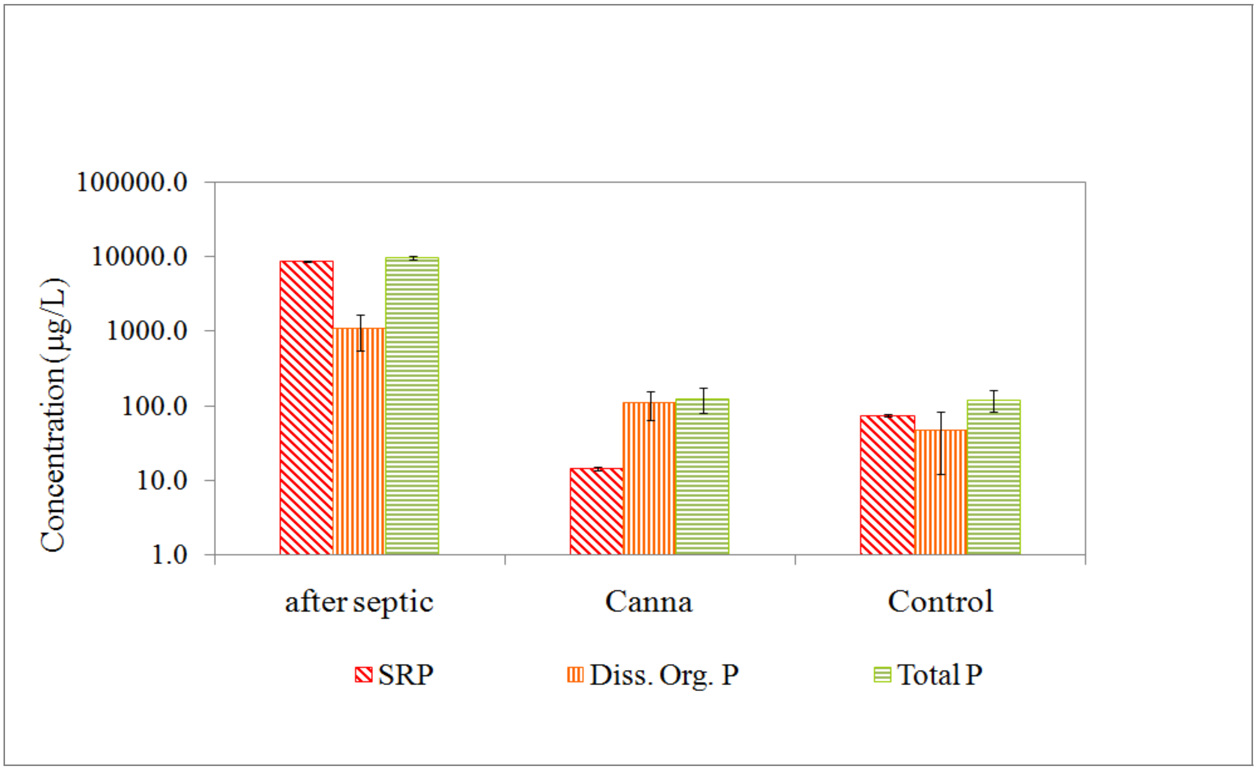


Figure 39 Phosphorus concentrations in Cold Weather Stress Test

Figure 39 shows the difference of phosphorus removal in those two cells. Canna displayed a higher SRP removal efficiency, but a lower removal of organic P. The mean TP removal efficiency of both cells was about 98.7 %. The result verified that the cold weather does not affect the TP removal in SUW. The TN removal efficiency in the Canna cell declined slightly during the cold weather stress test. But it still reached the level of 87.4%, which reveals that Canna would be a highly competitive candidate to be planted in terms of aesthetics and nutrient control all year around.

6.5 Operation Reliability

At least 5 observations were made each week to the experimental site to assess the operation of all the OSTDS being tested. At no time was there any odor reported from the SUW as well as there was no appearance of water ponding on the surface, unless it was forced by closing the discharge valve, as is common when the discharge pipe is checked for flow and clogging. The level of water in the SUW was never reported to go more than two inches above the level of the discharge pipe invert during operation. Nevertheless, the invert of the discharge can be set lower if desirable or the SUW effluent pipes can be set in duplicate to minimize the failure of one of the pipes.

Chapter 7 Performance-based Evaluation of a Conventional OSTDS with Four Passive Nutrient Reducing OSTDSs

7.1 Comparison of removal efficiencies

In this chapter, the average removal efficiencies for the conventional septic tank and washed builder's sand drainfield system is compared to the three passive nutrient removal OSTDSs. These include the passive conventional DF with recirculation designs, the B&G Filter system, and the SUW (with Canna). When recirculation is added to a conventional OSTDS, 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 40 there is negligible differences in the measures of TSS, $CBOD_5$, and bacteria among the six 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 41 shows that the SUW with Canna and B&G Filter had higher removal effectiveness of total nitrogen and phosphorus. All six 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 drainfield designs, even with recirculation, did not perform well in removing total nitrogen. Meanwhile, the soluble phosphorus increased relative to the influent.

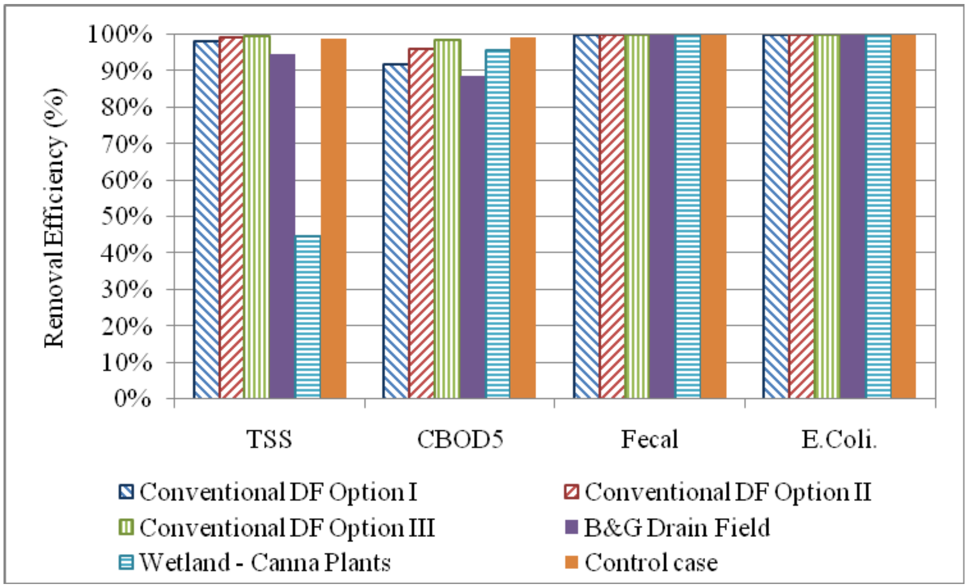


Figure 40 Removal Efficiencies for OSTDSs tested for TSS, $CBOD_5$, and Bacteria

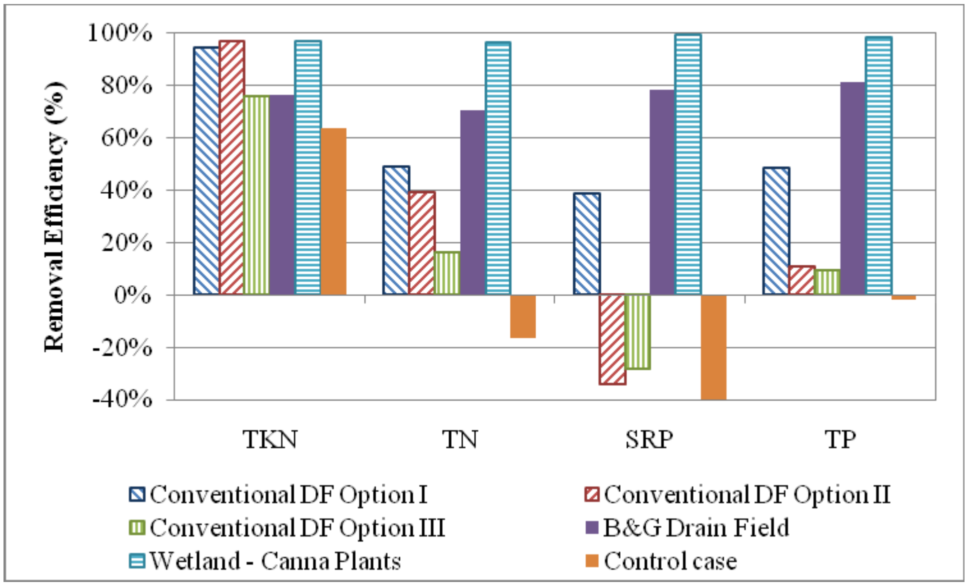


Figure 41 Nutrient Removal Efficiencies for OSTDSs tested for Nitrogen and Phosphorus Species

7.2 Removal rate per unit area of drainfield or media filter area

To evaluate the relative importance of the surface area of the drainfield or media filter area with respect to pollutant removal, we calculated the removal rates per unit area. 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 Filter showed the best total nitrogen unit area removal efficiency as shown in Figure 42. Since there is minimal nitrate in the raw waste, the removal efficiency should not be significant even if no nitrate appears in the effluent. However, if nitrate appears in the effluent (as it does in conventional designs) then a negative removal efficiency can be expected. In regard to the phosphorus removal per unit area, the SUW with Canna plants and the B&G Filter present the best performance (see Figure 43). For TSS unit area removal, the B&G media filter was the best, while for BOD_5, the conventional system with recirculation and the B&G Filter were the best (see Figure 44).

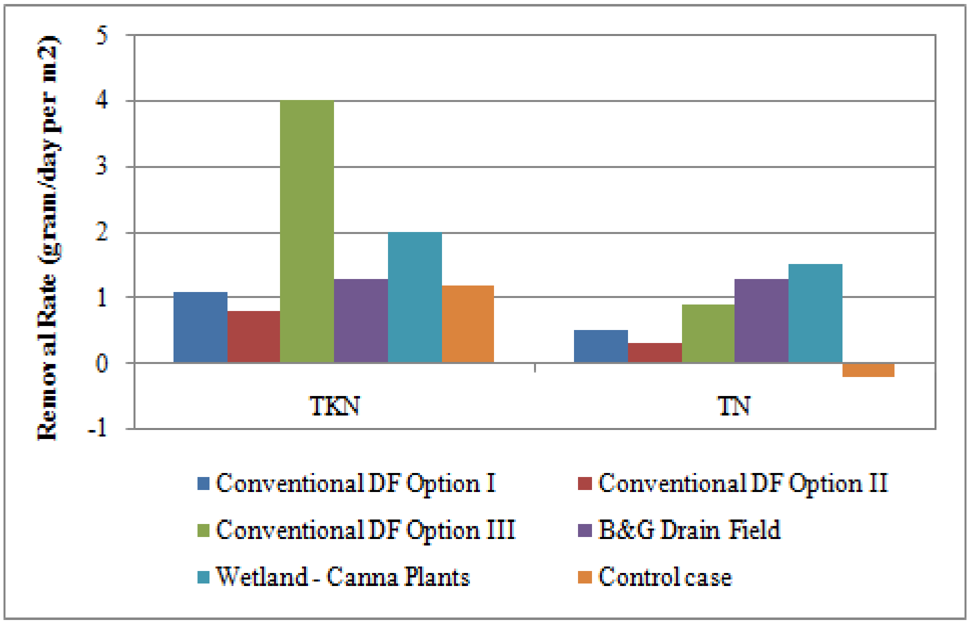


Figure 42 Nitrogen Species Removal Rate per Unit Area

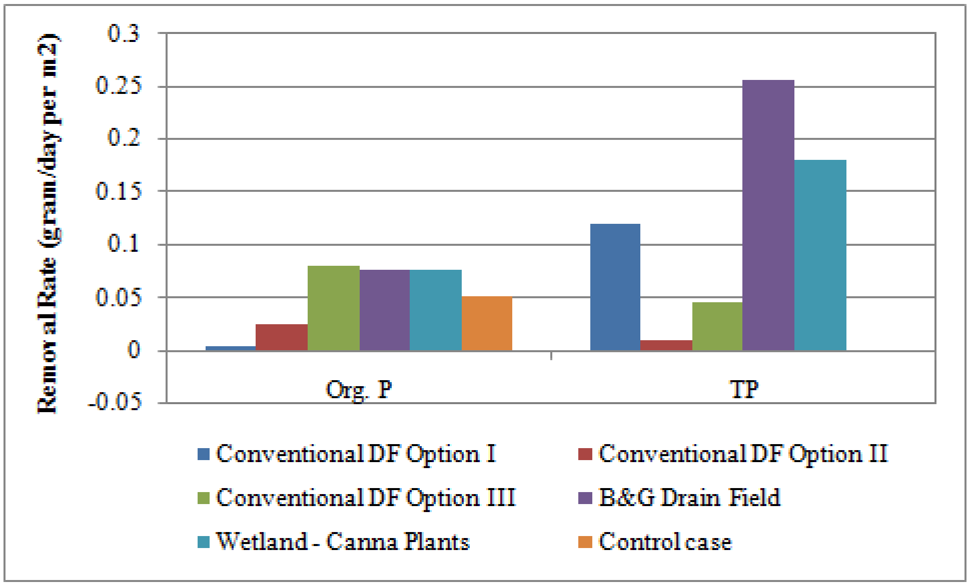


Figure 43 Phosphorus Species Removal Rate per Unit Area

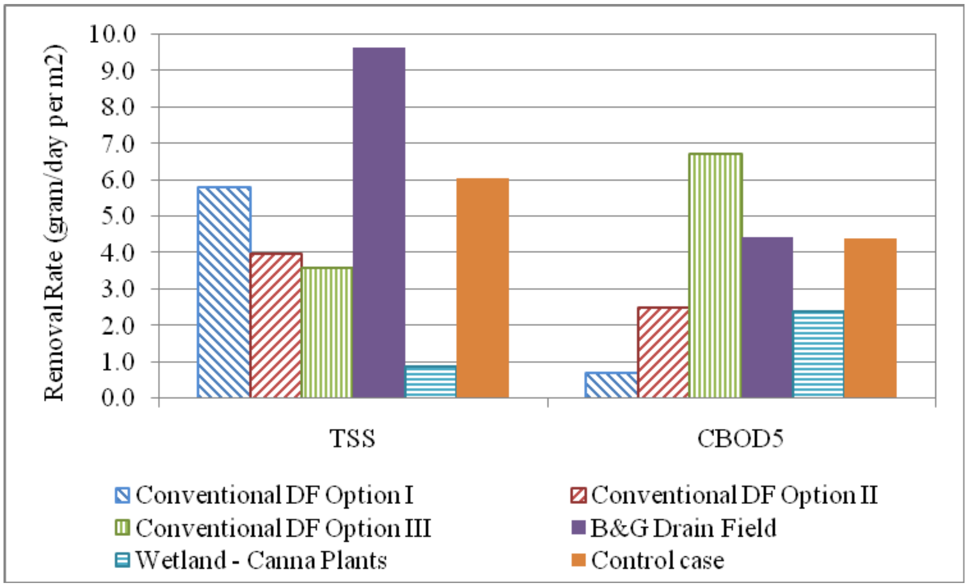


Figure 44 TSS and $CBOD_5$ Removal Rate per Unit Area

7.3 Comparison of effluent concentrations

The effluent data are summarized in Tables 11 and 12 to assist in understanding the variations versus averages with Table 11 listing the standard deviation and Table 12 listing the overall average effluent concentrations (all data are listed in Appendix B).

Table 11 Standard Deviations for Effluent Parameters

	Standard Deviation of Effluent					
Parameter	Conventional Drainfield Control	Conventional Drainfield Recirculation Design I	Conventional Drainfield Recirculation Design II	Conventional Drainfield Recirculation Design III	B&G Filter	SUW - Canna Plants
Alkalinity (mg/L)	33.2	54.4	2.1	18.9	22.2	70.1
TSS (mg/L)	0.34	1.5	1.9	0.4	8.0	4.7
BOD5 (mg/L)	0.48	0.8	8.4	0.9	9.4	2.7
CBOD5 (mg/L)	0.94	0.0	7.5	1.0	7.1	1.3
Ammonia-N (µg/L)	2098	29	24	5,578	1,928	499
NO_X-N (µg/L)	2156	23,490	5,149	4,495	3,454	5
Nitrite-N (µg/L)	38.1	2.3	3.9	1,137	55	0.9
Nitrate-N (µg/L)	2191	23,488	5,146	3,657	3,417	4.9
Org. N (µg/L)	6108	26,229	1,074	16,940	7,647	632
TKN (µg/L)	5581	26,205	1,093	14,857	7,769	500
TN (µg/L)	5787	23,881	15,394	10,698	4,431	499
SRP (µg/L)	379	1,647	1,013	1,445	1,111	6.6
Org. P (µg/L)	1285	285	229	224	304	25.2
TP (µg/L)	444	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

In Table 12, a comparison of the six OSTDSs using average effluent concentrations illustrate that TSS and BOD removals were significant with the concentrations of these parameters being less than expected from centralized primary and secondary wastewater treatment plants. With respect to TN and TP removal, the effluent concentrations for the SUW with Canna even meet those of an Advanced Wastewater Treatment Facility of 5, 5, 3, 1 for BOD, TSS, TN and TP in mg/L. However, TP and TN for the conventional septic tank and drainfield with and without recirculation remained high.

Table 12 Average Effluent Concentrations

	Average Effluent Concentration					
Parameter	Conventional Drainfield Control	Conventional Drainfield Recirculation Design I	Conventional Drainfield Recirculation Design II	Conventional Drainfield Recirculation Design III	B&G Filter	SUW - Canna Plants
Alkalinity (mg/L)	54	203	96	30	221	379
TSS (mg/L)	2	4	2	BDL*	11	**
BOD5 (mg/L)	1.2	3	13	1	11	5
CBOD5 (mg/L)	1	2	7	1	8	4
Ammonia-N (µg/L)	37	47	44	3,829	6,102	860
Nitrite-N (µg/L)	3.3	6	7	1,062	52	2
Nitrate-N (µg/L)	41,970	14,860	29,749	38,923	3,146	6
Org. N (µg/L)	6,076	3,134	1,283	11,898	3,361	1,097
TKN (µg/L)	6,113	3,181	1,327	15,727	9,463	1,957
TN (µg/L)	48,086	18,211	31,749	55,711	12,902	1,964
SRP (µg/L)	4,577	3,071	6,436	4,729	1,004	18
Org. P (µg/L)	347	812	208	795	258	78
TP (µg/L)	4,924	3,883	6,780	5,524	1,387	96

*BDL Below Detection Limits ** Sampling error, solids added to sampling port
Note: The Fecal and E. Coli data are shown in the appendices. The removals were significant for all OSTDS. Most likely there would be no violation of fecal standards in a receiving water body (less than 10% of samples > than 400 cfu/100mL).

Based on effluent concentration, the SUW had the lowest nitrogen concentration with the B&G Filter having the second lowest total nitrogen concentration and the passive conventional drainfield systems having the highest nitrogen levels (see Figure 45). Similarly, the phosphorus level in the SUW with Canna cell (#1) was the lowest. B&G Filter had the second lowest level of phosphorus. The passive conventional drainfield systems had the highest level of phosphorus in the effluent (see Figure 46). The bacteria level in the SUW effluent was the highest; however all were considered to be low. Nevertheless, there were single measures where the fecal coliform counts exceeded the water quality standard of 800 cfu/100mL. Half of the effluent samples were below the EPA MCL standard which requires zero cfu of both fecal coliform and *E. coli* for drinking water. The effluent concentration of CBOD$_5$ in all systems was low as shown in Figure 47.

