Final Report FDOT Project BDK78 977-02

Stormwater Harvesting Using Retention and In-Line Pipes for Treatment Consistent with the new Statewide Stormwater Rule

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Editorial Review by Erica Kresh
May 2013

METRIC CONVERSIONS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	Inches	25.4	Millimeters	mm
Ft	Feet	0.305	Meters	m
Yd	Yards	0.914	Meters	m
Mi	Miles	1.61	Kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	Acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	Milliliters	mL
Gal	Gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
Mm	Millimeters	0.039	Inches	in
M	Meters	3.28	Feet	ft
M	Meters	1.09	Yards	yd
Km	Kilometers	0.621	Miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
Ha	Hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
G	Grams	0.035	Ounces	oz
Kg	Kilograms	2.202	Pounds	lb

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F

TECHNICAL REPORT DOCUMENTATION

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Stormwater Harvesting Using Retention and In-Line Pipes for Treatment Consistent with the new Statewide Stormwater Rule		5. Report Date May 14, 2013 6. Performing Organization Code Stormwater Management Academy
7. Author(s) Martin Wanielista, Mike Hardin, Andrew Hood, Ikiensinma Gogo-Abite, and Manoj Chopra		8. Performing Organization Report No. SMA 1660 7023
9. Performing Organization Name and Address Stormwater Management Academy University of Central Florida Orlando, FL 32816		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BDK78 977-02
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30 Tallahassee, FL 32399		13. Type of Report and Period Covered Final Report May 15, 2008 – May. 14, 2013 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Wet detention ponds collecting runoff from highways were examined as possible candidates for harvesting (reuse). Media mixes and methods to filter water for reuse were demonstrated.

Filter media mixes categorized as Biosorption Activated Media (BAM) were laboratory tested for pollution removal and filtration rates. The media mixes with highest removal effectiveness were then demonstrated in pipes placed in operation at existing wet detention ponds. The use of a media mix was also demonstrated in a pilot operation to simulate retention areas in swales along highways.

Down-flow and up-flow media filters were installed to improve water quality from wet detention ponds. Three of the filters were installed with provisions for removing debris and with mechanisms to backwash the filter media. A mobile pipe-in-pipe system was also demonstrated at a high rate of filtration. A disc filter operation was also demonstrated and water quality effectiveness documented.

A swale filter system was demonstrated to document pollutant removal. The water quality of the percolate was improved with BAM. The removal was especially significant when new sod was used over the filter media as the new sod added nutrients to the water before entering the BAM. In a field location, a pipe was used to collect the filtrate from the BAM filter, and the water was of a quality sufficient for reuse. For a BAM augmented swale, calculations for removal and cost were presented.

One potential obstacle to reuse from a highway wet detention pond was the ability to document possible effects on the surrounding groundwater. Thus, a computer program, called SHARP for Stormwater Harvesting and Assessment for Reduction of Pollution, was developed to help predict a safe yield, and an associated reuse rate that was constrained by adjacent groundwater levels. The use of the model was demonstrated at an Interstate wet detention pond in Miramar, Florida.

17. Key Word Highway Runoff, Water Quality, Wet Detention, Media Filtration, Stormwater Reuse, Safe Yield, Surface/ Ground Water Computer Model, Biosorption Activated Media (BAM)		18. Distribution Statement No Restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 150	22. Price

ACKNOWLEDGEMENTS

The authors greatly appreciate the technical guidance and funding support provided by the Florida Department of Transportation. Without their support, research such as this would not be possible. In particular, Rick Renna and Amy Tootle provided valuable assistance in the development and conduct of the research activities.

This work was completed by students, staff, and faculty from the Stormwater Management Academy located at the University of Central Florida. The staff and students of the Academy provided valuable assistance in the collection and analyses of laboratory and field data. There were nine students, one staff, and two faculty members conducting the research. Three of the students are listed as authors for this publication.

The work would also not have been possible without the help of individuals from two consulting firms, namely Watermark Engineering Group, Inc., and GAI Consultants, Inc. In addition, support for a part of the computer work with water quality analyses was provided by the City of Miramar. The State Department of Environmental Protection (DEP) also provided financial support for the construction of the disc and the up-flow filters through grants and contracts with the municipalities. We are very thankful for assistance provided by the professional staff from both consulting companies as well as those from the DEP, Sarasota County, and the City of Miramar.