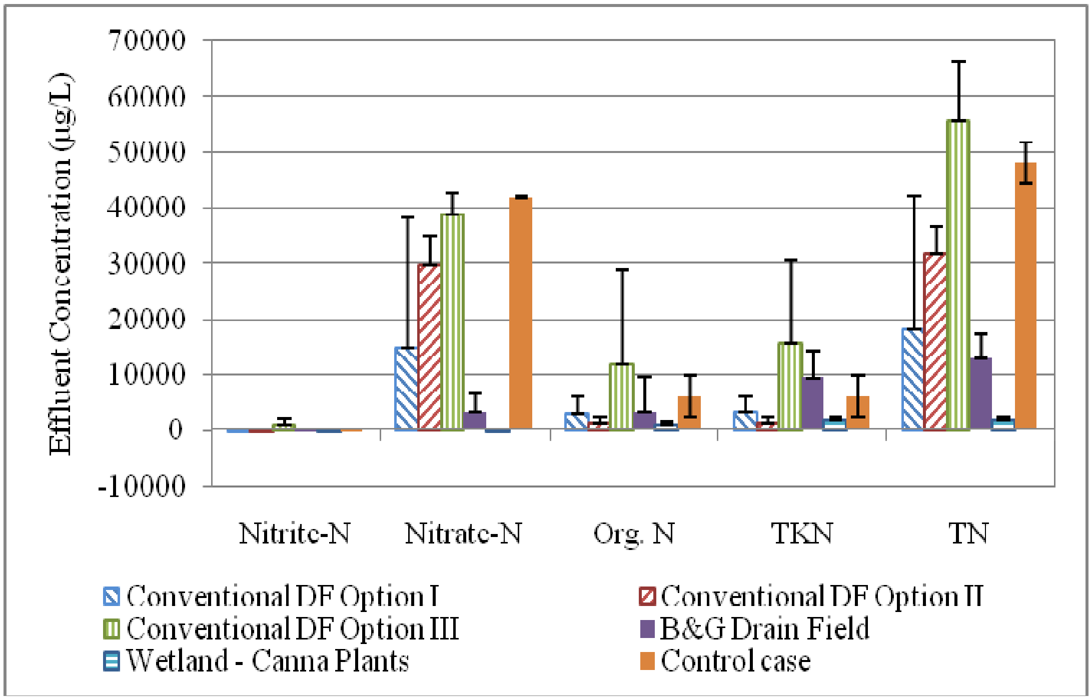


Figure 45 Comparison of Effluent Nitrogen Species

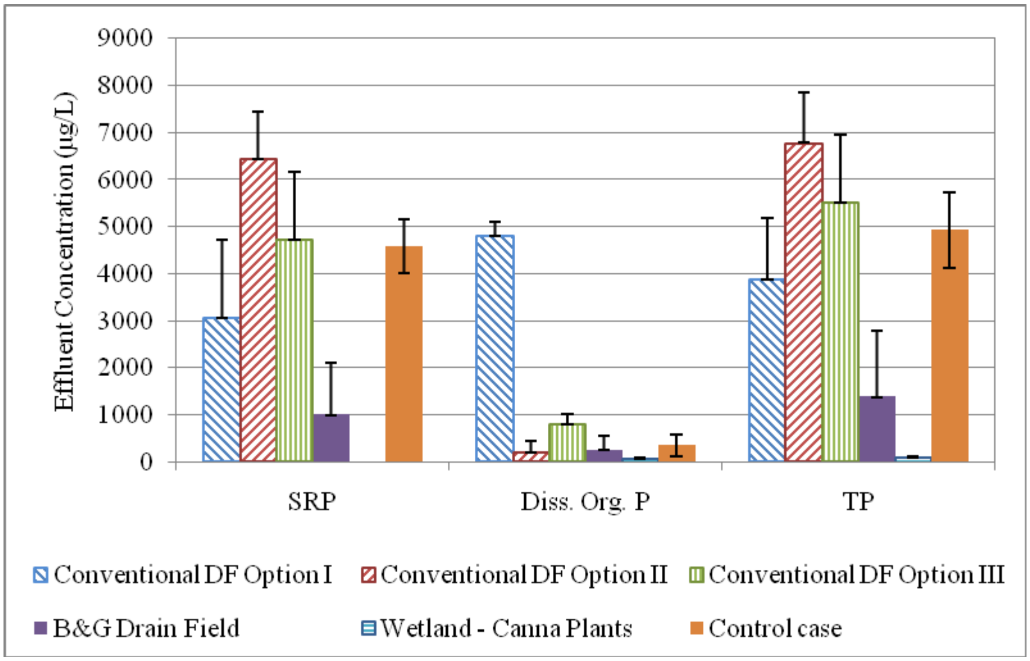


Figure 46 Comparison of Phosphorus Effluent Concentrations

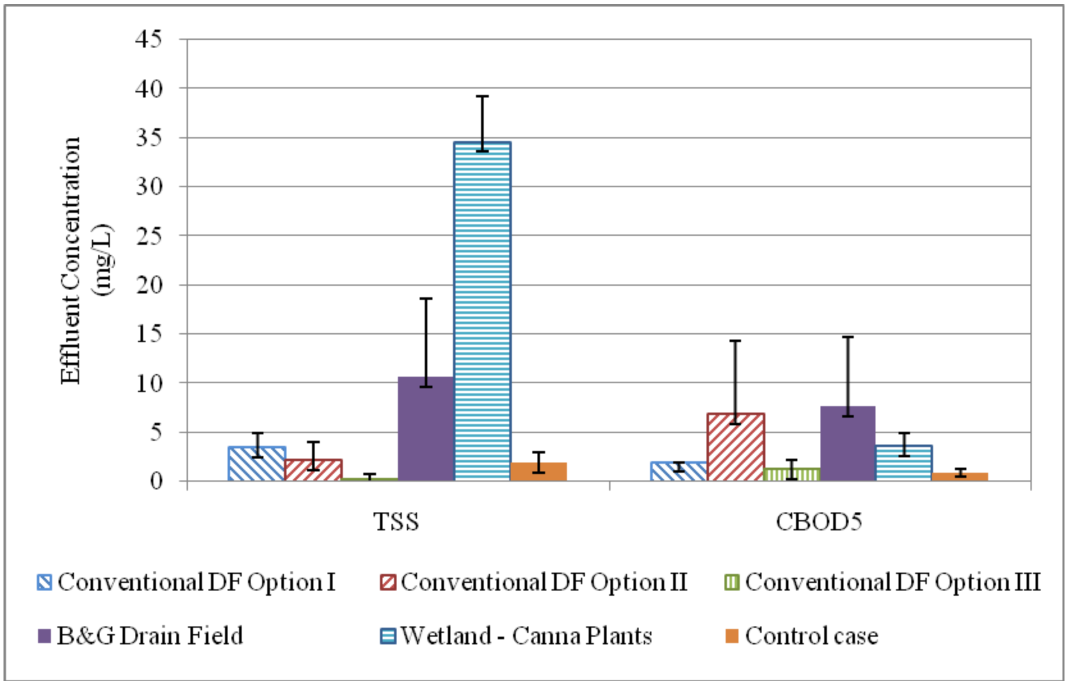


Figure 47 Comparison of TSS and CBOD$_5$ Effluent Concentrations

At least two of the RSF designs are considered to be an improvement over the conventional and this can be summarize by the following observations:

1) In November 2008, the fine sand-based RSF tank was clogged, which increased the HRT inside the RSF tank, dramatically. The increased HRT may have caused the reduction of nitrogen species because of the longer residence time. The sample location of S3 is at the RSF inlet, and the sample location of S4 is at the RSF outlet. The two samples collected at the S4 sampling point in November 2008 showed relatively low nitrogen concentrations (see Table 13). Figure 48 reveals that the nitrogen species are removed during the clogging period in the RSF unit in November 2008. The trend for nitrogen removal is also shown using the time-series data of TN concentrations as shown in Figure 48.
2) The overall nitrogen removal with two septic tank-RSF-drainfield systems was relatively better within these designs and the results indicate the HRT in RSF needs to be increased from a half day to 1-2 days to enhance nitrogen removal.

3) Table 14 shows the data of the septic tank and washed builder's sand drainfield without the use of RSF (i.e., control case). An average effluent TN concentration from the 3 datasets was about 48 mg/L. When comparing to the recirculation designs I, II, in Table 12, it confirms that the use of RSF could improve the TN effluent water quality to some extent based on the overall performance.

Table 13 Water Quality at Different Sampling Locations before (10/14) and after the RSF

Sample Date 2008	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)
10/14	B1	288	52	39.4	29.9	28309	16	331	5409	33,718	34,065
10/14	S3	322	42	6.6	4.2	37538	32	9	5166	42,704	42,745
10/14	S4	236	15	11.6	6.8	14813	1635	1343	6758	21,571	24,549
11/5	B1	353	110	79.5	75.3	32557	5	0	1928	34,485	34,490
11/5	S3	273	26.5	20	7	6398	5	0	1915	8,313	8,318
11/5	S4	244	<. 7	< 2	< 2	199	6	10	7114	7,313	7,329
11/19	B1	324	57.3	73.5	57.6	12174	5	0	1697	13,871	13,876
11/19	S3	268	14	17.6	14.4	4791	5	0	3220	8,011	8,016
11/19	S4	252	3.2	2.7	< 2	400	8	6496	1279	1,679	8,183

Table 14 Data for Conventional OSTDS (Control with Washed Builder's Sand Drainfield) and Without the Use of RSF

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
1/19/2010	S10	104	0.9	0.7	0.5	62	2	41892	6,381	6,443	48,337	4,015	147	4,162		
1/26/2010	S10	24	3	1	0.9	19	0	41956	2,224	2,243	44,199	4,560	286	4,846		
2/9/2010	S10	34	2	2	1.3	29	8	42062	9,624	9,653	51,723	5,156	609	5,765	<1	<1

Another comparison to illustrate reduction in TN for seven OSTDS is a time series comparison of influent and effluent concentrations. Figure 48 shows the arithmetic mean of TN, which shows removal of TN with time for each of the OSTDS. Near the end of the sampling time, the B&G Filter and three SUW systems with plants had the lowest effluent concentrations, while the conventional and SUW control (without plants) had the highest effluent concentrations.

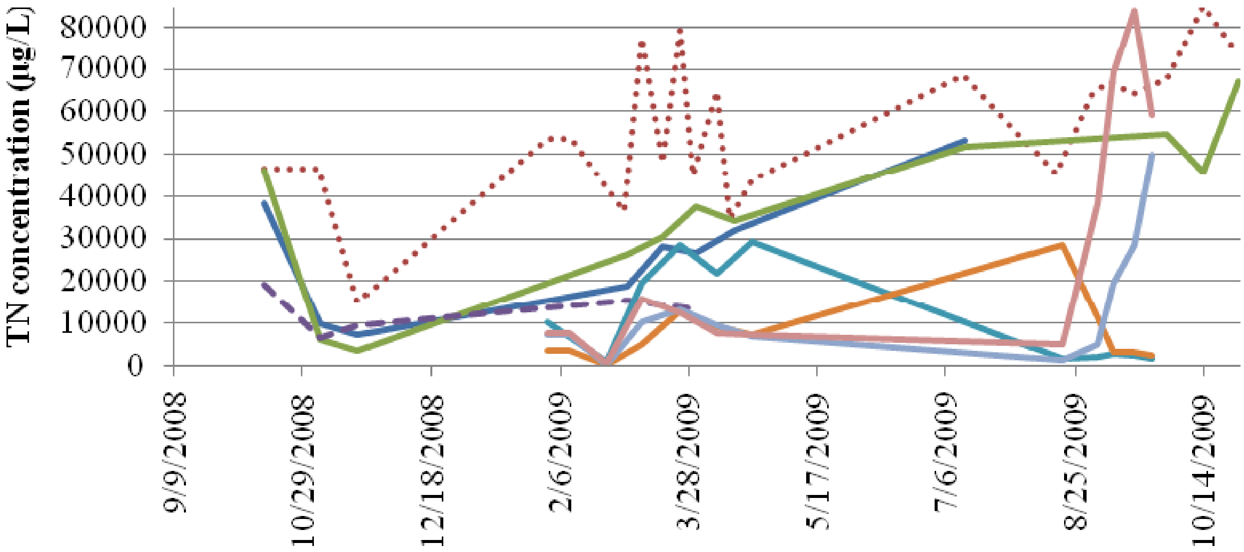


Figure 48 Comparison of Influent and Effluent TN Concentrations with Time

Legend:

● ● ● Raw Water Inlet Concentration
▬ Conventional OSTDS (Septic Tank and Washed Sand DF) Effluent
▬ Conventional OSTDS (Septic Tank and Astatula Sand DF) Effluent
- - Bold & Gold Effluent
▬ SUW with Canna Effluent
▬ SUW with Blue Flag Effluent
▬ SUW with Bulrush Effluent
▬ SUW Control (no plants) Effluent

Chapter 8 Modeling the Subsurface Upflow Wetlands (SUW) System for Wastewater Effluent Treatment

8.1 Tracer study

Rhodamine WT is a synthetic red to pink dye having brilliant fluorescent qualities with molecular formula C29H29N2O5ClNa2 and CAS Number: 37299-86-8. It is also known as Acid Red #388. Further, it is often used as a tracer within water to determine the rate and direction of flow and transport. In our study, the Rhodamine WT liquid (20% solution) was purchased from Keystone Aniline Corporation. 0.04 g active ingredient of Rhodamine WT solution was added into the inlet of the cell planted with Blue flag. 50mL of water sample was collected from each sampling port by using a peristaltic pump. The grab samples with the Rhodamine dye were measured by Aquafluor™ (Turner Designs 998-0851) handheld fluorometer and detected using its Green channel. The linear detection range for both dyes is 0.4 to 300 PPB (active ingredient). Since Rhodamine WT fluorescence is susceptible to photolysis and sensitive to temperature, samples should be collected in glass bottles and kept in the dark prior to analysis. Besides, the solution with known concentration was analyzed on site for calibration prior to the sample measurement. Eventually, the Rhodamine WT distribution was demonstrated by 3D Data Visualization software, Voxler® (Golden software).

8.1.1 Tracer HRT

Ten sets of data were collected and measured during July, 2010. In Table 15, shown are the accumulated time and computational procedure for calculating the tracer HRT. In our study, the tracer HRT was calculated by following Headley and Kadlec's (2007) practical guide. Figure 49 is the measured Residence Time Distribution (RTD) curve resulting from an impulse addition of 0.04 g (20ml 2×10^6 ppb) Rhodamine WT.

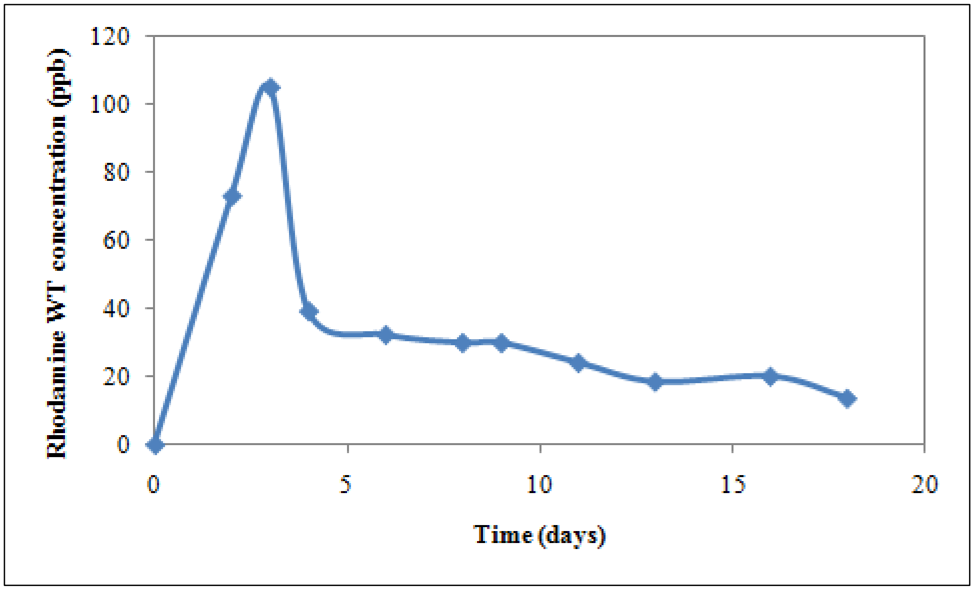


Figure 49 Measured RTD Curve

The tracer detention time (often referred to as the “tracer HRT” or “mean HRT”, τ, can be achieved by the Equation 8. It can be seen that τ is equal to 7.1 days (4376.1 divided by 618.6).

$$\tau = \frac{\int_0^\infty tC(t)\,dt}{\int_0^\infty C(t)\,dt} \qquad (8)$$

Table 15 Computational Procedure for Calculating the Tracer HRT

t(d)	C(t) (ppb)	C(t) dt	tC(t) dt
0.0	0.0	-	-
2.0	73.1	146.2	292.4
3.0	105.1	105.1	315.3
4.0	39.3	39.3	157.3
6.0	32.4	64.8	388.8
8.0	30.0	60.1	480.5
9.0	30.0	30.0	270.1
11.0	24.2	48.3	531.5
13.0	18.5	37.1	481.8
16.0	20.1	60.4	966.7
18.0	13.7	27.3	491.8
-	-summation-	**618.6**	**4376.1**

8.1.2 Distribution of tracer in the wetland

The distribution of tracer in the B&G Filter was plotted by Voxler® (Golden software). This robust program can display the data in a variety of formats: 3D volrender, isosurfaces, contours, 3D slices, orthographic and oblique images, scatter plots, stream lines, and vector plots.

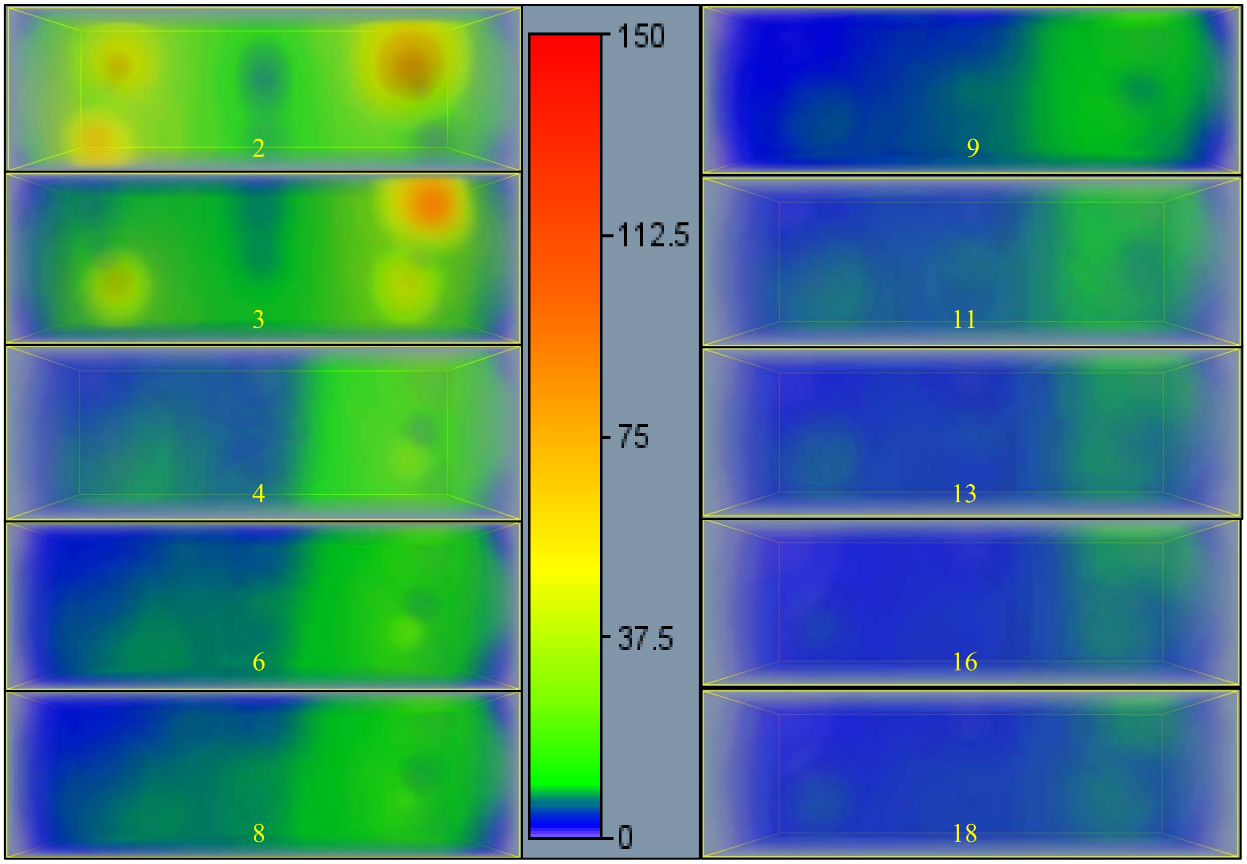


Figure 50 Profile View of the Tracer Distribution in Wetland. (Left five small images: 2 days, 3 days, 4 days, 6 days, 8 days; Right five: 9 days, 11 days, 13 days, 16 days, 18 days) with the vertical scale showing the concentration (ppb)

Figure 50 shows a detail flow of water with dye. For each small image, bottom left is the inlet and upper right outlet. The “2 days” figure indicates the tracer flew with water throughout the bottom layer and moved upward at two ends of wetland within 2 days. The blue color in the middle shows that the tracer had not reached that part at that time, which means there might be some clogging or hardening of media mixture with time in the wetland. But such observation served exactly as a testimony to our upflow pattern design. Most of tracer at the top layer came from the bottom, instead of horizontal moving. In the third day, the tracer gradually faded away at the inlet side and continued to rise at the outlet side. From 4 to 8 days, there was a rising progress of tracer in the middle and the peak of tracer moved out of the outlet. From 9 to 18 days, the remaining tracer flew out gently of the wetland. In short, there might be some clogging caused the delayed rising of tracer in the middel of the cell though, the tracer distribution results provided a strong support for the upflow hypothesis.

8.2 Simulation Analysis of SUW by using system dynamic model

The satisfactory nutrient and pathogen removal efficiency and upflow pattern have been fully proven in the previous text. To be in concert with our field-scale pilot testing of a new-generation subsurface upflow wetland (SUW) system, the following text highlights an advancement of modeling the SUW system with a layer-structured compartmental simulation model. This is the first wetland model of its kind in the world to address the complexity between plant nutrient uptake and media sorption. Such a system dynamics model using STELLA® as a means for a graphical formulation was applied to illustrate the essential mechanism of the nitrification and denitrification processes within a sorption media-based SUW system, which can be recognized as one of the major passive on-site wastewater treatment technologies in this decade.

8.2.1 Conceptual model

There are five main nitrogen transformations in wetlands (Kadlec and Wallace, 2008).

a. Organic nitrogen to ammonium nitrogen (ammonification or mineralization). Organic nitrogen cannot be extracted by plants directly but is gradually transformed to NH_4^+ by heterotrophic microorganisms:

$$NH_2CONH_2 + H_2O \rightarrow 2NH_3 + CO_2 \qquad (9)$$

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^- \qquad (10)$$

b. Ammonium nitrogen to nitrate nitrogen (nitrification). In aerobic oxidized condition, ammonium transforms to NO_3^- through the process of nitrification in two steps by Ammonia Oxidizing Bacteria (AOB):

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ \qquad (11)$$

And by Nitrite Oxidizing Bacteria (NOB):

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad (12)$$

When there is adequate oxygen available, nitrification can also occur in the oxidized rhizosphere of plants.

c. Nitrate nitrogen to gaseous nitrogen (denitrification). Denitrifiers use the oxygen from NO_3^- instead of O_2 to convert NO_3^- to nitrogen oxide and N_2.

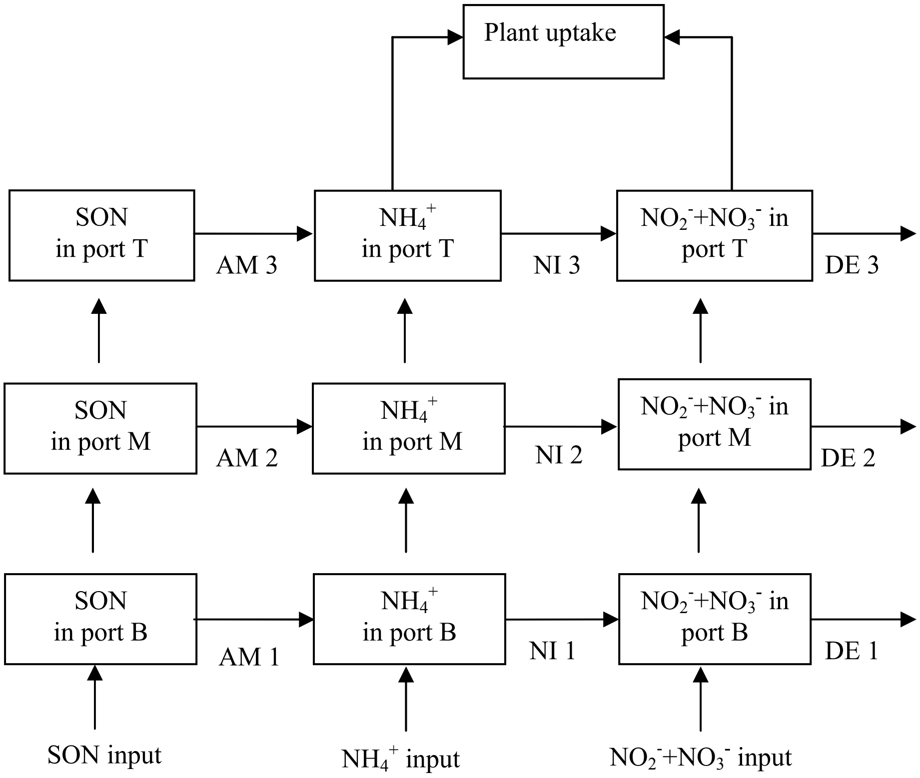
$$NO_3^- + 0.833CH_3OH \rightarrow 0.5N_2 + 0.833CO_2 + 1.167H_2O + OH^- \qquad (13)$$

$$NO_3^- + 0.208C_6H_{12}O_6 + \rightarrow 0.5N_2 + 1.25CO_2 + 0.75H_2O + OH^- \qquad (14)$$

d. Nitrate or ammonium nitrogen to organic nitrogen (assimilation or immobilization). Immobilization can be considered as the reverse reaction of mineralization. Inorganic nitrogen (NO_3^- and NH_4^+) is converted to organic nitrogen by microbes and used by plants, which roughly is counted as plant uptake in the model.

e. Biomass nitrogen to organic nitrogen (decomposition). Since the plant grew well and had no residue in late summer, this part of nitrogen transformation can be ignored.

Assume that each media layer is a continuously stirred treatment reactor (CSTR). Based on the above understanding, the conceptual model for nitrogen removal of SUW is shown in Figure 51 below.



Note: SON = Soluble Organic Nitrogen; AM = ammonification; NI= nitrification; DE= denitrification

B= Bottom layer; M = Middle layer, and T = Top layer

Figure 51 General Conceptual Model of Nitrogen Removal in SUW

8.2.2 Implementation of system dynamics model

The stock and flow diagram of nitrogen removal in SUW using STELLA® simulation program is presented in Figure 52 in which the modeling structure follows the layered structure for nitrogen removal. Note that Table 16 below shows the description of symbols in Figure 52 by taking the sand layer as an example.

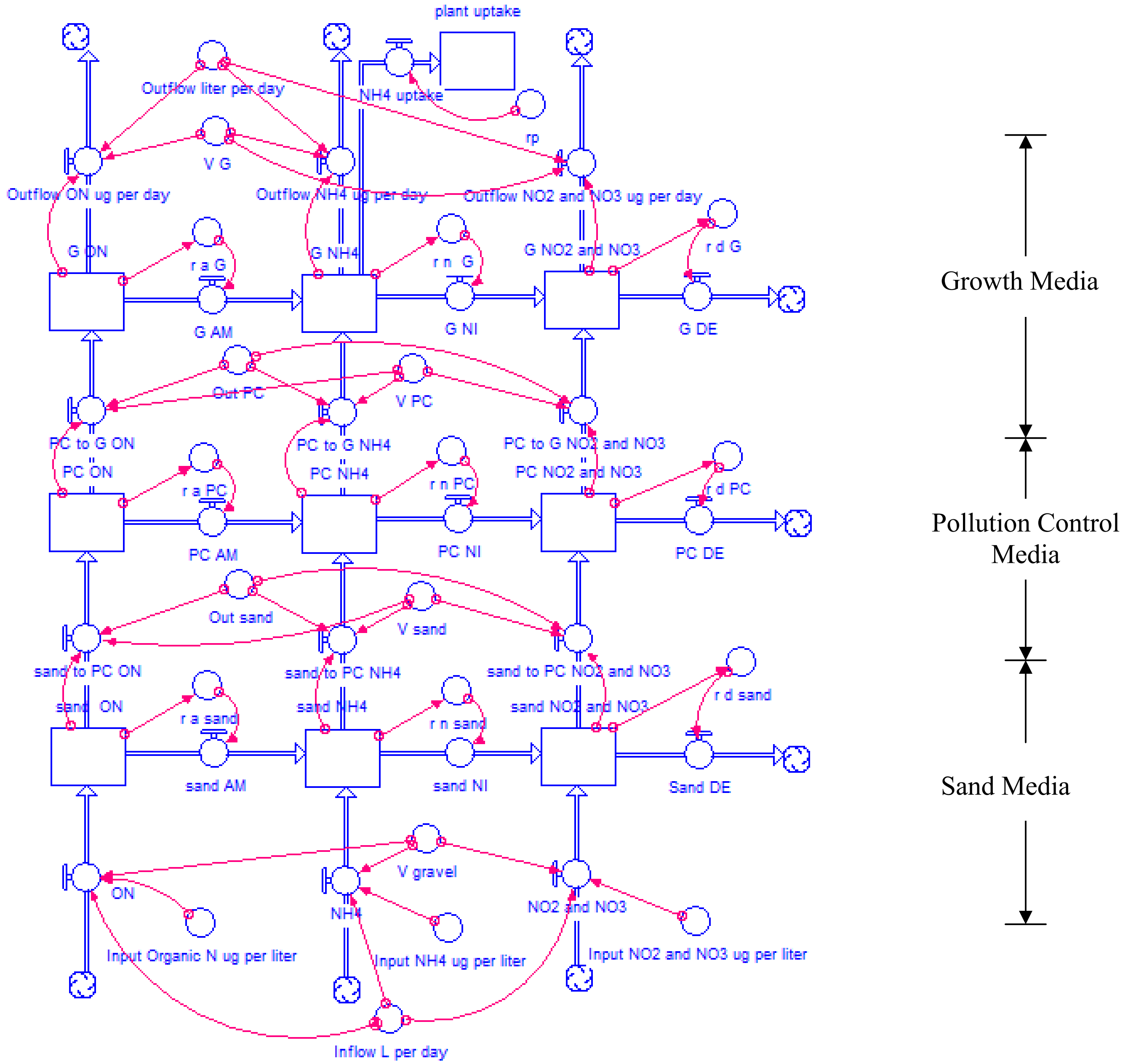


Figure 52 SUW Flow Diagram of Nitrogen Removal Model

Table 16 Description of Symbols in Stock and Flow Diagram of Figure 52

Symbol	Description
“sand ON”	ON (μg/day) in sand layer;
“sand NH_4”	NH_4 (μg/day) in sand layer;
“sand NO_2 and NO_3”	$NO_2 + NO_3$ (μg/day) in sand layer;
“sand AM”	ammonification (μg/day) in sand layer
“sand NI”	nitrification (μg/day) in sand layer
“sand DE”	denitrification (μg/day) in sand layer
“sand to PC ON”	ON (μg/day) transfer from sand layer to PC layer
“sand to PC NH_4”	NH_4 (μg/day) transfer from sand layer to PC layer
“sand to PC NO_2 and NO_3”	$NO_2 + NO_3$ (μg/day) transfer from sand layer to PC layer
“r_a sand”	ammonification rate (day^{-1}) in sand layer
“r_n sand”	nitrification rate (day^{-1}) in sand layer
“r_d sand “	denitrification rate (day^{-1}) in sand layer

8.2.3 Model equations

The equations below are used to predict the organic nitrogen (ON), NH_4 and the sum of nitrite and nitrate (NO_2+NO_3). The unit form, μg/L/day, was used for all flows and stocks. Only plant uptake is a real and ultimate stock (Figure 52). The rest of nine stocks have their own outflow to reach a steady state condition. Thus, the value in stock can be represented as the “instantaneous concentration” in a unit volume or a point (i.e. sampling port). Assume that the upflow rate decreased linearly due to the evapotranspiration and plant uptake with the increase of the elevation. V is considered as the effective volume (product of volume and porosity) of each layer where water flows. The NO_2+NO_3 concentrations in all layers are so low that the NO_2+NO_3 uptake by plant is negligible. Figure 53 shows the model equations automatically generated in the Equation interface of STELLA® model with the measured data as initial value. In this study, September was picked as the experiment period when wetland plants had grown well. So a constant rate of biomass production for simplification was assumed. The rest of parameters need to be measured or assumed so that they may be determined integrally via the model calibration stage as summarized by Table 17.

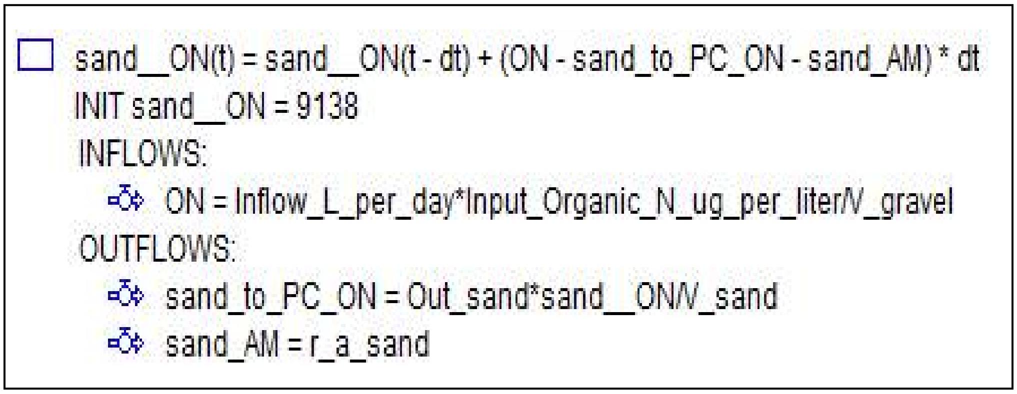
$$\mathrm{dON/dt} = \frac{Q_{in}}{V_{in}} ON_{in} - \frac{Q_{out}}{V_{out}} ON_{out} - r_a \tag{15}$$

$$\mathrm{dNH_4/dt} = \frac{Q_{in}}{V_{in}} NH_{4in} - \frac{Q_{out}}{V_{out}} NH_{4out} + r_a - r_n - r_p \text{ (only in G media layer)} \tag{16}$$

$$\mathrm{d(NO_2{+}NO_3)/dt} = \frac{Q_{in}}{V_{in}} (NO_2 + NO_3)_{in} - \frac{Q_{out}}{V_{out}} (NO_2 + NO_3)_{out} + r_n - r_d \tag{17}$$

Table 17 Description of Parameters in SUW Model

Parameter	Description	Rate equations	Values	Source
k_a	Ammonification constant	$r_a = kaC_{ON}$	Optimized	Beran and Kargi, 2005
gp	Plant growth rate	$r_p = iNPgp$	0.5	Yi et al, 2009
iNP	Plant N content	$r_p = iNPgp$	Measured	Yi et al, 2009
u_N	Nitrosomonas growth rate	$r_n = \frac{u_N}{Y_N} e^{0.098(T-15)} [1 - 0.833(7.2 - pH)](\frac{C_{AN}}{1 + C_{AN}})(\frac{C_{DO}}{1.3 + C_{DO}})$	Optimized	Kadlec and Knight,1996
Y_N	Nitrosomonas yield coefficient	$r_n = \frac{u_N}{Y_N} e^{0.098(T-15)} [1 - 0.833(7.2 - pH)](\frac{C_{AN}}{1 + C_{AN}})(\frac{C_{DO}}{1.3 + C_{DO}})$	Optimized	Kadlec and Knight,1996
K_{20d}	Denitrification rate	$r_d = K_{20d} \theta_d^{(T-20)}$	Optimized	Mayo and Mutamba, 2005



```
☐ sand__ON(t) = sand__ON(t - dt) + (ON - sand_to_PC_ON - sand_AM) * dt
  INIT sand__ON = 9138
  INFLOWS:
     ON = Inflow_L_per_day*Input_Organic_N_ug_per_liter/V_gravel
  OUTFLOWS:
     sand_to_PC_ON = Out_sand*sand__ON/V_sand
     sand_AM = r_a_sand
```

Figure 53 Model Equation Related to Organic Nitrogen (ON) in Sand Layer “Sand ON”

8.2.4 Model calibration

Wetland cell 1 was selected to develop the system dynamics model. Since we assume a constant rate of plant growth, the third run considered to have the average rate of plant growth was used to do the model validation in the next subsection. The average value of results from the other three runs and the hydraulics values listed in Table 18 were used to calibrate the SUW nitrogen removal dynamic model. Runge-Kutta 4 was used as the integration method. The nitrification has a wide range of optimum pH of 7.0 to 9.0 (Sajuni et al., 2010). The pH below 7.0 adversely effects on ammonia oxidation (Lin et al, 2001). Besides, the empirical formula is valid for water temperatures between about 5 and 30°C. The expression of nitrification rate was finally reorganized as Eq. 18. The model calibration started from adjusting the ammonification rate (i.e., the nutrient source, ON, in sand layer) to minimize the discrepancies between modeled and measured values. Then the model calibration can be moved on along the direction of nutrient transport (i.e. from bottom to top) and nitrogen transformation (i.e. from left to right) in relation to all three parameters of interest. The three parameters were intimately related to rate of ammonification, nitrification and denitrification, and their final values were determined within an effort of model calibration based on other measured parameter values assigned in Table 19. After such errands of model calibration, the final agreement between the measured and simulated values of organic nitrogen (ON), ammonium (NH_4) and the sum of nitrite and nitrate (NO_2+NO_3) is shown in Figure 54. The slope of the regression line was 0.9791, and the correlation (R^2) was 0.9998, which supports the model calibration.

$$r_n = \frac{u_N}{Y_N} C_T C_{pH} \left(\frac{C_{DO}}{1.3 + C_{DO}}\right) C_{AN} \qquad (18)$$

$$C_T = \begin{cases} e^{0.098(T-15)}, \text{ for } T < 30^{\circ}\text{C}; \\ e^{0.098(30-15)}, \text{ for } T \geq 30^{\circ}\text{C}; \end{cases}$$

$$C_{pH} = \begin{cases} 1 - 0.833\,(7.0 - pH), \text{ for pH} < 7.0; \\ 1, \text{ for pH} \geq 7.0; \end{cases}$$

Table 18 Hydraulics Values Used in SUW Model

Parameters	Description	Values
Q_{in}	Inflow rate	113.4 L/d
Q_{sand}	Flow rate out of sand layer	93 L/d
Q_{PC}	Flow rate out of PC media layer	52 L/d
Q_{out}	Outflow rate	31.5 L/d
Φg	Porosity of gravel	0.34
Φs	Porosity of sand	0.43
Φ_{PC}	Porosity of PC media	0.42
Φ_{G}	Porosity of G media	0.50

Table 19 Rate Equations of Ammonification, Nitrification and Denitrification in Model

	Rate equations	Unit	In sand layer	In PC media layer	In G media layer
k_a	$r_a = k_a C_{ON}$	day^{-1}	0.08	0.42	0.28
$\frac{u_N}{Y_N}$	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	day^{-1}	0.12	0.18	0.37
DO	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	mg/L	3.41	3.39	2.51
pH	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	N/A	7.02	7.00	7.01
T	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	^{o}C	29.94	30.08	29.69
K_{20d}	$r_d = K_{20d} \theta_d^{(T-20)} C_{NN}$	day^{-1}	180	235	80
r_p	$r_p = iNPgp$	day^{-1}	N/A	N/A	140

C_{ON} = Concentration of organic nitrogen, C_{AN} = Concentration of ammonium nitrogen,
C_{NN} = Concentration of nitrate nitrogen.