EXECUTIVE SUMMARY

Stormwater rules and regulations are evolving. Thus, there is a need for research that supports alternative methods for water quality treatment of runoff water. The information in this report supports the use of filtration media called Biosorption Activated Media (BAM) that improves runoff water quality. Runoff to impaired waters may need additional treatment or reduced volume of discharge to meet a mass discharge limitation. In addition, some nutrients in runoff waters may need to be removed before they percolate to nutrient sensitive areas such as aquifers with discharge to springs or estuaries. Thus, stormwater harvesting or reuse is another best management practice that can be used to reduce the mass of pollutants in runoff discharged to surface waters.

Harvesting of stormwater for a single user is typically done by direct use of the water from a pond provided there is no cross connection and that a screen filter is used. When contact with the general public is expected, irrigation quality water is needed. The water in a stormwater pond has to be treated by some form of filtration to provide irrigation quality water. Treatment methods considered within this report are those resulting from biosorption filtration media, commonly called BAM, and from disc technologies. When using BAM, the media can be placed in a pipe or other suitable containment and the runoff water or wet detention pond water passes through the filter in either a down-flow or up-flow configuration. Another option is to place BAM in a pipe within a pipe in a wet detention pond and draft the water through the pipe. This BAM pipe-in-pipe can then be moved from one location to another, and thus is considered to be a mobile treatment method. Some options for the use of BAM are called pipe treatment systems because of their practical installation configurations.

Harvesting can also occur after runoff water has infiltrated into the ground, such as from shoulder or swale areas adjacent to roadways. This infiltrated water can either be collected by compartments (pipes are common) or be allowed to further percolate into the ground until they reach a point of discharge.

A concern resulting from harvesting water from a wet detention pond is the potential effect on the surrounding wetlands when the water in a wet detention pond is lowered. Thus, a computer model was developed and tested to determine the safe yield of a wet detention pond as controlled by the harvesting schedule and the minimum ground water level at select points in the study area. This integrated surface and ground water model was used for Stormwater Harvesting and Assessment for Reduction of Pollution and is thus called the SHARP model. The model was tested at an interstate highway wet detention pond in Miramar, Florida.

BAM filtration media mixes were laboratory tested for pollution removal and filtration rates. The laboratory work was conducted in six inch diameter columns, and the media mix depth was equal to what was expected in a full-scale operating filter (2 feet depth is common). The media mixes were then installed in pipes placed in operation at existing wet detention ponds, and effectiveness in the removal of nutrients was documented.

A wet detention pond in Tampa receiving runoff from an urban watershed composed of highways, parking lots, and buildings was the site of the down-flow filter. The down-flow media filter for water from this wet detention pond was successful in removing pollution. Another wet detention pond in Sarasota County was used as a demonstration for an up-flow filter. This pond collects both highway and residential runoff. The up-flow filter operation was demonstrated to include a backwashing operation and at a filtration rate of up to 2 million gallons per day. Both ponds require installation of provisions for removing debris and with mechanisms to backwash the filter media. A reliable and redundant operation was demonstrated since the water quality in the wet detention ponds did not meet a majority of the irrigation water quality standards.

A mobile pipe-in-pipe system was also demonstrated, but application at a high rate of filtration provided marginal improvement in water quality. Due to this, a lower filtration rate was recommended. This system can also be used in emergency situations.

The water quality effectiveness and continual operation of disc filtration using water from an interstate highway wet detention pond in Miramar, Florida was also documented. A disc filter was an alternative to filtration using BAM. It provided reliability and redundancy in meeting irrigation quality standards.

A swale filter system using BAM was also demonstrated and water quality effectiveness documented. The BAM filter removed more pollutants relative to the use of parent soils documented as Type A-3 soils. The removal was especially significant when new sod was used on top of the BAM filter. Runoff not collected in the slope of the swale can be collected in the bottom of the swale if not transported. This collection can be enhanced with the use of exfiltration or French drains. Also, since filtration is assumed using at least two feet of media, the collected water can be reused. Example calculations for a BAM filter with a swale were presented.