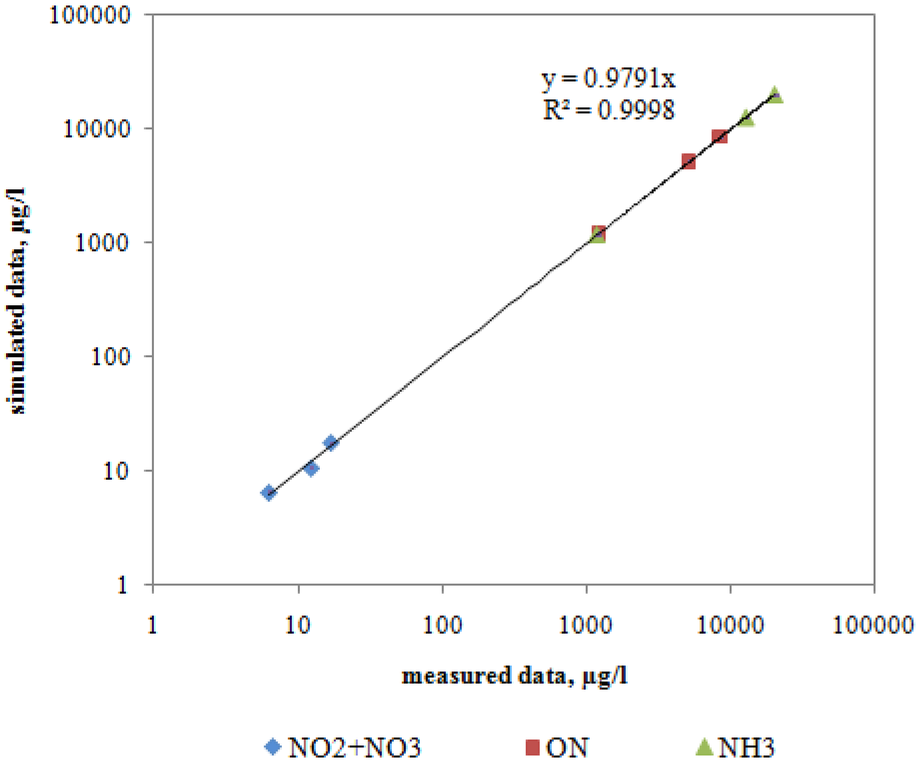


Figure 54 Correlation between the Measured and Simulated Values in Model Calibration

8.2.5 Model validation

The experimental data for third run was used for model validation. Table 20 lists the measured environmental values of the third run. The correlation between the measured and simulated values is shown in Figure 55. The slope of the regression line was 0.9532 and correlation (R^2) was about 0.9644, which shows the model validation, corroborating previous calibrated data shown in Table 19. The values of sum of nitrite and nitrate (NO_2+NO_3) led to a slightly lower R^2 value. The extremely low concentration, which is close to the lower detection limit, might increase the deviation. The ammonification rate constant (k_a) in PC media increased up to fivefold compared with that in sand layer. The denitrification rate constant in PC media was 30% more than that in sand layer and three times as much as in G media.

Table 20 Temperature, pH and Dissolved Oxygen Value Used in Model Validation (Third Run)

	DO (mg/L)	pH (dimensionless)	Temperature (°C)
Sand layer	3.02	7.77	32.23
PC layer	2.68	7.40	32.37
G layer	2.73	7.44	33.04

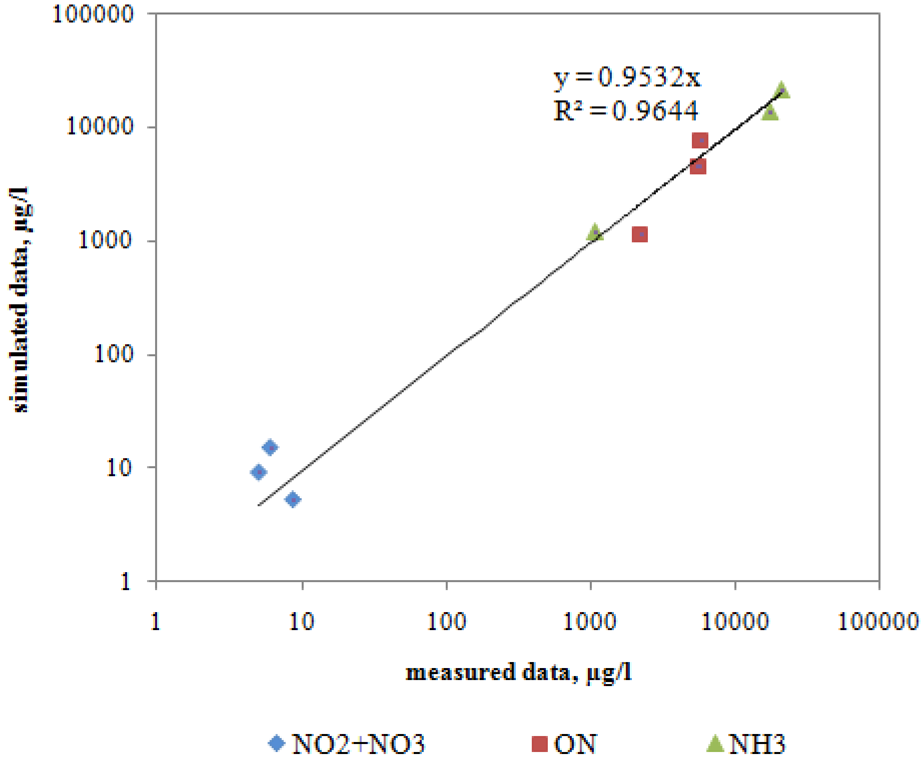
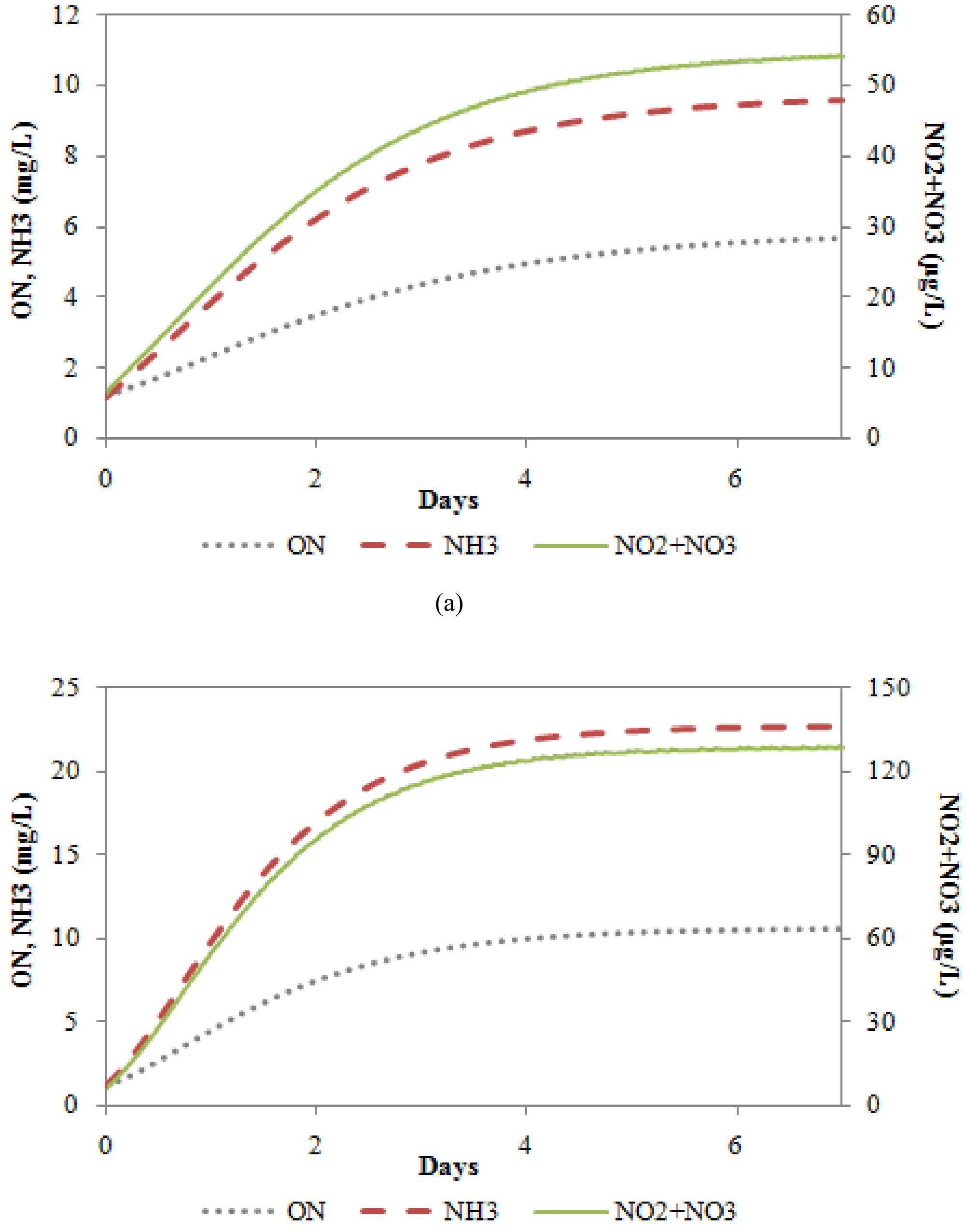


Figure 55 Correlation between the Measured and Simulated Values in Model Validation

8.2.5 Uncertainty prediction and sensitivity analyses

The exceptional ability of wetlands for nutrients removal in our study has been confirmed. However, wetland 1 treated the wastewater with the loading of 113.4 liters per day (30 gallons per day), which is smaller than the amount of wastewater produced from most common family. It is important to know how the SUW functions under higher loading to fully meet the requirement of higher flows. In such a case, the flexibility of the dynamic simulation model is useful. A new wastewater loading number is used for input and the model is "run" with the new input conditions. This relieves the extensive effort to manually increase the wastewater loading into wetland and collect the water samples for analyses. Keeping the inflow concentration for all three forms of nitrogen: 14.0 mg/L of organic nitrogen (ON), 55.1 mg/L of ammonium (NH_4)

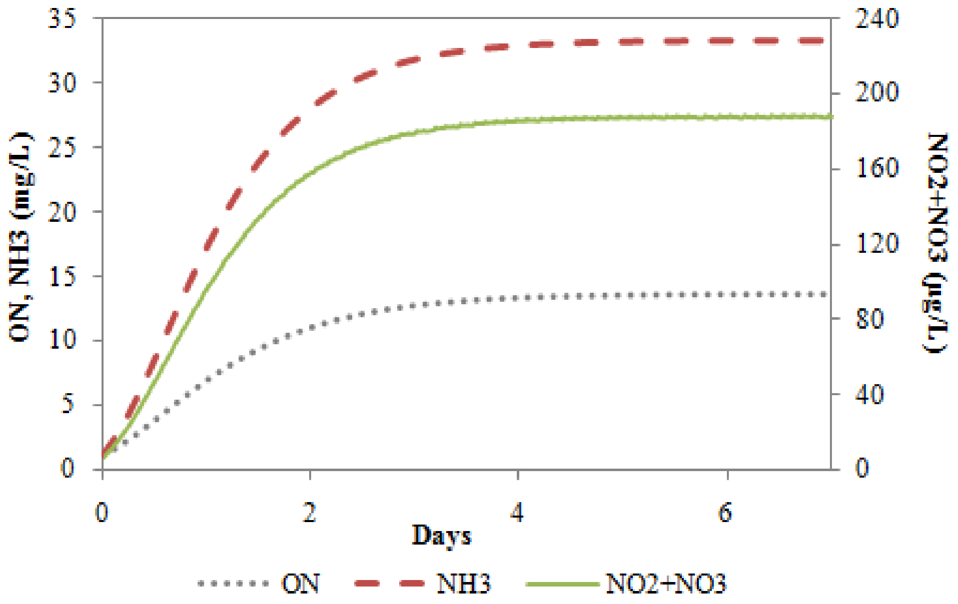
and 7.0 μg/L of the sum of nitrite and nitrate (NO_2+NO_3), 378 liters per day (100 gallons per day), 576 liters per day (200 gallons per day), 1134 liters per day (300 gallons per day), and 1512 liters per day (400 gallons per day) were input as the inflow rate into the model interface, all the parameters were kept the same as used in model calibration. The concentration of organic nitrogen (ON), ammonium (NH_4) and the sum of nitrite and nitrate (NO_2+NO_3) from the outlet were shown in the graphs of Figure 56.



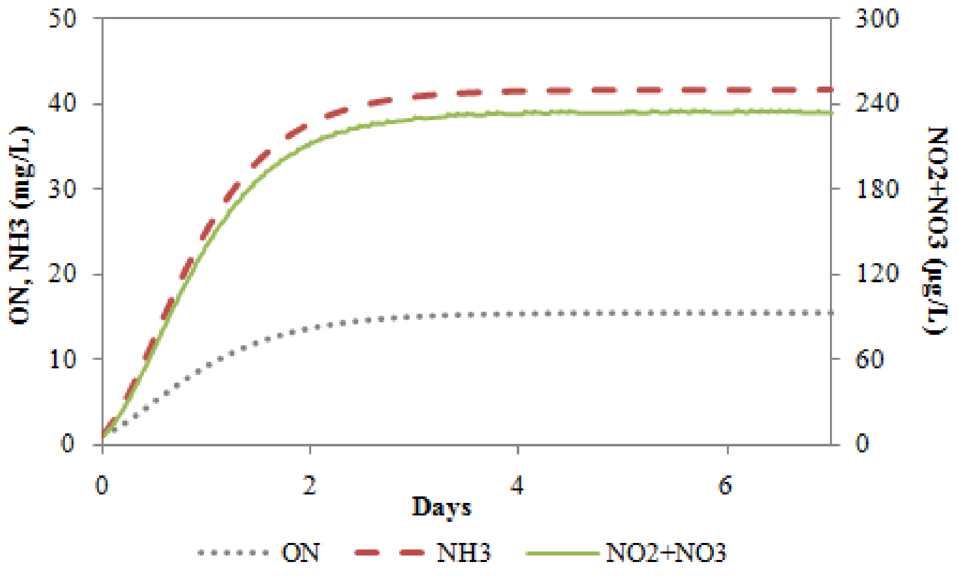
(a)

(b)

Figure 56 Effluent Quality of Different Wastewater Loadings: a) 378 liters per day (100 gpd), b) 756 liters per day (200 gpd), c) 1134 liters per day (300 gpd) and d) 1512 liters per day (400 gpd)



(c)



(d)

Figure 57 Continued Effluent Quality of Different Wastewater Loadings: a) 378 liters per day (100 gpd), b) 756 liters per day (200 gpd), c) 1134 liters per day (300 gpd) and d) 1512 liters per day (400 gpd)

With the flow rate of 378 liters per day, three forms of nitrogen keep increasing with the time. With the increase up to fourfold wastewater loading, the concentrations of NH_4 and NO_2 + NO_3 increased with almost the same ratio. The ON concentration had a less increase after triple loading. With the loading of 1,512 liters per day, the concentrations of NH_4, NO_2 + NO_3 and ON were less than 42 mg/L, 250 µg/L and 16 mg/L, respectively. The NO_2 + NO_3 concentration was still far beyond the maximum contaminant levels (MCLs) drinking water standard. With the wastewater loading increase, we can obviously see that the concentrations of nitrogen reach a stable level after the 2-day treatment. That is to say, the dimension of wetland had been overdesigned due to the remarkable nitrogen removal of the media. Half of original dimension is more than enough. The complexity of nitrification rate has significant influence on the model accuracy. Further sensitivity analyses especially for the nitrification rate may certainly help us understand the mechanism according to the nitrogen removal leading to modify the model up to a more sophisticated level in the future. Temperature (T), pH and Dissolved Oxygen (DO), all of them are the variables of the nitrification rate equation. Certain ranges of these three parameters were introduced to examine how they individually work on the nitrification rate.

The data of Table 21 shows, the nitrification rate is hardly affected by temperature. Instead, DO and pH value are critical for the nitrification. The lower level of DO resulted in an enlarged range of variation of nitrification rate presumably because of the Monod style expression. The G media layer had an extreme low DO value, 1.3 mg/L, which might explain the 31.18 % decrease of the nitrification rate. Slightly acidic wastewater with pH as 6.67 also might produce a decrease of 27.49 % in the nitrification rate.

Table 21 Min and Max Value of Temperature, pH and Dissolved Oxygen with The Percentage Each Correspondingly Influences the Nitrification Rate Compared with the Average Value. (“+”, increase; “-”, decrease)

	DO (mg/L)		pH (dimensionless)		Temperature (^oC)	
	MIN	MAX	MIN	MAX	MIN	MAX
Sand layer	2.87 (-5.16%)	4.46 (+6.70%)	6.86 (-11.66%)	7.46 (+0.00%)	26.1 (-0.35%)	33.2 (+0.01%)
PC layer	2.24 (-9.69%)	4.56 (+7.11%)	6.81 (-15.83%)	7.35 (+0.00%)	25.5 (-0.36%)	33.6 (+0.00%)
G layer	1.3 (-31.18%)	3.77 (+2.35%)	6.67 (-27.49%)	7.4 (+0.00%)	26.3 (-0.28%)	33.1 (+0.03%)

Recently, two more nitrogen transformations ANAMMOX (anaerobic ammonia oxidation) and nitrate-ammonification (conversion of ammonia to nitrate under anaerobic conditions) have been studied in the constructed wetlands (CWs) (Dong and Sun, 2007). Both transformations might have contributed the high nitrogen removal efficiency in our study. However, the extent of these reactions in CWs is far from certain. There is still a lack of information about these processes in CWs and their role in treatment process (Vymazal, 2007). Thus, we temporarily count those effects as an integral part of generalized nitrification/denitrification in our model if they do exist. Even they can be confirmed, our system dynamic model will still be useful and applicable after just adding two set of transformation rate to respond to these two more nitrogen transformations.

Chapter 9 Simulation Analyses for Nutrient Removal in B&G Filter

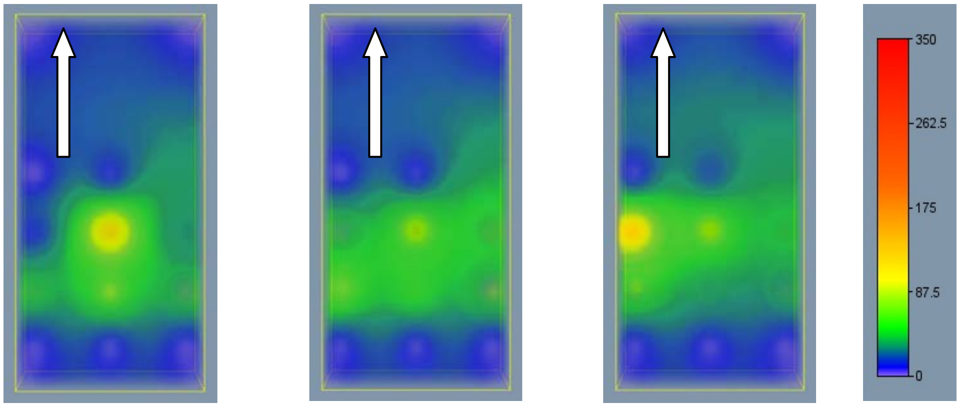
9.1 Tracer study

The objective of this study is to perform an integrated tracer-based system dynamics modeling for simulation analyses of nutrient removal in the lined media filter. For the identification of hydraulic or flow patterns in the media filter, a tracer study was conducted to determine the direction and velocity of water movement in the media filter. Due to the advantages of low detection limits, zero natural background, low relative cost, and easy on-site analysis, Rhodamine WT was selected as the water tracing dye to determine the hydraulic pattern and hydraulic retention time of the media filter.

An ideal tracer should follow the same path as the water and should have the following characteristics including easy detection, inexpensive analysis procedure, low toxicity, high solubility and low background in the system tested. There are three most popular choices for a tracer: isotope (Kadlec et al., 2005; Ronkanen and Kløve 2007, 2008); ions, and dyes. The isotope technology has high accuracy but is expensive. Ionic compounds, especially bromide, have been widely used as a groundwater tracer (Harman et al., 1996; Wang et al., 2008). Małoszewski et al (2006) used instantaneously injected bromide to evaluate of hydraulic characteristics of a duckweed pond in Mniów, Poland. Yet, for ionic tracers, they rely on less reliable measuring probes. Dyes have advantages of low detection limits, near zero natural background and low relative cost. One of the most popular dyes is rhodamine WT (Dierberg and DeBusk, 2005; Lin et al., 2003; Giraldi et al., 2009**)**.

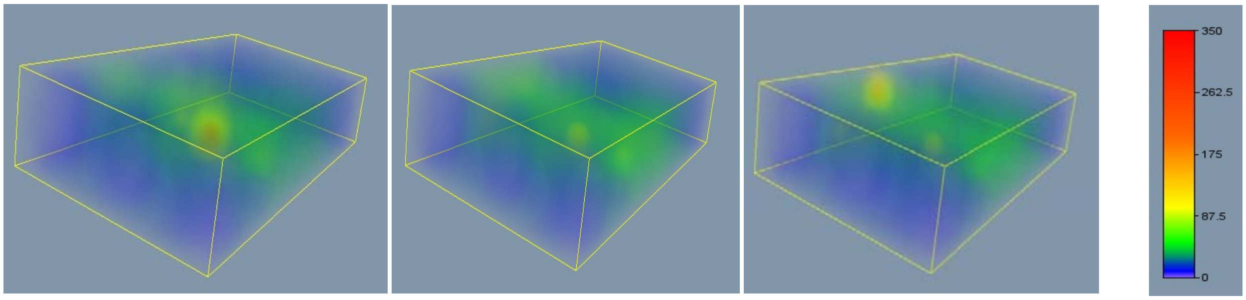
In this study, 70mL of 2×10^7 PPB (1.4g active ingredient) Rhodamine WT solution was added into the pipe before the inlet of the media filter. Five sets of data were collected and measured in April, 2010. The tracer with 25% of the designed water loading was dosed into the media filter. The 3D distribution of tracer in the media filter was plotted by Voxler® (Golden software). The tracer was shown to move along the established path in the media filter as expected (See Figure 57). For the images of Figure 57, the bottom is the inlet side of media filter and upper is the outlet. The arrow sign indicates the flow direction of water. The orange color in the Figure 57a shows the preferential accumulation points in the media filter. Figure 57b indicates the dispersion of tracer when tracer was moving around due to the pressure gradient and the dispersion property of the green sorption media. As shown in Figure 57c, from the 10th to

14th day, the tracer kept dispersing throughout the first three sections as expected and the peak started to penetrate through the anaerobic zone getting close to the final treatment zone (e.g., anaerobic zone) before the riser. At this moment, the concentration of tracer in previous two preferential points was diluted and dwindled as time moves on. Because of the pulse dosing, the concentrations of tracer at the front end (inlet) exhibit relatively higher concentrations throughout the beginning days. Figure 58 exhibits the 3-dimensional scenarios of tracer distribution in the 7th, 10th, and 14th days. The plume moves onto the riser as time goes on as expected.