Every time runoff water is not discharged, pollution removal can be expected. This pollution removal can be quantified and the total maximum daily load reduction estimated. Limited cost and removal information for these systems are presented.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
B&G™	Bold & Gold™
BAM	Biosorption activated media
C	Runoff coefficient
$\mathbf{C_c}$	Coefficient of gradation
cfu	Colony-forming units
$\mathbf{C_u}$	Uniformity coefficient
D	Rainfall duration and pond discharge (volume)
$\mathbf{D_{10}}$	Effective size: particle diameter corresponding to 10% finer by mass on the particle distribution curve
$\mathbf{D_{30}}$	Particle diameter corresponding to 30% finer by mass on the particle distribution curve
$\mathbf{D_{60}}$	Particle diameter corresponding to 60% finer by mass on the particle distribution curve
e	Void ratio
E	Harvesting efficiency and free surface water evaporation
EIA	Equivalent impervious area
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FS	Factor of safety
$\mathbf{G_S}$	Specific gravity of soils
H	Distance from weir crest to water surface and harvested water volume
$\mathbf{i_D}$	Average rainfall intensity of the design storm
$\mathbf{I_d}$	Design infiltration rate
IDF curve	Intensity-duration-frequency curve
$\mathbf{I_a}$	Initial abstraction volume

I_{IRR}	Irrigation volume
k	Coefficient of permeability
K_{vu}	Unsaturated vertical hydraulic conductivity
L	Perimeter of inlet box
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
N	Nitrogen
NELAC	National Environmental Laboratory Accreditation Conference
NH_3	Ammonia
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NSQD	National Stormwater Quality Database
NTU	Nephelometric turbidity units
OP	Orthophosphorus
P	Phosphorus
PAHs	Polycyclic Aromatic Hydrocarbons
PO_4^{3-}	Orthophosphate
Qgw	Groundwater seepage [L T-1]
$Q_{harvested}$	Volumetric flow rate of harvesting stream
$Q_{influent}$	Total volumetric flow rate entering the treatment system. Also known as the influent volumetric flow rate.
REV curve	Rate-efficiency-volume curve
R	Rainfall on pond volume [L]
RO	Surface runoff [L]
R_h	Hydraulic radius
S	Side slope of swale and roadside
SRP	Soluble reactive phosphorus
TDS	Total dissolved solids
TKN	Total Kjeldahl Nitrogen

TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
U.S. EPA	United States Environmental Protection Agency
UCF	University of Central Florida
V/H	Vertical/horizontal
VR	Volume of runoff from a drainage area
y	Number of time periods

CHAPTER 1 INTRODUCTION, OBJECTIVES, AND LIMITATIONS

1.1 BACKGROUND

Harvesting (reuse) of stormwater is a stormwater management option. In addition, it may be an economic alternative to providing a non-potable source of water. It is also used to meet stormwater discharge pollution limits because in a wet detention pond, stormwater may not achieve sufficient removal of some pollutants before discharge. However, if a volume of stormwater can be removed by harvesting the stored water before discharge, the cumulative amount of pollutants in the discharge will be reduced. This can be accomplished using stormwater harvesting (reuse) ponds.

The use of Biosorption Active Media (BAM), a soil amendment, is also helpful in the reduction of pollutants as the water passes through the media. The concentrations of pollutants are reduced before surface water discharge or deep percolation. This can be accomplished using retention or biodetention areas. After retention or biodetention, water can be stored for harvesting.

Nutrient loadings, especially nitrogen and phosphorus, in stormwater runoff are a major concern in Florida, and loading reductions are found in research areas where regulations continue to evolve. Stormwater runoff from highways is a source of pollution to surface water bodies and groundwater; thus, the results of this project developed options for treatment/harvesting systems that reduce nutrient and concurrent pollutant loadings from highway runoff.

Stormwater runoff from highways and other impervious surfaces often has levels of nitrogen and phosphorus not acceptable to receiving surface or ground waters (1). Nitrate, a species of nitrogen, can have harmful health effects when ingested. Nitrogen and phosphorus species concentrations are also of importance in watersheds because they are limiting nutrients for plant and algal growth in aquatic systems. Excess nitrogen and phosphorus in surface waters causes eutrophication, which can eliminate the beneficial use of the water body.

Nitrate contamination of groundwater is of concern due to the large number of private drinking water wells that are not monitored or treated. Nitrate is listed by the U.S. EPA as a primary drinking water standard with a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 10 mg/L as nitrogen (2). Lower concentration limits for Nitrate are set to minimize environmental impacts to surface and groundwater.

Typically, the primary limiting nutrient for plant and algal growth in freshwater systems is phosphorus, and in marine ecosystems it is nitrogen (4). An excess of limiting nutrients is a major factor in eutrophication. Eutrophication is defined by the United States Environmental Protection Agency (U.S. EPA) as the increase and accumulation of primary producer biomass in a water body through time (5). According to the National Oceanic and Atmospheric Administration (NOAA), the most common single factor causing eutrophication is an increase in the concentrations of nitrogen and phosphorus species (6). Several different algal species (7) have stimulated growth when there are sufficient nutrients available to them. The increase in the number and types of algal species in water also has additional effects on the use of the water which contains the algal populations. In some situations, the water becomes unusable for specific purposes, such as a source of drinking water and for recreational uses. (8).

Oxygen depletion is also noted when there is nutrient excess. Excess inorganic nitrogen loads, either due to stormwater influent or algal die off, increase nitrifying bacteria and as a result, a significant amount of oxygen is consumed.

The practical implementation for stormwater treatment is governed by regulations requiring either a fixed removal percentage or net improvement of the receiving water body which implies a reduction of a target water quality parameter. The target parameter in many areas is a nutrient species. The removal of nutrients is also one of the more common targets for Total Maximum Daily Load (TMDL) reduction.

1.2 OBJECTIVES

The purpose of this work is to develop additional filtration options for the treatment of nitrogen and phosphorus found in stormwater. In addition, the options must address field operating conditions. The expectation is to provide these options consistent with current rules and regulations regarding stormwater treatment.

Specific Statements of Objectives are:

1. Develop filtration media mixes that remove nutrients from the water in stormwater wet detention ponds.

2. Deploy at least two of the mixes in a full scale operation to demonstrate successes and problems of operation.

3. Address the concern of effects on adjacent ground water when harvesting from a wet detention pond.

1.3 LIMITATIONS

The testing was done for harvesting systems in the state of Florida, thus the climate conditions of the State have an effect on the results. Since the testing was completed using UCF's Bold & Gold™ Biosorption Activated Media (BAM), the results may not translate to other BAM products. The pollutants of interest were limited to solids, turbidity, nitrogen, and phosphorus.

CHAPTER 2 BACKGROUND AND LITERATURE INFORMATION

2.1 HIGHWAY RUNOFF POLLUTANTS

Pollutants contained in stormwater runoff from highways can lead to environmental problems, such as harmful algal blooms, and human health problems (2; 7). FDOT (11) and others provide many options to mitigate pollutants. Pollutants in highway runoff have several sources including wet and dry deposition, vehicle exhausts, vehicle wear, roadway wear, and accidents (12). Table 2 shows the average concentrations of some pollutants found in freeway runoff, according to the National Stormwater Quality Database (NSQD), and Florida highway runoff, according to the Florida Runoff Concentration Database.

Table 1. Average Concentrations of Pollutants in Freeway Runoff from the NSQD (13) and Florida Highway Runoff (14)

Pollutant	National Freeway Runoff Concentrations	Florida Highway Runoff Concentrations
NH_3	1.07 mg/L as N	na
TKN	2.0 mg/L as N	na
$NO_2^- + NO_3^-$	0.28 mg/L as N	na
Total Nitrogen	2.28 mg/L as N	1.37 mg/L as N
Filtered Phosphorus	0.20 mg/L as P	na
Total Phosphorus	0.25 mg/L as P	0.167 mg/L as P
pH	7.10	na
Total Suspended Solids (TSS)	99.0 mg/L	na

Incomplete combustion of fuel results in production of carbon monoxide, nitrogen oxides, ketones, aldehydes, and polycyclic aromatic hydrocarbons (PAHs). Consumption of the oil in the crankcase contributes to the emission of aromatic hydrocarbons. Furthermore, tires are a source of zinc and cadmium while brake shoe wear produces lead, chromium, cadmium, and magnesium (15).

Atmospheric deposition is also a significant pollutant source in highway runoff and occurs in two forms, dry and wet (12). Wet deposition refers to the process in which pollutants are removed from the atmosphere via rain, sleet, snow, fog, or other forms of precipitation and are deposited on the Earth's surface; dry deposition refers to the falling of small particles and gases to the Earth's surface without the involvement of precipitation (16). Atmospheric deposition accounts for 10-30% of the total dissolved solids (TDS), total suspended solids (TSS), total phosphorus, and nitrate/nitrite; 30-50% of copper, chromium, lead, and ortho-phosphorus; and 70-90% of Total Kjeldahl Nitrogen (TKN) and ammonia found in highway runoff (17).

The surface of the roadway also contributes to the pollutant loading in highway runoff. Asphalt is composed of approximately 95% stone materials and 5% bituminous binders. The stone components contain a variety of different metals while the bituminous binder contains hydrocarbons and trace metals such as vanadium, iron, nickel, magnesium, and calcium (12).