(a) 7th days **(b) 10th days** **(c) 14th days**

Figure 58 Plan View of the Tracer Distribution in the Media Filter; units: ppb. The Arrow Shows the Flow Direction.



(a) 7th days **(b) 10th days** **(c) 14th days**

Figure 59 3-dimensional Scenarios of Tracer Distribution in the Media Filter; units: ppb.

9.2 System dynamics model

9.2.1 Model calibration

Calibration is the process of finding the best match between simulated and observed values. The model used is shown in Figure 59 with the description of symbols given in Table 22. Data collected on March 18th, 2009 was used for model calibration. Table 23 shows the values of reaction rates and environmental parameters applied in simulation analyses. The final agreement between the measured and simulated values of organic nitrogen (ON), ammonia (NH_3) and the sum of nitrite and nitrate (NO_2+NO_3) can be shown in Figure 60. The slope of the regression line was 0.87, and the correlation (R^2) was 0.96, which supports the success of model calibration. The denitrification rate constant in anaerobic zone is 35 times larger than the value in aerobic zone whereas the nitrification rate is extremely high in aerobic zone. This observation verifies the design hypotheses.

Table 22 Description of Symbols in Stock and Flow Diagram of Figure 59

Symbol	Description
"Aerobic ON"	ON (μg/day) in aerobic zone;
"Aerobic NH_3"	NH_3 (μg/day) in aerobic zone;
"Aerobic NO_2 & NO_3"	NO_2 +NO_3 (μg/day) in aerobic zone;
"Aerobic AM"	ammonification (μg/day) in aerobic zone
"Aerobic NI"	nitrification (μg/day) in aerobic zone
"Aerobic DE"	denitrification (μg/day) in aerobic zone
"ON Aerobic to Anoxic"	ON (μg/day) transfer from aerobic to Anoxic zone
"NH_3 Aerobic to Anoxic"	NH_3 (μg/day) transfer from aerobic to anoxic zone
"NO_2 &NO_3 Aerobic to Anoxic"	NO_2 +NO_3 (μg/day) transfer from aerobic to anoxic zone
"r_a Aerobic"	ammonification rate (day^{-1}) in aerobic zone
"r_n Aerobic"	nitrification rate (day^{-1}) in aerobic zone
"r_d Aerobic "	denitrification rate (day^{-1}) in aerobic zone

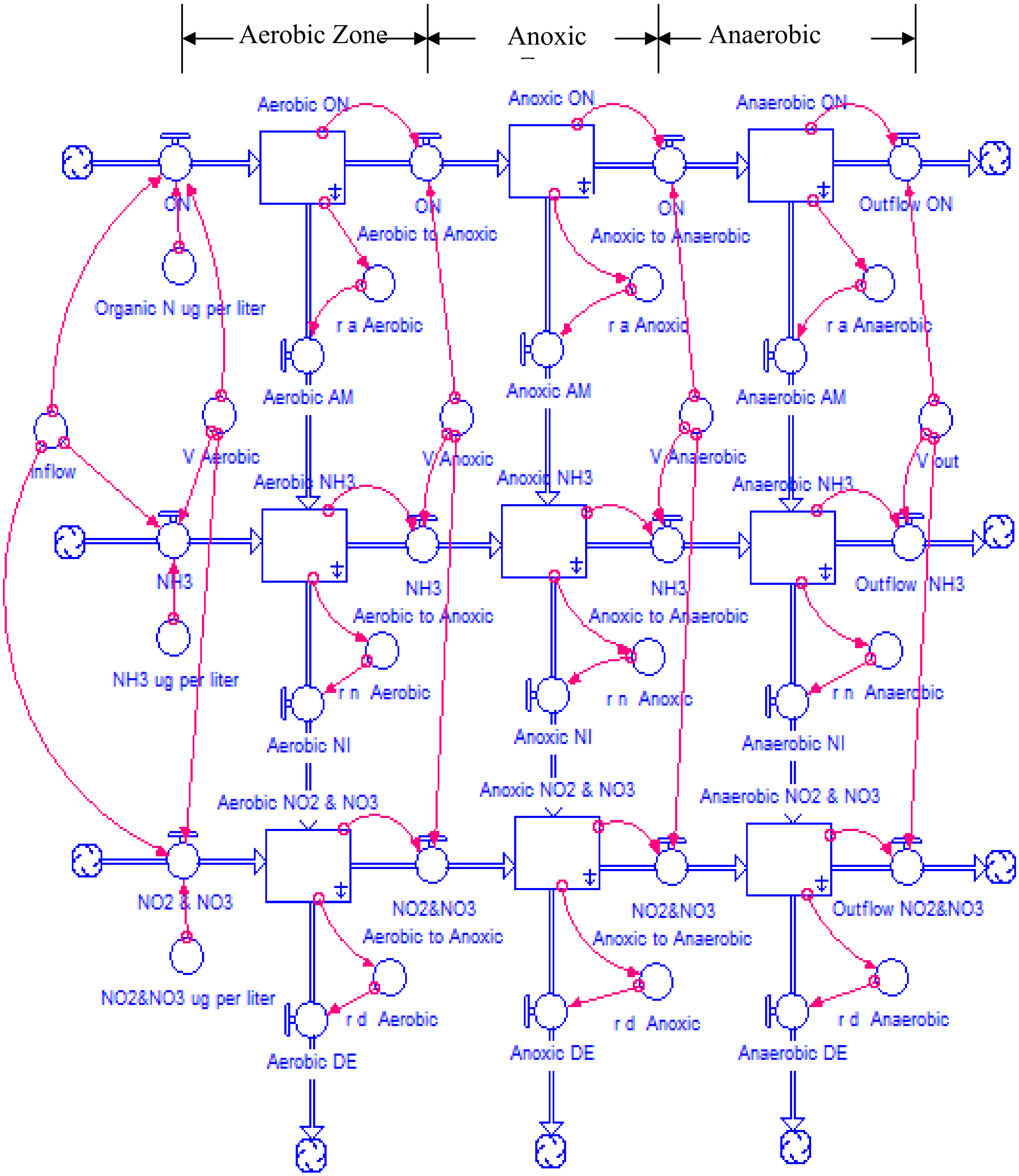


Figure 60 Flow Diagram of Nitrogen Removal Model

Table 23 Values Used in the Rate Equations of Ammonification, Nitrification and Denitrification

	Rate equations	Unit	Aerobic zone	Anoxic zone	Anaerobic zone
k_a	$r_a = k_a C_{ON}$	day^{-1}	0.05	0.42	0.23
$\frac{u_N}{Y_N}$	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	day^{-1}	3.96	0.32	0.006
K_{20d}	$r_d = K_{20d} \theta_d^{(T-20)} C_{NN}$	day^{-1}	0.26	5.8	9.0
DO	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	mg/L	4.42	1.33	1.41
pH	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	N/A	6.54	6.70	6.71
T	$r_n = \frac{u_N}{Y_N} C_T C_{pH} (\frac{C_{DO}}{1.3 + C_{DO}}) C_{AN}$	^oC	26.4	24.2	23.9

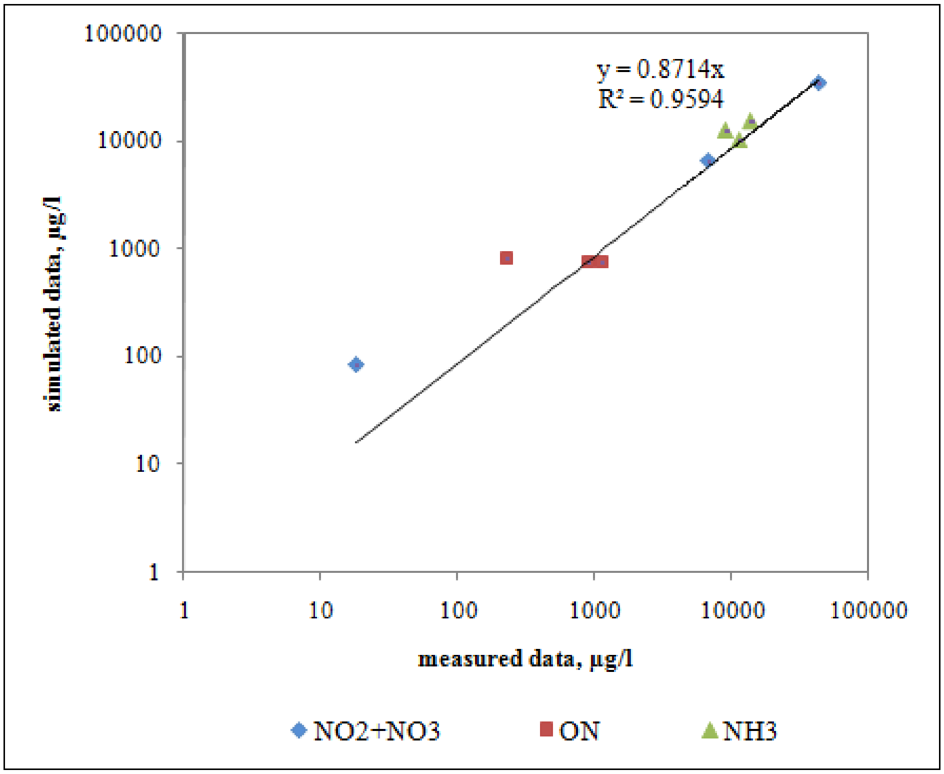


Figure 61 Correlation between the Measured and Simulated Values in Model Calibration

9.2.2 Model validation

Two sets of data collected in March 2009 were used for model validation with the same reaction parameters. Table 24 lists the measured values of the other two sets of data. The correlation between the measured and simulated values is shown in Figure 61. The slope of the regression line was 1.05 and correlation (R^2) was about 0.87, which shows the agreement of the model validation. Most of points are close to the 45 degree line except one overrated oxidized nitrogen value.

Table 24 Parameter Values Used for Model Validation

March 4	Unit	Aerobic zone	Anoxic zone	Anaerobic zone
DO	mg/L	3.54	1.09	0.94
pH	N/A	6.44	6.66	6.70
T	^oC	18.4	18.8	18.6
March 31	Unit	Aerobic zone	Anoxic zone	Anaerobic zone
DO	mg/L	3.54	1.30	1.05
pH	N/A	6.70	6.74	6.71
T	^oC	25.7	23.4	24.5

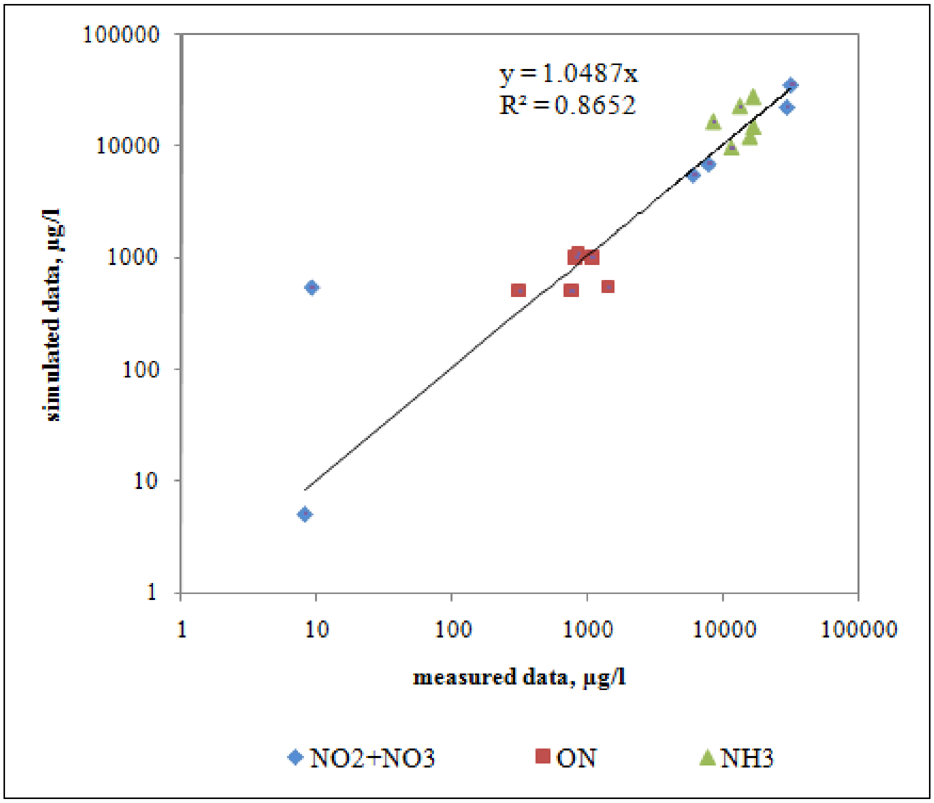


Figure 62 Correlation between the Measured and Simulated Values in Model Validation

9.2.3 Sensitivity analysis and model prediction

With the aid of the calibrated and validated system dynamics model, Table 25 shows the corresponding ranges of effluent concentrations with ± 30% fluctuations of influent nitrogen concentrations. In this sensitivity analysis, the variations of influent organic nitrogen concentrations have the expected direct effect on the effluent ammonia concentrations (30% values), while the influent Nitrite and Nitrate concentrations do not affect the effluent concentrations as expected.

Table 25 Corresponding Nutrient Ranges of Effluent Concentrations in Model Prediction

	Organic N		Ammonia		NO_2+NO_3	
	(-30%)	(+30%)	(-30%)	(+30%)	(-30%)	(+30%)
Organic N	(-1.22%)	(+1.12%)	-	-	-	-
Ammonia	(-30.0%)	(+30.0%)	(-28.8%)	(+28.4%)	-	-
NO_2+NO_3	(0.08%)	(+0.08%)	(-29.9%)	(+29.9%)	(-0.04%)	(+0.01%)

Chapter 10 Conclusions

10.1 Summary and remarks

Several passive OSTDS designs, including the B&G Filter and the subsurface upflow wetland (SUW) OSTDSs were evaluated for nutrient removal. The B&G Filter and SUW systems have an advantage over conventional and performance-based OSTDS due to their higher nutrient removal efficiency, energy saving, and low maintenance requirements. To illustrate removal effectiveness for the passive systems, Table 26 summarizes data for the conventional OSTDS (control) and three conventional with RSF designs, the B&G Filter, and the SUW with Canna as the plant species. For non-nutrient pollutants, the performance for the B&G Filter and the SUW is similar to the conventional septic tank systems. For nutrients, the B&G Filter and the SUW perform much better. Table 26 is developed based on the average raw water (inflow) and outflow conditions during the testing period. To understand the performance of each OSTDS where the sorption media were applied, Table 27 summarizes the removal efficiencies of each process using the effluent from the septic tank.

Part IV of Chapter 64E-6, F.A.C. establishes the requirements for Performance based Treatment Systems (PBTS). Although Florida PBTS regulations do not require a specific concentration of nitrate discharged to the groundwater, PBTS must be designed to meet the appropriate level of treatment for the area. This can be either secondary, advanced secondary, or advanced wastewater treatment, with the following corresponding concentrations of TN – Not Specified, 20 mg/L, 3 mg/L. Also, systems in some parts of Florida must meet 10 mg/L TN. There are only selected instances that a TN standard of 10 mg/L applies, and more common is the advanced secondary treatment standard of 20 mg/L TN. Given that the advanced secondary treatment standard of 20 mg/L is used, the B&G Filter and SUW systems would be very promising alternatives, because the effluent concentration data of the B&G Filter have shown TN between 6.5 – 19 mg/L in six sampling campaigns and the results collected from the SUW system are even better. Also, given a goal to protect and restore surface waters by having a TN of less than 1 mg/L, both the B&G Filter and the SUW provide high levels of nitrogen removal. Also it is important to note that these passive systems require no energy and construction cost is relatively low, especially compared to a performance-based OSTDS.

Table 26 Percent Concentration Change for OSTDSs

	Concentration Changes (- or negative entry indicates an increase)					
Parameter	Conventional Drainfield Control	Conventional Drainfield Recirculation Design I	Conventional Drainfield Recirculation Design II	Conventional Drainfield Recirculation Design III	B&G Filter	SUW - Canna Plants
Alkalinity (mg/L)	77.10%	32.63%	67.88%	88.02%	26.33%	-46.76%
TSS (mg/L)	98.91%	98.13%	99.17%	99.53%	94.73%	*
BOD5 (mg/L)	99.04%	90.14%	95.91%	98.51%	85.15%	94.79%
CBOD5 (mg/L)	99.23%	91.86%	96.01%	98.45%	88.35%	95.74%
Ammonia-N (µg/L)	99.93%	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)	63.57%	74.91%	97.21%	76.16%	82.71%	97.04%
TN (µg/L)	-16.47%	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)	32.28%	3.21%	86.73%	66.91%	83.56%	96.68%
TP (µg/L)	-1.76%	48.70%	11.01%	9.21%	81.79%	98.41%
Fecal (cfu/100mL)	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%
E.Coli. (cfu/100mL)	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%	>99.9%

* No entry when sampling errors were present, such as particulate matter present in sample or residual nutrients.
# Change or removal is based on influent concentration values and the effluent from the drainfields or the media fields. Nitrate is not included because in raw sewage the nitrogen form typically is not nitrates or near zero.

Table 27 Removal Efficiencies for OSTDS Process Units Compared to Septic Tank Effluent

Parameter	RSF Design I	RSF Design II	RSF Design III	B&G Filter	Wetland 1	Wetland 2	Wetland 3	Control wetland
Alkalinity	15.2%	24.1%	-15.5%	34.6%	-11.4%	8.1%	-7.3%	35.9%
TSS	66.9%	62.1%	53.0%	81.2%	-116.3%	-10.0%	-100.0%	-46.6%
BOD5	51.5%	58.5%	65.0%	90.9%	88.8%	83.2%	84.5%	75.3%
CBOD5	20.3%	62.7%	72.0%	93.9%	87.7%	88.3%	85.4%	83.3%
Ammonia-N	68.4%	37.3%	1.1%	82.3%	98.4%	88.2%	68.3%	22.6%
Org. N	-47.1%	39.3%	-22.2%	43.6%	91.1%	75.2%	71.8%	27.9%
TKN	48.2%	37.6%	-8.0%	79.7%	97.1%	85.8%	69.0%	23.5%
TN	32.2%	18.2%	-7.9%	66.1%	97.1%	85.8%	69.0%	23.5%
SRP	43.5%	-3.1%	-0.6%	84.7%	99.6%	95.7%	99.6%	99.4%
Diss. Org. P	92.7%	-60.0%	-18.6%	5.5%	95.3%	81.0%	94.7%	61.8%
TP	47.8%	-1.9%	-5.0%	77.6%	98.3%	91.3%	98.2%	88.4%
Fecal	99.3%	87.1%	98.9%	100.0%	99.9%	98.5%	98.3%	98.4%
E.Coli.	99.8%	70.5%	98.3%	100.0%	100.0%	99.0%	98.0%	98.3%

10.2 Groundwater impacts from conventional drainfield

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 groundwater were measured based on full scale operation of the conventional septic tank and drainfield designs. The average measured data from 16 groundwater sampling wells (2 beneath the conventional OSTDS drainfield) as shown in Figures 6,7, and 8 indicate that the nutrient levels are greater under the conventional drainfield relative to the background average nutrient values. Maximum levels of nutrients under the drainfield are also noted and compared to the lowest background levels in 5 up-gradient wells as shown in Table 28. 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 drainfield are similar to those data reported in the Wakulla springs drainfield study (Katz, 2010). These water quality data show the potential impact of increasing nutrients on groundwater if nutrients are not controlled.