Nutrient loadings, especially nitrogen and phosphorus, in stormwater runoff are a major concern in Florida and can result in eutrophication and/or groundwater contamination. As a result, this research will primarily be focused on the capture and removal of nitrogen and phosphorus species.

2.2 WHAT IS STORMWATER HARVESTING?

Stormwater harvesting (reuse) is any intentional method for the use of detained stormwater for some beneficial purposes. Such benefits are derived from irrigation of grass areas, rehydration of wetlands, cooling tower makeup water, industrial process water, salt water intrusion barriers, ground water augmentation, agricultural water, low flow augmentation, and others.

Typically, waters are stored in surface ponds and the detained water is reused at a rate that does not affect surrounding vegetation, as shown in the two designs of Figure 1.

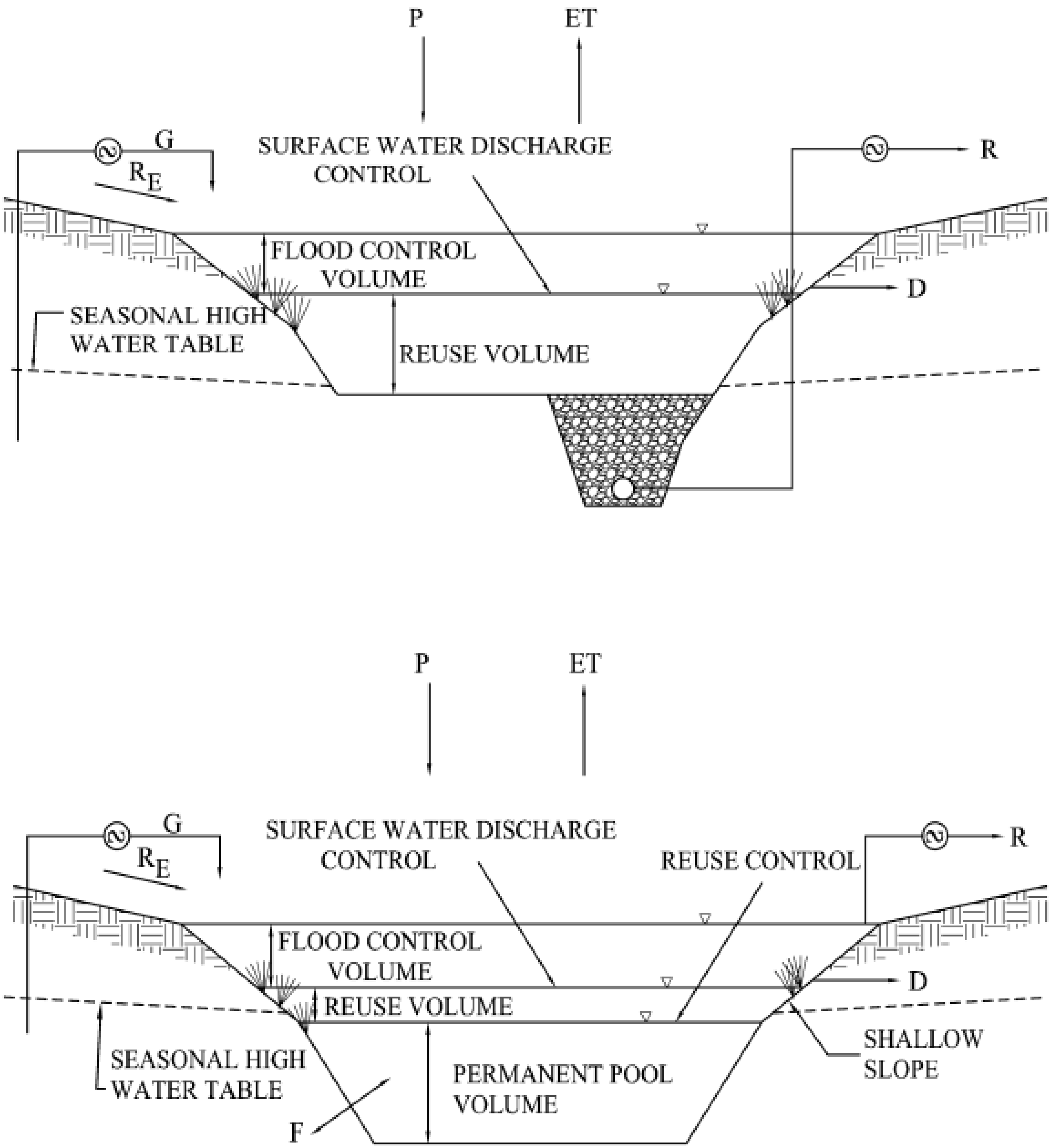

Figure 1. Stormwater Harvesting Pond (from reference 11)

Reuse water is either taken directly from the pond by pumps and a surface filter, or it can be withdrawn using a horizontal well, as shown in the schematic of Figure 2. Withdrawal directly from the pond usually has to be supplemented with another supply of water, as the water for irrigation does reach limiting amounts of none during the dry season. In almost every circumstance, a direct withdrawal of water from the pond requires a back-up supply, frequently provided by a shallow well or by combining with treated wastewater. The horizontal well has the added benefit of providing a safer and more consistent yield year around because the surface pond water is supplemented with ground water. Care is always exercised to minimize impact to the surrounding ground water. In some areas (typically coastal), ground water recharges surface ponds thus providing larger safe yield withdrawals relative to those ponds with minimal ground water interaction.

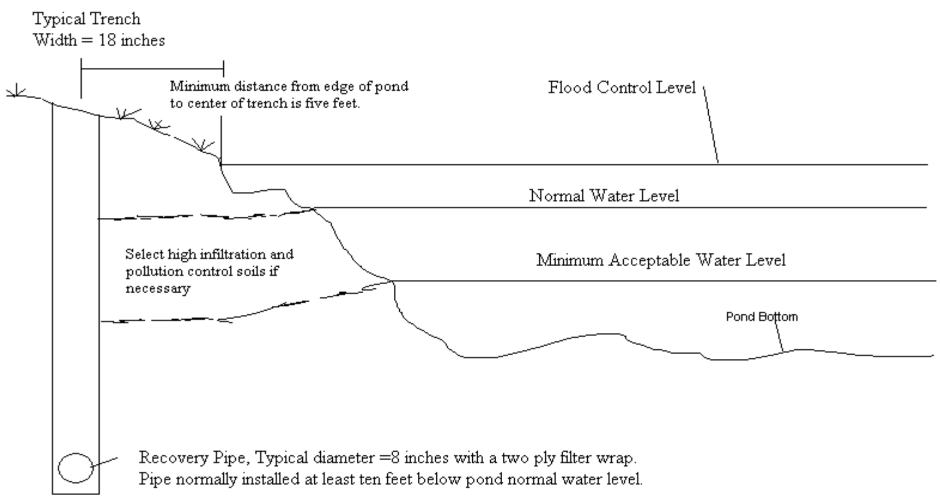

Figure 2. Horizontal Well Schematic (from reference 11)

An alternative and cost effective way of harvesting stormwater is proposed in this report. It builds on the popular stormwater practice of constructed swales and adds sorption medium as the soil medium of the swale and underground storage. The reuse water is then extracted from the storage area beneath the swale.

There are two commonly used and acceptable designs. One is called retention, which is when the discharge from the storage is allowed or intentionally infiltrated into the ground waters. The pollution removal can be enhanced when a bio-treatment media is added before the stormwater enters the storage area or upon discharge. The other method discharges from storage to a surface water and thus the term detention is used. When a bio-treatment media is used with a wet detention system, the system has additional pollution control. To achieve pollution control, BAM is necessary.

2.3 REMOVAL MECHANISMS OF BIO-TREATMENT SYSTEMS

The selection of a bio-treatment system depends on the pollutants that are targeted for removal and the rate at which the stormwater is removed from the site. First, a decision has to be made on whether to retain and treat water on site or move it to another site for treatment. Once a decision is made for treatment site, the pollutants of interest are then determined. In the case of this research, solids and nutrients were selected. However, other water quality indicators are used in this research to complete an understanding of the processes. The processes for removal are a combination of filtration, chemical, and biological means. The processes of interest and terminologies are discussed in the next sections.

Bio-Treatment Systems Defined

Bio-treatment systems are shallow depressions, with select medium and usually with vegetation into which stormwater drains and infiltrates. Stormwater entering the bio-treatment system is first filtered by the vegetation and surface medium before entering the remainder of the medium. While in the medium, the stormwater is further filtered and pollutants are captured via depth filtration, sorption, precipitation, and ion exchange. Initially, sorption is done by the adsorption potential of the medium. The removal is sustained by the uptake of pollutants by vegetation, media absorption, and microbial degradation. The vegetation also aids in preventing the media from clogging thus maintaining the system’s infiltration characteristics (18) & (19).