Table 28 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 drainfields
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

10.3 Cost analyses

The construction and operating cost factors for each unit constructed at the UCF OSTDS Test Center are available for calculations of an annual and a unit cost for treatment. Comparisons to other geographic locations are not done because of many site conditions and labor rate variables among different geographic locations. Nevertheless, it is noteworthy to cite other literature to show that other cost data for evaluations are available. One such detailed effort was an evaluation of OSTDS completed for the Keys in the late 1990s with an assessed cost for a variety of OSTDS (Anderson et al., 1998). Another evaluation for the Wekiva area of Florida is also available (Anderson, 2006).

The cost of operating the B&G Filter is considered to be equal to the cost of operating a conventional OSTDS and the operating cost of the SUW is assumed based on the replacement of plants. Plant replacement cost was estimated on a yearly basis and assumes that 20% of the plants will be replaced. The OSTDS at UCF were operated by dosing the systems, and the cost of the dosing pump increases the cost per 1000 gallons by $0.12, for the OSTDS of this report. When the recirculation sand filter is added to a conventional system, an energy cost is also assigned because of the pump operation. A one-half horse power pump is used for recycling in the example recirculation OSTDS of this report.

Construction cost estimates are based on the construction and materials used for the septic tank, drainfield, connectors, B&G Filter and SUW as built at the UCF OSTDS Test Center. All OSTDS cost estimates are based on a flow rate of 500 gallons per day (gpd), thus the cost data for the UCF Test Center had to increase based on additional flow, and the increase was calculated from construction materials and labor as installed for the UCF site. Additional flow rates and cost estimates with details are provided by Wanielista (2008). It is recognized that other OSTDS technologies are designed to incorporate nutrient removal and will have construction and operating costs, but are not reported here. The construction cost increase for the B&G Filter is approximately $2,600 more than the conventional OSTDS (septic tank and drainfield) and the construction cost increase for the SUW is $3,300 more. Cost data are from actual purchased prices for materials and labor for installation and includes a 20% contingency margin.

Cost comparison data from other OSTDS studies are presented but many assumptions make these only approximate. First, a 500 gallon per day flow rate basis to be consistent with the data in Table 29 is made. The cost for the passive conventional, B&G Filter, 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. Thus, assumptions for data reported in 1998 are made to inflate to mid-year 2009 using a 60% increase in construction cost and a 40% increase in operating cost to adjust cost data in the literature reported in 1998 to a mid-year 2009 estimate. The increases can be based on a building cost index and the estimate does take into account a construction cost decrease of 8.4% from mid-year 2008 through 2009 (Turner, 2009). Using the cost data from the Wekiva area of Florida, Anderson (2006) concluded that for a specific nitrogen removal system not studied at the UCF Test Center, the life cycle cost per year would be about $2233 and $12.24/thousand gallons.

The lowest annual cost for the OSTDSs listed in Table 29 is $700 per year ($500 annualized construction plus $200 operating) for the conventional OSTDS. However the conventional design as tested does not remove significant nutrients. The cost per 1000 gallons of flow is calculated assuming that an average of 500 gallons passes through the OSTDS every day and in a year 182.5 thousand gallons (365 days per year / 2 days for 1000 gallons) are treated. Thus the cost per thousand gallons is $3.84 (700/182.5). For nutrient reduction, the B&G Filter and the SUW annual and unit costs are listed in Table 29. The B&G Filter, RSF, and SUW sorption options for nitrogen removal from the UCF OSTDS Test Center within this report show annual construction plus operation cost range from $925 or $5.07/thousand gallons [($925/182.5 yearly thousand gallons) = $5.07] for the B&G Filter to $1185 or $6.49/thousand gallons [($1185/182.5 yearly thousand gallons) = $6.49] per year for the SUW. The RSF OSTDS cost comparison data are presented however the nutrient removal for the configurations tested are not as consistent or as high as the B&G Filter and SUW OSTDS options. The annual cost does not include cost of certification if required. It should be noted that the cost in Table 29 are highly variable from region to region in the State of Florida, but relative cost comparisons of each with respect to the conventional OSTDS should remain the same if the designs are the same as used here. Also, there may be different site conditions for the same OSDTS configurations and thus the cost may indeed be less or more than reported in Table 29.

Table 29 Cost Comparison for OSTDS Technologies Including B&G Filter and SUW Designed at 500 gpd (Mid-year 2009 Basis)

System Technology	Construction Cost in 2009 ($) except last entry	Annualized Construction Cost at 6% interest rate and 20 years ($)	Annual Operating Cost ($)	Unit Cost $/1000 gallons
Conventional OSTDS	5,770	500	200	3.84
B&G Filter media and DF	8,370	725	200	5.07
Conventional OSTS with RSF	6,920	600	390	5.42
SUW with sorption media and plants	9,070	785	400	6.49

10.4 Certification and commercialization

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

10.5 Future work

Continuing efforts will be directed toward additional modeling efforts based on the test data from this report and other data. 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 to fit in a variety of real world systems are inevitable. The processes of this report and modifications should be applied to different sites in differing regions country wide.

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Appendix A: Groundwater Sampling and Data Record

Table 30 Groundwater Data

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	NOX-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
11/4/2008	M1	80.4	120	14	4.4	64	145	11	134	792	856	2810	22	26	146	<1	<1
11/18/2008	M1	38	31	2	<2	73	60	51	9	1022	1,095	1155	55	ND	144	<1	<1
11/4/2008	M2	16.4	1344	10	9.2	1159	38	5	33	1637	2,796	14435	31	36	349	4	<1
11/18/2008	M2	<.5	1493	5	3.7	558	15	11	4	441	999	1014	44	ND	146	<1	<1
3/3/2009	M2	15.2	1050	9.3	4.8	21,315	610	30	580	1,406	22,721	25,701	14	20	345	<1	<1
3/18/2009	M2	ND	ND	ND	ND	3,029	335	14	321	669	3,698	8,816	64	64	174	<1	<1
3/30/2009	M2	ND	ND	ND	ND	1,675	166	5	161	8,505	10,180	10,346	24	318	342	<1	<1
4/13/2009	M2	ND	ND	ND	ND	996	163	6	157	755	1,751	1,914	19	61	80	<1	<1
4/27/2009	M2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1
9/29/2009	M2	6	63.5	1.1	0.5	821	194	3	191	839	1660	1,854	20	4	24	ND	ND
10/13/2009	M2	ND	ND	ND	ND	1,003	444	3	441	504	1507	1,951	100	6	106	577	<1
10/27/2009	M2	ND	ND	ND	ND	1,486	566	5	561	3,204	4690	5,256	40	156	196	ND	ND
11/10/2009	M2	ND	ND	ND	ND	1,549	3,155	7	3148	2,539	4088	7,243	60	51	111	1,630	<1
11/18/2009	M2	ND	ND	ND	ND	1,352	5,159	19	5140	2,508	3860	9,019	86	5	91	ND	ND
1/19/2010	M2	ND	ND	ND	ND	68	19134	15	19119	841	909	20043	617	74	691	ND	ND
1/26/2010	M2	ND	ND	ND	ND	161	15183	7	15176	13974	14135	29318	587	285	872	ND	ND
2/9/2010	M2	ND	ND	ND	ND	168	1428	3	1425	44234	44402	45830	74	2041	2115	ND	ND
11/4/2008	M3	120	337	6	4.9	96	245	19	226	561	657	3419	19	21	88	<1	<1
11/18/2008	M3	111	42	3	<2	5	265	8	257	691	696	961	21	ND	58	<1	<1
1/26/2010	M3	ND	ND	ND	ND	106	521	3	518	338	444	965	37	5	42	ND	ND
2/9/2010	M3	ND	ND	ND	ND	99	1125	7	1118	5001	5100	6225	35	125	160	ND	ND
10/2/2008	M4	389	128	3.5	<2.0	444	5	4	1	1268	1,712	1402	36	39	135	<1	<1
11/4/2008	M4	376	335	5.6	4.9	373	24	5	19	757	1,130	876	7	26	49	4	2
11/18/2008	M4	311	1493	<2	<2	218	6	5	1	712	930	936	31	ND	61	<1	<1
9/29/2009	M4	356	10	6.3	2.7	35	15	8	7	287	322	337	28	9	37	ND	ND
1/19/2010	M4	ND	ND	ND	ND	13	416	3	413	195	208	624	29	7	36	ND	ND

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**NOX-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
11/5/2008	M5	172	22.5	<2	<2	56	9	5	4		56	2200	138	ND	167	<1	<1
11/4/2008	M6	62	1144	7.4	6.1	813	2815	324	2491	3853	4,666	5044	31	63	303	<1	<1
11/19/2008	M6	46	159	7	2.5	1823	2474	52	2422	1950	3,773	6247	85	ND	212	<1	<1
3/3/2009	M6	40.6	695	9.6	5.7	42,618	279	23	256	2,477	45,095	46,398	97	5	504	ND	ND
3/18/2009	M6	ND	ND	ND	ND	1,419	1024	37	987	1004	2,423	7,715	128	104	495	<1	<1
3/30/2009	M6	ND	ND	ND	ND	2,026	1,039	877	162	1,017	3,043	4,082	202	16	218	<1	<1
4/13/2009	M6	ND	ND	ND	ND	1,749	785	43	742	385	2,134	2,919	204	4	208	<1	<1
9/29/2009	M6	26	501	2.9	1.9	2,341	304	32	272	3,959	6300	6,604	215	185	400	ND	ND
10/13/2009	M6	ND	ND	ND	ND	3,575	953	31	922	2,171	5746	6,699	137	67	204	180	<1
10/27/2009	M6	ND	ND	ND	ND	2,502	345	71	274	6,122	8624	8,969	463	136	599	ND	ND
11/10/2009	M6	ND	ND	ND	ND	1,171	1,312	37	1275	3,465	4636	5,948	651	65	716	5,910	<1
11/18/2009	M6	ND	ND	ND	ND	1,787	1,222	58	1164	1,852	3639	4,861	382	755	1,137	ND	ND
1/19/2010	M6	ND	ND	ND	ND	79	4	30	-26	981	1060	1064	273	39	312	ND	ND
1/26/2010	M6	ND	ND	ND	ND	1510	508	19	489	1028	2538	3046	472	80	552	ND	ND
2/9/2010	M6	ND	ND	ND	ND	1321	2064	15	2049	6835	8156	10220	487	863	1350	ND	ND
10/2/2008	M7	55.2	263	2.4	<2.0	7873	788	5	783	9338	17,211	9610	400	443	526	<1	<1
11/4/2008	M7	28.4	259	5.1	4.8	496	1186	28	1158	1982	2,478	2568	124	159	198	<1	<1
11/18/2008	M7	40	1300	<2	<2	759	904	32	872	1168	1,927	2831	115	ND	130	<1	<1
10/2/2008	M8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	57	<1
11/3/2008	M8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	9
11/4/2008	M8	188	934	8	7	163	144	20	124	790	953	3681	31	40	208	<1	9
11/18/2008	M8	145	58	2.6	<2	75	48	9	39	1305	1,380	1428	38		105	<1	<1
9/29/2009	M8	183	109	7.9	3.6	227	25	4	21	1,052	1279	1,304	40	62	102	ND	ND
3/30/2009	MW1	269	20	6	3	91	5	5	0	333	424	426	<1	62	62	<1	<1
4/27/2009	MW1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1
10/2/2008	MW2	58.4	6.6	<2.0	2.7	153	2233	13	2220	3190	3,343	3284	28	29	32	<1	<1
11/4/2008	MW2	116	1.6	5.8	3.1	86	1727	17	1710	1938	2,024	2414	13	41	53	<1	<1
9/29/2009	MW2	137	1	0.9	0.6	42	530	11	519	300	342	872	63	39	102	ND	ND
10/13/2009	MW2	ND	ND	ND	ND	93	332	6	326	273	366	698	37	34	71	40	<1
10/27/2009	MW2	ND	ND	ND	ND	34	6	2	4	491	525	531	34	34	68	ND	ND
11/10/2009	MW2	ND	ND	ND	ND	58	18	17	1	442	500	518	29	28	57	1,523	<1

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	NOX-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
11/18/2009	MW2	ND	ND	ND	ND	41	14	8	6	405	446	460	42	11	53	ND	ND
10/2/2008	MW3	400	44.8	2.2	<2.0	1592	64	8	56	2651	4,243	2686	33	43	59	<1	<1
11/4/2008	MW3	116	12.8	4.8	4.3	2082	50	5	45	2133	4,215	2909	5	36	42	<1	<1
3/3/2009	MW3	260	2816	10.5	9.3	1,759	21	5	16	1,208	2,967	8,942	10	8	749	ND	ND
3/30/2009	MW3	ND	ND	ND	ND	1,390	5	5	0	211	1,601	1,603	15	40	55	<1	<1
4/27/2009	MW3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1
10/2/2008	MW3 Duplicate	399	53.4	2	<2.0	1576	65	8	57	2600	4,176	2624	35	42	61	ND	ND
11/4/2008	MW3 Duplicate	289	10.6	4.1	4	2083	52	5	47	2154	4,237	2860	13	37	47	<1	<1
3/3/2009	MW3 Duplicate	275	370	8.4	7.8	1,523	20	5	15	1,479	3,002	7,036	12	8	179	ND	ND
10/2/2008	MW4	99.2	8.5	<2.0	<2.0	179	1579	33	1546	2475	2,654	2624	68	69	89	4	<1
11/4/2008	MW4	41.6	35.4	4.3	3	236	920	16	904	1422	1,658	1902	12	38	52	<1	<1
3/3/2009	MW4	45.2	1505	6.6	<2.0	810	24	5	19	290	1,100	7,625	4	12	765	<1	<1
3/30/2009	MW4	ND	ND	ND	ND	1,357	35	5	30	5,804	7,161	7,196	17	842	859	ND	ND
1/19/2010	MW4	ND	ND	ND	ND	114	18	2	16	270	384	402	72	101	173	ND	ND
1/26/2010	MW4	ND	ND	ND	ND	143	49	3	46	339	482	531	42	5	47	ND	ND
2/9/2010	MW4	ND	ND	ND	ND	138	16	1	15	352	490	506	26	7	33	ND	ND
10/2/2008	MW5	112	78.3	2.3	<2.0	369	12	15	-3	2013	2,382	2021	25	28	135	4	<1
11/4/2008	MW5	208	62.3	4.9	4.6	979	49	8	41	1328	2,307	2295	13	60	72	<1	<1
3/30/2009	MW5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1
10/13/2009	MW5	ND	ND	ND	ND	154	93	7	86	352	506	599	83	37	120	ND	ND
10/27/2009	MW5	ND	ND	ND	ND	2,283	6	3	3	899	3182	3,188	495	380	875	ND	ND
11/10/2009	MW5	ND	ND	ND	ND	579	6	3	3	422	1001	1,007	184	69	253	3,840	<1
11/18/2009	MW5	ND	ND	ND	ND	260	28	10	18	329	589	617	196	3	199	ND	ND
10/2/2008	MW6	84	7.4	<2.0	<2.0	1534	1325	21	1304	3035	4,569	3610	905	1111	1270	7	<1
11/4/2008	MW6	254	91	4.8	3.3	445	13	5	8	872	1,317	1738	13	40	52	<1	<1
3/3/2009	MW6	30.4	476	6.9	4.2	520	9,151	10	9141	257	777	13,138	73	7	400	<1	<1
3/30/2009	MW6	ND	ND	ND	ND	2,283	3,189	12	3177	337	2,620	5,809	56	876	932	<1	<1
4/27/2009	MW6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1
10/2/2008	MW7	109	5.8	<2.0	<2.0	318	1660	16	1644	4558	4,876	4564	98	1740	1759	4	<1
11/4/2008	MW7	143	40	5	3.6	1382	4629	35	4594	6030	7,412	7737	482	508	634	<1	<1

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	NOX-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
3/3/2009	MW7	68.2	2900	10.2	3	654	29,950	34	29916	1,159	1,813	40,414	2,877	181	6,529	<1	<1
3/30/2009	MW7	ND	ND	ND	ND	314	24,299	18	24281	3,413	3,727	28,026	2,359	751	3,110	<1	<1
9/29/2009	MW7	131	34.5	2	1.6	84	5,579	11	5568	380	464	6,043	2,890	92	2,982	ND	ND
10/13/2009	MW7	ND	ND	ND	ND	75	2,469	16	2453	958	1033	3,502	2,390	37	2,427	2,560	20
10/27/2009	MW7	ND	ND	ND	ND	15	2,589	3	2586	2,207	2222	4,811	2,063	16	2,079	ND	ND
11/10/2009	MW7	ND	ND	ND	ND	1,119	9,506	5	9501	17,240	18359	27,865	2,301	65	2,366	109	<1
11/18/2009	MW7	ND	ND	ND	ND	1,721	10,684	12	10672	11,503	13224	23,908	2,412	1,804	4,216	ND	ND
1/19/2010	MW7	ND	ND	ND	ND	3	20743	7	20736	91	94	20837	3368	25	3393	ND	ND
1/26/2010	MW7	ND	ND	ND	ND	12	22632	7	22625	18212	18224	40856	3510	2808	6318	ND	ND
2/9/2010	MW7	ND	ND	ND	ND	44	1344	5	1339	16594	16638	17982	227	2042	2269	ND	ND
10/2/2008	MW8	177	4	<2.0	2	1085	67	8	59	1277	2,362	1308	72	83	98	<1	<1
11/4/2008	MW8	87.6	28.4	4.1	3.8	62	2410	33	2377	2552	2,614	2580	69	72	87	<1	<1
9/29/2009	MW8	362	832	1.6	1.5	594	82	1	81	3,225	3819	3,901	59	425	484	ND	ND
10/13/2009	MW8	ND	ND	ND	ND	226	47	7	40	1,269	1495	1,542	121	169	290	ND	ND

Appendix B: OSTDS Sampling and Analysis Record

Table 31 Average Removal Efficiencies of the Above-Ground Media Filter Tank

Removal Efficiency	**Alkalinity**	**TSS**	**BOD5**	**CBOD5**	**Ammonia-N**	**Org. N**	**TKN**	**TN**	**SRP**	**Diss. Org. P**	**TP**
Design I	15%	67%	51%	20%	68%	-47%	48%	32%	44%	93%	48%
Design II	24%	62%	58%	63%	37%	39%	38%	18%	-3%	-60%	-2%
Design III	-15%	53%	65%	72%	1%	-22%	-8%	-8%	-1%	-19%	-5%

Table 32 Data - Sample Location ID S1 (Raw Wastewater)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S1	293	175	31.3	31.2	32864	8	3	13395	46259	46270	4928	32	7200	898000	852000
11/4/2008	S1	316	268	41.6	37.1	42143	8	94	3865	46008	46110	4918	5005	9891	4120000	2140000
11/5/2008	S1	316	268	41.6	37.1	42143	8		3967	46110	46110	4918		9891	4120000	2140000
11/18/2008	S1	295	117	6.2	5.4	11921	18	10	2935	14856	14884	5174		5616	3620000	2580000
11/19/2008	S1	295	117	6.2	5.4	11921	18	10	2935	14856	14884	5174	4960	5616	3620000	2580000
2/1/2009	S1	277	250	725	204	37040	20	5	9525	46565	53410	4469	1021	8310	1952000	752000
2/10/2009	S1	277	250	725	204	37040	20	5	9525	46565	53410	4469	1021	8310	1952000	752000
2/24/2009	S1	275	212	232	181	32990	27	4	7008	39998	41752	3859	697	6356	800000	600000
3/3/2009	S1	275	50.9	62.5	34.5	1114	777	4630	22181	23295	36060	6604	118	7857	450000	450000
3/10/2009	S1	264	644	355	350	67685	71	34	231	67916	77202	8026	2586	14037	3024000	650000
3/18/2009	S1	284	165	5.9	4.6	38901	5	19	1062	39963	47930	4453	660	6689	2440000	100000
3/25/2009	S1	521	454	345	260	55657	15	36	15537	71194	79219	6659	159	6985	3955000	2510000
3/30/2009	S1	283	82	293	156	41884	31	17	3016	44900	44948	3164	3694	6858	3080000	1550000
4/8/2009	S1	279	342	310	241	45194	13	2	19238	64432	64447	5128	4688	9816	1600000	1230000
4/13/2009	S1	250	150	149	132	27266	8	1	7044	34310	34319	2383	2070	4453	760000	430000
4/22/2009	S1	286	259	345	136	41944	30	14	1633	43577	43621	3627	512	4139	3355000	2075000
7/13/2009	S1	297	53	116	96	61201	3	15	6949	68150	68168	3910	1910	5820		
8/18/2009	S1	231	39	79.5	69.9	38029	2062	792	4344	42373	45227	2513	508	3021		
9/1/2009	S1	334	29.3	79.5	63.9	49667	3	13	14713	64380	64396	3815	1935	5750	920000	326667
9/8/2009	S1	315	71.4	57.3	39.6	57055	1	14	9836	66891	66906	4433	527	4960	506667	400000