Bio-treatment means that the system is biologically active, as opposed to simply being a biologically inactive filter or adsorption bed. The distinction between a biologically active and biologically inactive pollutant capture system is the use of biological processes for retention and sequestration of the pollutants, and regeneration of the contaminant removal capacity and the hydraulic properties of the media. There are a variety of bio-treatment designs available; some use conventional bio-treatment medium having slow filtration rates and thus require large unit storage volumes and others use specialized medium, such as Bold & Gold™, which have higher filtration rates and thus require small surface storage volumes and small footprints (20).

Within-Storm and Inter-Storm Treatment Processes

An extensive discussion of the treatment process is found in the work of Andrew Hood (21). He presented two general categories of treatment processes that exist in bio-treatment systems, namely within-storm treatment processes and inter-storm treatment processes. Within-storm treatment processes occur during the storm as stormwater enters and flows through the system, and shortly after the storm as the water level in the media is drawn down until inter-storm event moisture content is reached, frequently referenced as the medium's field capacity. The inter-storm treatment processes occur during the time periods between runoff events. Within-storm treatment processes are responsible for the sequestration of pollutants from the water while inter-storm treatment processes are important for regeneration of the sequestration potential of pollution removal (20).

Within-Storm Treatment Processes

Within-storm treatment processes are divided into two general categories, inert filtration and reactive filtration. Inert filtration is the removal of particulate-bound pollutants via physical processes. Inert filtration is primarily accomplished via sedimentation, straining, and depth filtration (20; 22). Reactive filtration captures dissolved and colloidal pollutants through chemical processes such as adsorption and ion exchange (20). The dominant filtration mechanism in the filter is based upon media and pollutant particle sizes, as shown in Table 2.

Table 2. Dominant filtration mechanism based upon media grain and influent pollutant particle sizes (20)

Condition	Dominant Removal Mechanisms for Particulates
(D50 media) / (D50 influent) < 10	Straining (Inert Filtration)
10 < (D50 media) / (D50 influent) < 20	Depth filtration (Inert Filtration)
(D50 media) / (D50 influent) > 20	Physical adsorption (Reactive Filtration)

D50 media is the media grain diameter corresponding to 50% finer by mass on the particle distribution curve.
D50 influent is the influent particle diameter corresponding to 50% finer by mass on the particle distribution curve.

Straining

Particles are removed via straining when the particles' diameter is greater than the pore spaces of the media. Straining, also known as surface filtration occurs near the top of a filter bed, especially if the medium is poorly graded. When the media is tightly packed, straining will occur when the ratio of particle diameter to media grain diameter is in excess of 15% (22). Straining often times results in filter cake formation on the top of the filter bed; this subsequently leads to cake filtration. Cake filtration occurs when the influent passes through a cake of previously strained particles. As the cake develops, particles with progressively smaller diameters than the filter bed media's pore spaces will be removed via straining (23). Cake filtration increases particle removal efficiency by capturing particles with smaller diameters than the pore spaces of the media, however cake filtration also increases the head loss across the filter bed. Furthermore, a system that primarily uses straining makes poor use of the underlying media since most of the particles are captured on the surface of the bed. As a result, rapid filtration beds are designed to minimize surface filtration and maximize the hydraulic loading rate. This is accomplished by selecting a medium fairly uniform in size with an effective size (D10), typically no smaller than 0.5 mm (22). The effective size of a medium is the diameter at which 10% of the media particles by mass have equal or smaller diameters (24).

Depth Filtration

Depth filtration captures the particles throughout the entire depth of the bed, thus enabling a high solids retention capacity without quickly clogging as surface filtration would (22). Depth filtration is composed of a two- step process involving the transport of the particles to or near the media surface followed by the removal of the particles from the fluid via attachment to the media grain surface. Sedimentation occurs both at the surface of the filter bed and inside the filter bed as part of depth filtration. Particles with densities significantly greater than that of water will deviate from the fluid streamlines due to the combined effects of gravity, buoyancy, and fluid drag (22; 25). Surface sedimentation occurs when particles settle on the surface of the filter bed during sheet flow or while non-flowing water has pooled. In the case of depth filtration, sedimentation is a means of transporting the particle to a grain of filter media, termed the collector. The particle is not removed from the solution, unless attachment occurs; attachment will be further discussed in the following sections (25). The transport of particles is one of the physical-hydraulic processes where as attachment is a chemical process (26; 27). After a particle is transported to, and collides with, a collector, the particle will either attach to the collector or bounce off it. Attachment is achieved via surface interaction forces due to the electric double layer, London-van der Waals forces, hydration of ions at surfaces, the steric interactions of adsorbed macromolecules, and the interaction of hydrophobic surfaces (28).