9/17/2009	S1	337	47.8	73.5	57.3	51994	5	2	12024	64018	64025	4079	719	4798	780000	460000
9/24/2009	S1	289	58.5	136	118	36397	15	6	29533	65930	65951	2662	3525	6187		
9/30/2009	S1	329	47.3	75.5	57.5	54147	9	6	13097	67244	67259	3656	3665	7321	5800000	3750000
10/14/2009	S1	102	139	176	162	35796	41	68	48889	84685	84794	4468	5766	10234	20200000	2940000
10/28/2009	S1	89	76.4	108	104	30252	24	1136	41969	72221	73381	3828	2578	6406	2300000	1333333
11/11/2009	S1	280	213	124	119	32130	9	21	16679	48809	48839	2914	1958	4872	6200000	1266667
11/17/2009	S1	149	88.6	106	104	34070	25	1643	19960	54030	55698	2755	4032	6787		

Table 33 Data of Sample Location ID S1 Field Duplicate (Raw Wastewater)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
3/18/2009	S1 Field Dup	282	230	7.9	4.7	38,321	5	20	1552	39,873	48,467	4595	752	7094		
3/30/2009	S1 Field Dup	284	92	318	151	41,279	32	16	5,030	46,309	46,357	3,045	2,904	5,949	2,250,000	1,445,000
4/13/2009	S1 Field Dup	250	176	128	101	27,674	8	1	6,913	34,587	34,596	2,423	2,092	4,515		
4/27/2009	S1 Field Dup														48333	38333
7/13/2009	S1 Field Dup	299	45.5	109	90.3	60,561	4	10	8,410	68,971	68,985	4,033	1,627	5,660		
9/30/2009	S1 Field Dup	326	57.7	84.5	71	54803	9	4	11426	66229	66242	3456	3433	6889		
10/14/2009	S1 Field Dup	103	94.5	173	161	35194	42	1007	46822	82016	83065	4495	5379	9874	8320000	2640000
10/28/2009	S1 Field Dup	86	109	120	116	31610	24	157	48530	80140	80321	3901	2670	6571	2800000	866667
11/11/2009	S1 Field Dup	277	158	109	105	32304	11	18	20968	53272	53301	2920	2627	5547	6666667	866667
11/17/2009	S1 Field Dup	153	90.8	107	97.8	34029	26	1654	18896	52925	54605	2753	3985	6738		

Table 34 Data of Sample Location ID S3 (Recirculation Sand Filter Inlet/Drainfield Inlet)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S3	322	42	6.6	4.2	37538	32	9	5166	42,704	42745	4271	1254	6440	768000	6594
11/5/2008	S3	273	26.5	20	7	6398	5	BDL	1915	8,313	8318	3122		3802	2820000	1810000
11/19/2008	S3	268	14	17.6	14.4	4791	5	BDL	3220	8,011	8016	3597		4140	1510000	135000
3/4/2009	S3	269	59.3	56.7	43.5	18,664	5	2	87	18,751	21,740	5,508	261	7,621	>8000	>8000
3/18/2009	S3	266	48	58.5	54	29,750	5	BDL	638	30,388	31,085	7537	170	7972	2,255,000	13,666
3/31/2009	S3	264	32	100	84	30,316	12	3	9,380	39,696	39,711	5,577	639	6,216	300,000	290,000
4/15/2009	S3	290	33.3	44.5	39	31,660	8	5	5,847	37,507	37,520	5,031	569	5,600	965,000	285,000
7/7/2009	S3														64000	52000
7/14/2009	S3	404	28.1	97.8	90.6	54,356	1	4	4,379	58,735	58,740	5,564	642	6,206		
9/30/2009	S3	377	9.4	57.3	34.8	58,164	5	2	1,137	59,301	59,308	4,201	1,393	5,594		
10/14/2009	S3	368	22.8	62.1	55.2	37,883	1	271	27,180	65,063	65,335	5,047	2,248	7,295	2,920,000	1,485,733
10/28/2009	S3	104	29.1	63.4	61.6	32,615	21	12	48,613	81,228	81,261	4,435	1,269	5,704	860	1
11/11/2009	S3	328	23.4	29.8	28.6	25	9	1270	49,044	49,069	50,348	3,746	102	3,848	316,667	83,333
11/17/2009	S3	313	16.6	40.4	30.8	37,801	10	280	13,596	51,397	51,687	2,506	2,622	5,128		

Table 35 Data of Sample Location ID S4 (Recirculation Sand Filter Outlet)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S4	236	15	11.6	6.8	14813	1635	1343	6758	21,571	24549	339	92	827		
11/5/2008	S4	244	<.7	<2	<2	199	6	10	7114	7,313	7329	2725		2918	23333	2300
11/19/2008	S4	252	3.2	2.7	<2	400	8	6496	1279	1,679	8183	3143		3763	1067	12
3/4/2009	S4	194	16	15.3	11.7	7,602	882	7152	301	7,903	17,421	5,387	341	6,528		
3/18/2009	S4	197	20	24	18	20,262	134	5310	1050	21,312	28,067	7740	770	8612	159,000	960
3/31/2009	S4	200	25	38	31	22,253	1,147	2423	2,626	24,879	28,449	6,354	909	7,263	155,000	95,000
4/15/2009	S4	236	4.4	30.5	21.5	19,083	908	6747	5,702	24,785	32,440	4,917	603	5,520	141,667	77,500
7/7/2009	S4														11600	8000
7/14/2009	S4	403	16.2	40.7	32.6	51,399	1	2	2,176	53,575	53,578	4,410	1,118	5,528		
9/30/2009	S4	367	5.3	30.8	20.1	56,837	4	1	8,064	64,901	64,903	4,156	1,909	6,065		
10/14/2009	S4	349	10.6	11.2	8.7	38,399	14	36	51,242	89,641	89,691	6,151	2,959	9,110	10,000	<1
10/28/2009	S4	407	10	11.1	10.3	34,290	80	194	50,857	85,147	85,421	4,462	910	5,372	37	1
11/11/2009	S4	325	11.9	16.8	6.4	22	3	305	51,392	51,414	51,722	3,954	420	4,374	24,840	17,280
11/17/2009	S4	336	6.8	12.2	6.4	37,359	8	732	12,105	49,464	50,204	2,509	2,497	5,006		

Table 36 Data of Sample Location S5 (Astatula Sand, Conventional Drainfield at 8-inch Below Filtrating Media)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S5	NS	NS	NS	NS	23	25	60110	4527	4,550	64685	2720	70	2920	119	40
11/5/2008	S5	237	0.7	2	2	56	5	BDL	4676	4,732	4737	2815		2989	1	1
11/19/2008	S5	247	8	<2	<2	36	5	4820	718	754	5579	2228		2843	1	1
3/4/2009	S5	114	2	11.5	11.1	119	23	23206	580	699	23,992	5,326	182	5,758	1	1
3/18/2009	S5	108	2	7.5	6.6	963	532	23944	1120	2,083	26,853	7502	19	7828	37	8
3/31/2009	S5	116	3	11.1	7.8	59	5	29906	480	539	30,450	5,900	941	6,841	345,000	200,000
4/15/2009	S5	122	0.8	19	17	68	5	26563	5,794	5,862	32,430	4,777	852	5,629	1	1
4/27/2009	S5														<1	<1
7/14/2009	S5	63.2	2	0.21U	0.5U	12,780	56	40663	2,164	14,944	55,663	4,408	437	4,845		

Table 37 Data of Sample Location S6 (Astatula Sand, Conventional Drainfield at 16-Inch Below Filtrating Media)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S6	202	1	<2	<2	26	80	55453	9011	9,037	64570	4302	48	4440	<1	<1
11/5/2008	S6	228	0.8	2	2	48	5	BDL	6621	6,669	6674	2591		2774	1	1
11/19/2008	S6	224	3	<2	<2	39	5	6123	1547	1,586	7714	2752		3536	1	1
3/4/2009	S6	136	3.6	3.9	<2.0	35	5	20009	289	324	22,184	6,000	217	6,604	1	1
3/18/2009	S6	136	2	8.1	6.2	31	7	9876	8403	8,434	19,868	8004	27	8121	1	1
3/31/2009	S6	128	1	15.9	12.9	80	7	31255	2,338	2,418	33,680	7,456	454	7,910	1	1
4/15/2009	S6	124	1.2	20.5	12	662	59	25838	4,884	5,546	31,443	5,255	721	5,976	1	1
4/27/2009	S6														<1	<1
7/7/2009	S6														4	ND
7/14/2009	S6	69.2	0.2	0.3U	1.1U	6,476	523	30599	4,037	10,513	41,635	4,852	89	4,941		

Table 38 Data of Sample Location S7 (Astatula Sand, Conventional Drainfield at 24-Inch Below Filtrating Media)

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	S7	119	1	2.1	<2	1354	504	4073	32164	33,518	38095	5511	49	5655	20	<1
11/5/2008	S7	219	<0.7	<2	<2	110	31	13	9776	9,886	9930	2289		2897	1	1
11/19/2008	S7	233	<0.7	2.1	<2	37	5	6138	953	990	7133	3073		3714	1	1
3/4/2009	S7	128	3.6	3.3	<2.0	1,442	88	15305	182	1,624	18,683	5,826	354	6,528	1	1
3/18/2009	S7	130	6	4.5	3	1,900	113	25322	331	2,231	28,189	8101	85	8229	1	1
3/31/2009	S7	136	7	18.9	15.3	2,544	5	BDL	24,171	26,715	26,717	5,087	1,568	6,655	1	1
4/15/2009	S7	132	6.4	22.5	14.5	3,536	160	23021	5,204	8,740	31,921	4,974	840	5,814	1	1
4/27/2009	S7														<1	<1
7/7/2009	S7														ND	ND
7/14/2009	S7	14.8	1	0.8U	1.1U	16,700	306	35609	574	17,274	53,189	5,256	79	5,335		

Table 39 Data of Sample Location S8 (Washed Builder's Sand, Conventional Drainfield at 8-inch Below Filtrating Media)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S8	188	1	<2	<2	2193	935	31644	7323	9,516	42095	3411	69	3535	<1	<1
11/5/2008	S8	220	2.2	<2	<2	66	9	2	4051	4,117	4128	2273		2430	1	1
11/19/2008	S8	244	<.7	<2	<2	60	9	3239	3953	4,013	7261	2993		3534	1	1
3/4/2009	S8	132	1.6	10.2	7.5	285	79	22292	838	1,123	24,145	6,030	110	6,782	1	1
3/18/2009	S8	129	2	3.9	3.9	283	60	23057	1356	1,639	25,928	7570	5	7750	1	1
3/31/2009	S8	128	2	24.6	18.6	197	18	30346	990	1,187	31,551	7,086	216	7,302	1	1
4/15/2009	S8	126	0.8	19.5	7.5	9,707	785	18263	4,392	14,099	33,147	5,209	900	6,109		
4/27/2009	S8														<1	<1
7/14/2009	S8	100	0.7	1.1U	1.3U	12,217	705	36261	4,006	16,223	53,189	5,495	18	5,513		
9/30/2009	S8	64	0.3	1.7	1.1	20,200	348	25263	559	20,759	46,370	3,705	644	4,349		
10/14/2009	S8	85	0.3	1.3	0.7	2,173	272	39430	2,687	4,860	44,562	6,217	954	7,171	<1	<1
10/28/2009	S8	40	0.5	4.3	3.6	12,537	1,244	23168	33,152	45,689	70,101	4,731	160	4,891	40	1
11/11/2009	S8	90.4	0.3	2	1.9	10,085	832	27588	9,855	19,940	48,360	3,796	432	4,228	16	12
11/17/2009	S8	123	0.3	1.4	1	66	605	40734	6,648	6,714	48,053	2,157	2,312	4,469		

Table 40 Data of Sample Location S9 (Washed Builder's Sand, Conventional Drainfield at 16-Inch Below Filtrating Media)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (μg/l)**	**Nitrite (μg/l)**	**Nitrate (μg/l)**	**Org. N (μg/l)**	**TKN (μg/l)**	**TN (μg/l)**	**SRP (μg/l)**	**Diss. Org. P (μg/l)**	**TP (μg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S9					15	33	60167	4855	4,870	65070	2332	33	2430	<1	<1
11/5/2008	S9					32	5	BDL	11542	11,574	11579	2054		2214	1	1
11/19/2008	S9					30					14858			2229	1	1
3/4/2009	S9	129	2	6.9	2.4	43	5	21972	1,351	1,394	24,749	5,510	426	6,031	1	1
3/18/2009	S9	130	4	5.1	4.2	50	5	24522	425	475	26,001	6855	367	7616	1	1
3/31/2009	S9	126	2	21	17.1	73	11	34972	3,708	3,781	38,764	7,196	773	7,969	1	1
4/15/2009	S9	127	0.9	21.5	12.5	484	8	28508	8,233	8,717	37,233	5,399	383	5,782	1	1
4/27/2009	S9														<1	<1
7/14/2009	S9	170	0	0.2U	0.8U	389	21	44306	1,664	2,053	46,380	4,674	268	4,942		
9/30/2009	S9	254	0.8	1.3	1.1	32,983	1,871	19318	2,454	35,437	56,626	3,472	808	4,280		
10/14/2009	S9	156	0.4	0.9	0.7	1,908	423	37285	951	2,859	40,567	6,700	379	7,079	<1	<1
10/28/2009	S9	51	0.2	2.5	2.3	3,516	7,016	30121	25,749	29,265	66,402	4,808	639	5,447	1	1
11/11/2009	S9	148	0	0.6	0.5	3,122	769	39685	8,721	11,843	52,297	4,075	295	4,370	1	1
11/17/2009	S9	111	0.2	0.2	0.2	170	22	44604	4,215	4,385	49,011	2,586	1,800	4,386		

Table 41 Data of Sample Location S10 (Washed Builder Sand, Conventional Drainfield at 24-Inch Below Filtrating Media)

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	S10	141	5	3.5	<2	20	9	41938	3783	3,803	45750	4972	93	5160	3	<1
11/5/2008	S10	225	2	<2	<2	44	5		5618	5,662	5667	2072		3907	1	1
11/19/2008	S10	243	3.5	2.3	<2	78	5	2642	491	569	3216	2170		2582	1	1
3/4/2009	S10	96	1	8.7	2.1	22	5	23175	678	700	25,947	5,780	278	6,413	1	1
3/18/2009	S10	98	5	3.9	3	24	5	29144	245	269	30,017	7663	49	7901	1	1
3/31/2009	S10	95	1	22.2	18	69	13	35583	1,526	1,595	37,191	6,852	500	7,352	1	1
4/15/2009	S10	93	1.6	18	4.5	59	6	31093	2,683	2,742	33,841	5,450	4	5,454	1	1
4/27/2009	S10														<1	<1
7/14/2009	S10	37.8	0.5	0.3U	1.0U	201	13	46896	4,330	4,531	51,440	4,281	1,615	5,896		
9/30/2009	S10	51	0.8	1	0.8	10,269	2,284	40410	1,678	11,947	54,641	3,313	682	3,995		
10/14/2009	S10	26	0.1	0.9	0.7	561	863	41601	2,564	3,125	45,589	6,201	650	6,851	<1	<1
10/28/2009	S10	14	0	2.5	2.4	656	38	34758	31,452	32,108	66,904	4,673	1,053	5,726	1	1
11/11/2009	S10	46.8	0	0.5	0.1	117	4	44453	6,813	6,930	51,387	3,814	506	4,320	1	1
11/17/2009	S10	70.8	0.6	0.2	0.1	8,739	23	37078	3,474	12,213	49,314	2,686	1,319	4,005		

Table 42 Data of Sample Location S11 (Astatula Sand, Conventional Drainfield at 24-Inch Below Filtrating Media)

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
3/3/2009	S11														<1	<1
3/18/2009	S11	126	32	4.2	3	27	10	24257	141	168	25,150	7043	64	7326	1	1
3/31/2009	S11	120	5	22.5	20.1	77	5	30110	340	417	30,532	6,167	963	7,130	1	1
4/15/2009	S11	116	1.3	16.5	8.5	49	9	27315	6,410	6,459	33,783	4,623	259	4,882	1	1
4/27/2009	S11														<1	<1
7/7/2009	S11														100	4
7/14/2009	S11	28	0.5	0.5U	0.8U	173	21	41808	4,680	4,853	46,682	3,902	1,233	5,135		

Table 43 Data of Sample Location S12 (Washed Builder's Sand, Conventional Drainfield at 24-Inch Below Filtrating Media)

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
3/4/2009	S12					117	26	20146	2,571	2,688	23,604	5,251	103	5,425	1	1
3/19/2009	S12					74	8	98828	9823	9,897	20,550	4817	3403	8530	1	1
4/15/2009	S12					430	50	27513	1,918	2,348	29,911	3,376	552	3,928		
7/14/2009	S12	80.4	2.3	3.3U	3.8U	4,760	252	30337	2,166	6,926	37,515	3,115	72	3,187		
9/30/2009	S12	68	2	42.6	25.8	2,927	1,895	30957	3,002	5,929	38,781	847	23	870		
10/14/2009	S12	19	0.3	12.9	11.1	369	74	45616	1,250	1,619	47,309	4,377	168	4,545	<1	<1
10/28/2009	S12	14	0	54.9	50.7	1,014	195	40344	40,318	41,332	81,871	5,240	327	5,567	1	1
11/11/2009	S12	42.4	0.1	1.3	0.1	143	437	50653	13,009	13,152	64,242	4,831	288	5,119	1	1
11/17/2009	S12	50.4	0.9	0.1	0.1	111	16	42085	4,174	4,285	46,386	2,714	1,157	3,871		

Table 44 Data of Sample Location B1 (B&G Filter Inlet)

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B1	288	52	39.4	29.9	28309	16	331	5409	33,718	34065	4300	70	5215	662000	602000
11/5/2008	B1	353	110	79.5	75.3	32557	5	BDL	1928	34,485	34490	5480		6791	1700000	1560000
11/19/2008	B1	324	57.3	73.5	57.6	12174	5	BDL	1697	13,871	13876	4916	4370	5515	1645000	115000
2/1/2009	B1	618	64	599	91.5	28,160	20	1	12,166	40,326	40,880	4,871	721	7,040	1,648,000	288,000
2/10/2009	B1	618	64	599	91.5	28,160	20	1	12,166	40,326	40,880	4,871	721	7,040	1,648,000	288,000
2/24/2009	B1	342	62	143	112	42,530	24	6	822	43,352	48,952	5510	767	7867	150000	65000
3/4/2009	B1	336	56	123	94	40,137	41	76	501	40,638	45,687	5,440	1,616	7,589	8,000	8,000
3/10/2009	B1	340	70	115	107	42613	5	47	449	43,062	43748	5,365	573	6894	2,688,000	71,000
3/18/2009	B1	338	75	142	119	49,787	6	49	752	50,539	52,535	8053	25	8480	315,000	245,000
3/25/2009	B1	337	42	138	116	50,715	14	3	9069	59,784	61,541	8636	257	9585		
3/31/2009	B1	339	29	119	100	49,951	20	2	998	50,949	50,971	5,302	255	5,557	435,000	260,000
4/8/2009	B1	333	168	104	85	31,810	340	463	3,014	34,824	35,627	3,370	1,075	4,445	600,000	445,000
4/22/2009	B1	340	139	136	74.5	36,106	17	6	5,929	42,035	42,058	4,417	391	4,808	730000	565000

Table 45 Data of Sample Location B2

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B2	170	4.4	4.2	2	2724	9411	13214	3041	5,765	28390	1095	10	1155		
11/5/2008	B2	105	2.6	1.9	1.9	46	38	BDL	15511	15,557	15595	5430		14025	283	102
11/19/2008	B2	104	2.7	4	2	57	6	33288	2997	3,054	36348	4627	1105	5143	140	7
3/31/2009	B2	120	1	45	41.1	154	39	31213	155	309	31,561	5,976	210	6,186		

Table 46 Data of Sample Location B3

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B3	228	8.4	15.7	10.7	9138	3	154	575	9,713	9870	0.5	16	38	59	59
11/5/2008	B3	240	16.1	12.7	10.4	6102	46	2	1881	7,983	8031	300		979	2	1
11/19/2008	B3	275	12.6	14.5	4.9	14055	25	63	2218	16,273	16361	3770	17	4382	60	9
3/4/2009	B3	252	24.8	9.6	9.6	10,334	9	31	1,707	12,041	17,691	1,200	68	2,974	700	450
3/18/2009	B3	246	28	26.5	21	5,271	5	46	247	5,518	6,006	1784	180	3018	188,000	160,000
3/31/2009	B3	248	21	38.4	32.7	5,959	7	1	690	6,649	6,657	1,427	2,247	3,674	7,500	6,667

Table 47 Data of Sample Location B4

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B4	222	1.6	4.4	2.7	12218	5887	2527	2007	14,225	22639	1463	29	1500		
11/5/2008	B4	87	0.6	1.9	1.9	233	448	33	14224	14,457	14938	2842		4713	280	73
11/19/2008	B4	124	0.7	6.3	2	4772	2984	26815	4761	9,533	39332	5055	1492	5852	400	13
3/4/2009	B4	127	0.8	2.4	2.1	10,719	32	27779	1,456	12,175	40,522	6,199	251	7,232	650	170
3/18/2009	B4	64	7	17.7	15.6	10,742	975	47589	267	11,009	62,719	9466	53	9532	480	360
3/31/2009	B4	128	1	27.6	22.2	21,647	89	25314	991	22,638	48,041	6,362	31	6,393	16,667	10,000

Table 48 Data of Sample Location B5

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B5	200	13.2	15.9	9.1	2750	3	36	1453	4,203	4242	0.5	10	16	<1	<1
11/5/2008	B5	258	11.4	23.6	23	10555	3	BDL	586	11,141	11144	2		65	7	1
11/19/2008	B5	271	15.3	24.4	16.5	15550	4.9	5.1	6416	21,966	21976	1225	11	1881	27	11
3/4/2009	B5	210	1.2	8.4	4.8	12,724	323	8004	1,922	14,646	24,782	6,004	626	6,980	1,200	1,200
3/18/2009	B5	208	17	10.8	8.4	6,871	1232	16256	412	7,283	25,223	7006	75	7169	800	140
3/31/2009	B5	212	3	31.2	26.7	24,268	39	2921	1,305	25,573	28,533	7,780	789	8,569	6	2
8/18/2009	B5	294	18	9.1	9.1	22010	2	BDL	2800	24,810	24812	328	2315	2643	<1	<1
9/1/2009	B5	357	12.6	5.6	5.4	57761	4	5	9212	66,973	66982	2416	2122	4538	483	*12*
9/8/2009	B5	350	12	5.1	4.1	58,912	4	1	23,471	82,383	82,385	2,816	566	3,382	1200	<1

Table 49 Data of Sample Location B6

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B6	186	1.2	3.7	2	27583	9660	9139	9138	36,721	55520	2031	2055	2120		
11/5/2008	B6	121	1	1.9	1.9	342	388	22	13099	13,441	13851	3520		17170	2580	660
11/19/2008	B6	82.8	2.7	1.9	1.9	259	164	36642	1464	1,723	38529	4823	2055	5574	160	7
3/4/2009	B6	100	20	4.8	4.5	5,838	30	30842	34	5,872	37,573	6,367	571	7,862	1,200	1,200
3/18/2009	B6	101	5	20.4	12.3	11,976	218	36834	1971	13,947	51,402	8818	130	8974	520	152
3/31/2009	B6	94	4	24.3	16.8	12,191	56	37254	1,266	13,457	50,767	6,814	138	6,952	1,870,000	1,115,000
8/18/2009	B6	351	15	16.4	11.9	30434	2	BDL	2914	33,348	33350	3044	572	3616	2500	440
9/1/2009	B6	308	8.8	5.3	4.3	58028	9	21	3836	61,864	61894	3540	2554	6094	243	*20*
9/8/2009	B6	372	5.5	4.9	3	52,383	1	4	16,977	69,360	69,362	3,855	42	3,897	14000	<1

Table 50 Data of Sample Location B7

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	B7	112	10.4	15.7	10.8	10382	3	83	132	10,514	10600	4	7	31	37	30
11/5/2008	B7	251	9.4	22	20.4	7554	11	BDL	1272	8,826	8837	208		982	2	1
11/19/2008	B7	258	125	8.1	6.5	11697	295	1716	2176	13,873	15884	2197	7	3320	7	2
3/4/2009	B7	225	1.6	10.5	6.3	16,493	181	9262	558	17,051	30,774	5,251	126	5,913	400	115
3/18/2009	B7	224	50	9.6	6.3	14,845	584	1950	20	14,865	18,058	5665	92	5884	104	44
3/31/2009	B7	220	2	22.8	17.7	16,834	308	19916	533	17,367	37,591	7,307	318	7,625	40	26
8/18/2009	B7	293	16.2	9.2	5.8	31414	3	BDL	1348	32,762	32764	1629	772	2401	96	8
9/1/2009	B7	309	14	4.8	3.8	57341	5	4	10084	67,425	67434	2638	846	3484	40	*<1*
9/8/2009	B7	352	11	4.8	3.5	66,307	1	4	4,914	71,221	71,223	3,064	710	3,774	2140	<1

Table 51 Data of Sample Location B9

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
10/14/2008	B9	167	17.8	15.6	10.2	2317	3	11	15319	17,636	17650	7	10	15	10	10
11/5/2008	B9	241	14.8	23.7	23.5	15358	4.9	0.1	5183	20,541	20546	8		34	11	1
11/19/2008	B9	264	17.7	43.3	40.9	13241	4.9	0.1	7839	21,080	21085	115	10	1201	7	1
3/4/2009	B9	281	12.8	11.4	8.7	16,609	5	4	308	16,917	24,439	4,623	105	5,959	1	1
3/18/2009	B9	278	27	27	27	13,726	5	13	896	14,622	15,164	3953	20	5014	37	30
3/31/2009	B9	284	17	30.9	23.1	16,638	5	3	1,061	17,699	17,707	5,939	1,461	7,400	17	12
8/18/2009	B9	352	18.6	13.7	8.9	37573	2	0	870	38,443	38445	1671	225	1896	<1	<1
9/1/2009	B9	357	12.6	7.4	6.8	47212	4	1	9449	56,661	56666	2130	1334	3464	17	*<1*
9/8/2009	B9	349	18	7.8	5.4	57,411	1	4	2,706	60,117	60,119	1,969	1,071	3,040	116	<1

Table 52 Data of Sample Location B10 (B&G Filter Effluent)

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
10/14/2008	B10	208	23.3	5	2	2617	3	BDL	16401	19,018	19020	3	1	33	1	1
11/5/2008	B10	190	14.4	10.2	6.3	5972	4.9	2.1	541	6,513	6520	6		43	1	1
11/19/2008	B10	256	8.3	4.4	4.1	8533	40	119	676	9,209	9368	9	4	262	2	1
3/4/2009	B10	226	1.2	9.9	9.6	6,608	31	6820	845	7,453	15,343	1,639	669	2,568	1,400	1,400
3/18/2009	B10	228	13	8.1	3	6,556	94	5877	1206	7,762	14,143	2163	570	2909	40	33
4/1/2009	B10	215	4	29.7	21	6,323	141	6057	499	6,822	13,020	2,203	303	2,506	8	8

Table 53 Wetland Data at Sampling Locations

Sample Date	Sample ID	Alkalinity (mg/l)	TSS (mg/l)	BOD5 (mg/l)	CBOD5 (mg/l)	Ammonia-N (µg/l)	Nitrite (µg/l)	Nitrate (µg/l)	Org. N (µg/l)	TKN (µg/l)	TN (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	TP (µg/l)	Fecal	*E.Coli.*
8/20/2009	W11	429	52.8	24.9	6.3	21352	1	6	1112	22,464	22471	15	442	457	8800	1055
8/20/2009	W12	532	30.4	16.2	6.6	7698	2	3	1161	8,859	8864	14	101	115	4900	864
8/20/2009	W13	439	35.6	24.3	4.1	1706	1	2	84	1,790	1793	14	78	92	65600	32400
8/20/2009	W14	556	46.8	12.9	5.4	1500	1	4	535	2,035	2040	17	167	184	30800	8000
8/20/2009	W15	381	34	8.7	5.5	1199	1	3	337	1,536	1540	17	79	96	3000	30
8/20/2009	W21	383	37.2	12.3	6.8	28020	2	1	1070	29,090	29093	13	80	93	31845	3200
8/20/2009	W22	437	51.6	12.6	5.3	8848	1	4	517	9,365	9370	12	234	246	19600	9500
8/20/2009	W23	413	75.6	13.8	3.2	797	1	7	30	827	835	15	160	175	6800	127
8/20/2009	W24	392	34	24	4.1	6609	1	11	849	7,458	7470	51	350	401	28400	60
8/20/2009	W25	112	32	21.9	3.4	27566	3		760	28,326	28336	717	753	1470	51000	24600
8/20/2009	W31	148	18	15.6	2.4	30064	4	6	956	31,020	31030	212	1188	1400	39600	29600
8/20/2009	W32	172	44.8	18.3	2.3	5878	1	1	40	5,918	5920	14	118	132	98400	50400
8/20/2009	W33	160	7.6	12.6	2.9	300	1	10	1390	1,690	1701	19	93	112	12500	2400
8/20/2009	W34	159	11.6	17.7	3.6	1588	1	1	159	1,747	1749	18	108	126	7545	4300

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
8/20/2009	W35	141	28	13.2	3.1	805	2	8	333	1,138	1148	18	50	68	66800	49200
8/20/2009	W41	161	37.2	16.2	3.9	9798	2	4	692	10,490	10496	13	101	114	69200	56000
8/20/2009	W42	167	38.4	18.5	4	10887	1	6	547	11,434	11441	12	73	85	20400	11400
8/20/2009	W43	1663	14	12.6	3.7	491	1	15	43	534	550	17	3	20	196364	67200
8/20/2009	W44	186	15.2	15.6	3.7	207	2	4	341	548	554	16	52	68	432000	176000
8/20/2009	W45	102	36.8	19.2	3.9	4582	1	0	476	5,058	5059	12	53	65	62400	41200
9/3/2009	W11	477	38	17.9	17	11134	11	30	2319	13,453	13494	27	423	450	7,273	1
9/3/2009	W12	526	77.5	17.3	16.8	2952	4	23	1944	4,896	4923	23	26	49	1	1
9/3/2009	W13	413	33	6.6	4.3	1658	2	3	768	2,426	2428	25	21	46	3,000	1
9/3/2009	W14	579	51	5.9	4.1	529	2	3	980	1,509	1511	30	81	111	5,455	1
9/3/2009	W15	356	34.5	7.5	4.5	972	2	14	739	1,711	1727	27	98	125	1	1
9/3/2009	W21	400	37.5	18	17.5	4465	3	2	2393	6,858	6860	17	245	262	24,000	1
9/3/2009	W22	361	33.5	11.6	10.4	2374	2	3	1366	3,740	3742	19	56	75	1	1
9/3/2009	W23	413	36.5	5.7	5.1	459	3	2	815	1,274	1276	23	61	84	1	1
9/3/2009	W24	430	48.5	6.8	4.9	1215	5	47	116	1,331	1383	24	75	99	2,000	1
9/3/2009	W25	252	17	7.8	5.5	1415	15	5	9689	11,104	11124	104	479	583	3,000	1
9/3/2009	W31	341	32.5	14.8	11.8	1193	7	0	26830	28,023	28030	135	1074	1209	1,180,000	3000
9/3/2009	W32	409	29	11.7	11.5	2044	4	13	15169	17,213	17230	19	235	254	2,073	1
9/3/2009	W33	452	22.5	5.4	4.6	756	2	3	544	1,300	1302	29	100	129	1	1
9/3/2009	W34	527	41	7.2	5.7	2801	2	3	858	3,659	3661	25	14	39	1	1
9/3/2009	W35	482	50.5	7.7	5.7	4125	2	3	940	5,065	5067	23	79	102	1	1
9/3/2009	W41	556	23	12.8	8.1	2716	4	17	32999	35,715	35736	52	508	560	2,000	1
9/3/2009	W42	332	26.5	10.7	8	2519	13	5	32836	35,355	35373	111	828	939	1,000	1
9/3/2009	W43	433	30.5	11.8	8.6	1121	25	2	8515	9,636	9663	31	170	201	1	1
9/3/2009	W44	390	15	7.4	7.1	3068	4	6	20293	23,361	23371	115	33	148	1	1
9/3/2009	W45	375	25	7.8	5.7	12942	1	4	25355	38,297	38299	74	571	645	1	1
9/9/2009	W11	440	33.5	17.9	11.5	22,660	1	4	19,312	41,972	41,974	19	491	510	40	<1
9/9/2009	W12	517	47	15.2	11.4	10,488	1	4	10,512	21,000	21,002	24	120	144	8	<1
9/9/2009	W13	479	33	4.2	3.3	1,633	1	4	2,091	3,724	3,726	28	112	140	164	<1
9/9/2009	W14	551	46.5	6.6	4.4	564	2	3	1,869	2,433	2,435	24	128	152	<1	<1

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
9/9/2009	W15	465	33.5	3.7	2.8	1,437	1	4	1,139	2,576	2,578	22	101	123	263	1
9/9/2009	W21	400	32.5	10.7	6.9	31,406	1	4	7,682	39,088	39,090	15	712	727	7000	<1
9/9/2009	W22	457	37	9.4	6.8	10,797	1	4	7,490	18,287	18,289	17	113	130	33	<1
9/9/2009	W23	419	19	3.8	3	870	1	4	10,626	11,496	11,498	22	95	117	40	8
9/9/2009	W24	427	29	5.9	2.9	900	1	4	2,261	3,161	3,163	20	130	150	4	<1
9/9/2009	W25	369	12.5	3.6	3.1	1,025	1	4	1,888	2,913	2,915	28	95	123	120	1
9/9/2009	W31	315	22	10.8	7.5	59,200	1	7	5,678	64,878	64,886	1,211	1,773	2,984	60000	74
9/9/2009	W32	365	17.5	11	6.8	55,300	6	1	3,989	59,289	59,296	12	725	737	88	4
9/9/2009	W33	523	31.5	3.5	2.5	841	4	1	2,802	3,643	3,645	24	149	173	<1	<1
9/9/2009	W34	505	41	7.7	4.7	3,110	1	7	2,733	5,843	5,851	20	116	136	<1	<1
9/9/2009	W35	486	33	6.1	4.7	14,441	3	2	5,057	19,498	19,500	16	117	133	1	1
9/9/2009	W41	393	21	10.6	4.3	67,446	4	1	5,452	72,898	72,900	14	584	598	76	44
9/9/2009	W42	331	21	9.4	4.8	52,346	1	11	1,691	54,037	54,049	16	845	861	33	<1
9/9/2009	W43	433	23.5	7.7	6.3	15,152	10	83	5,767	20,919	21,012	16	182	198	<1	<1
9/9/2009	W44	349	21	7.5	5.2	40,406	62	297	4,348	44,754	45,113	15	102	117	4	<1
9/9/2009	W45	313	17.5	8.5	4.3	66,905	1	5	2,490	69,395	69,401	16	578	594	4	1
9/17/2009	W11	331	37.3	9.8	6.6	20,747	2	4	5,784	26,531	26,537	11	534	545	26000	<1
9/17/2009	W12	439	38.8	7.7	7.3	17,292	2	3	5,533	22,825	22,827	10	319	329	16	<1
9/17/2009	W13	453	41.5	3.5	3.4	2,427	2	9	2,376	4,803	4,814	11	207	218	<1	<1
9/17/2009	W14	503	30	4.1	3.6	393	1	5	2,228	2,621	2,627	13	144	157	12	<1
9/17/2009	W15	277	29	2.9	2.3	386	1	8	2,030	2,416	2,425	11	74	85	20	1
9/17/2009	W21	265	33	8.7	5.6	30,603	3	10	8,845	39,448	39,461	9	808	817	1024	581
9/17/2009	W22	404	28.5	6.3	5.5	18,858	4	11	8,991	27,849	27,864	8	257	265	28	<1
9/17/2009	W23	397	27	2.3	2.3	710	1	4	2,017	2,727	2,729	11	150	161	4	<1
9/17/2009	W24	417	18	3.5	2.9	935	3	2	1,951	2,886	2,888	11	120	131	176	<1
9/17/2009	W25	407	12.5	2.3	2.2	987	2	3	1,937	2,924	2,929	12	116	128	393	1
9/17/2009	W31	583	22	5.4	4.7	47,941	3	2	2,713	50,654	50,656	901	1,635	2,536	12	4
9/17/2009	W32	201	18.3	9.4	6.7	59,489	2	3	4,953	64,442	64,444	6	803	809	4	<1
9/17/2009	W33	541	27.5	2.9	2.1	1,210	1	4	2,688	3,898	3,900	14	193	207	12	4
9/17/2009	W34	421	34	5.6	4.8	3,563	2	3	4,158	7,721	7,723	11	73	84	44	8

Sample Date	**Sample ID**	**Alkalinity (mg/l)**	**TSS (mg/l)**	**BOD5 (mg/l)**	**CBOD5 (mg/l)**	**Ammonia-N (µg/l)**	**Nitrite (µg/l)**	**Nitrate (µg/l)**	**Org. N (µg/l)**	**TKN (µg/l)**	**TN (µg/l)**	**SRP (µg/l)**	**Diss. Org. P (µg/l)**	**TP (µg/l)**	**Fecal**	***E.Coli.***
9/17/2009	W35	459	30	5.9	5.7	20,622	1	4	7,835	28,457	28,459	10	137	147	20	16
9/17/2009	W41	175	19	9.4	6.7	67,162	2	3	7,489	74,651	74,653	9	681	690	15	8
9/17/2009	W42	206	19.5	8.4	5.9	58,782	2	3	14,696	73,478	73,483	8	704	712	28	<1
9/17/2009	W43	382	27.5	6.8	4.7	18,550	2	3	1,653	20,203	20,205	10	211	221	<1	<1
9/17/2009	W44	303	25	9.1	5	48,233	4	1	11,794	60,027	60,029	9	1,299	1,308	8	4
9/17/2009	W45	82	16	16.1	6	71,220	2	3	12,746	83,966	83,971	9	1,392	1,401	8	4
9/24/2009	W11	299	41	11.6	10.7	27,791	3	2	3,892	31,683		8	55	63		
9/24/2009	W12	367	40.5	9.6	9.2	25,466	3	2	2,977	28,443		9	65	74		
9/24/2009	W13	537	49	4.9	4.6	3,078	2	3	777	3,855		12	38	50		
9/24/2009	W14	642	37.5	4.4	3.8	591	3	2	1,407	1,998		14	32	46		
9/24/2009	W15	415	42	3.3	3.1	304	3	2	1,242	1,546	1,551	13	38	51	1	1
9/24/2009	W21	207	26	7.4	6.4	42,162	3	2	2,381	44,543		26	929	955		
9/24/2009	W22	281	32	7.7	7.6	34,584	3	6	2,432	37,016		9	369	378		
9/24/2009	W23	463	16.5	3.4	3.1	1,320	3	2	1,281	2,601		13	228	241		
9/24/2009	W24	451	22.5	4.4	3.9	1,629	2	3	1,660	3,289		12	180	192		
9/24/2009	W25	423	14	3.5	3.2	1,313	3	2	914	2,227	2,232	12	122	134	3440	66
9/24/2009	W31	165	12	3.6	2.7	52,677	31	4	5,867	58,544		2,117	442	2,559		
9/24/2009	W32	235	20.5	3.3	2.6	53,089	4	1	4,972	58,061		773	750	1,523		
9/24/2009	W33	526	48	3.8	2.2	2,240	2	3	16,044	18,284		14	101	115		
9/24/2009	W34	452	24.5	3.5	3.4	15,555	3	2	944	16,499		12	33	45		
9/24/2009	W35	256	18.5	3.2	2.5	46,645	3	2	3,129	49,774	49,779	9	55	64	289	235
9/24/2009	W41	293	21.5	3.2	2.9	54,999	4	1	2,335	57,334		9	207	216		
9/24/2009	W42	295	23	5.5	3.5	54,256	3	2	6,152	60,408		10	35	45		
9/24/2009	W43	367	31.5	5.6	4.4	20,358	3	2	2,500	22,858		12	134	146		
9/24/2009	W44	336	25.5	4.2	2.9	44,853	5	1	9,910	54,763		11	106	117		
9/24/2009	W45	217	22	5.8	4.9	56,233	3	2	3,169	59,402	59,407	10	548	558	310	4


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