Reactive Filtration

Reactive filtration removes dissolved and colloidal pollutants via the adsorption processes of physical and chemical adsorption, ion exchange, and biosorption. Adsorption is the process by which ions or molecules in one phase (adsorbate) accumulate on the surface of another phase (adsorbent) (29). The dissolved pollutants (adsorbates) are transported, via diffusion, into the porous adsorbent granule and are then adsorbed onto the adsorbent's inner surfaces (30). Although there are differences between these three types of adsorption, it is often difficult to distinguish which, if not all, is at work (29).

Physical & Chemical Adsorption

Physical adsorption occurs due to the principle of electrostatic force and is relatively nonspecific and generally reversible. Physical adsorption occurs when physical forces that exclude covalent bonding and coulombic attraction of unlike charges are involved (30). The electrostatic forces responsible for physical adsorption include dipole-dipole interactions, dispersion interactions (aka London-van der Waals forces), and hydrogen bonding (31). Physical adsorption is the dominant adsorption mechanism in water treatment (30).

Chemical adsorption, also referred to as chemisorption, is due to much stronger forces than physical adsorption and resembles the formation of chemical compounds and is rarely reversible (30). In chemisorptions, the tendency for an adsorbate to adsorb depends strongly on its identity and not solely on the surface charge as in physical adsorption (32). The adsorbate particles form a monolayer on the adsorbent. Once the adsorbent surface is completely covered by the monolayer of adsorbate the adsorption capacity is reached (29; 30).

The division between physical and chemical adsorption is not distinct. Physical adsorption is less specific for which compounds sorb to which surface sites, has weaker bond energies, is reversible, and can have multiple layers of adsorbates on the adsorbent. Chemisorption is rarely reversible. Adsorbates form a monolayer on the adsorbent. The bonds may be specific to particular functional groups on the adsorbent (29). A summary of the differences between physical and chemical adsorption is shown in Table 3.

Table 3. Comparison of physical and chemical adsorption (32) & (30)

Parameter	Physical Adsorption	Chemical Adsorption
Use for water treatment	Most common type of adsorption mechanism	Rare in water treatment
Process speed	Limited by mass transfer	Variable
Type of bonding	Nonspecific binding mechanisms: electrostatic interactions	species specific chemical interactions: covalent or ionic
Type of reaction	Reversible, exothermic	Typically nonreversible, exothermic
Heat of adsorption	4-40 kJ/mole	> 200 kJ/mole
Layers of adsorbate	multiple layers	single layer

Ion Exchange

Ion exchange occurs when ions of species A on an insoluble exchange material, such as BAM are exchanged for ions of species B from the stormwater (26). Ion exchange is classified as an adsorption process because the exchange occurs at the surface of the adsorbent and the exchanging ions undergo a phase change. Ion exchange, however, is different from the typical physical and chemical adsorption as there is an exchange of mobile ions between the solid and the stormwater (33).

Biosorption

Pollutants, such as nutrients, are also captured via the process of biosorption. Biosorption is the sorption of nutrients onto the cellular surfaces of the biomass or biofilm and is considered an abiotic process (35; 36). An abiotic process is a physiochemical process that resembles adsorption or ion exchange (36). A biofilm is a thin biological layer of bacteria, algae, and/or fungi that attaches itself to the surface of the media or soil (37). Biosorption is a metabolically-passive process and thus does not require an energy input from the cells. If equilibrium is reached on the biosorbent, the sorbate, the pollutants, can desorb back into solution (36). To prevent this from occurring, recharging of the biosorbent via biological processes is necessary.

Regeneration of the biosorption media is achieved via biological uptake. Biological uptake includes microbial-mediated transformations, such as nitrification and denitrification, and biological assimilation. Biological uptake involves the transport of biosorbed pollutants from the cellular surfaces of the biomass into the interior of the cell, mainly by energy-consuming active transport (36).

Both biosorption and biological uptake are continuous processes and occur during both the within-storm and inter-storm periods. Biosorption shall be considered to be considered both a within-storm and inter-storm treatment process since it is responsible for both capturing pollutants in the runoff during the storm event and removing pollutants from the soil water during the inter-storm periods. Although biological uptake occurs during both periods, it shall be considered a dominantly inter-storm process. The inter-storm period is much longer than the within-storm period and thus the majority of biological uptake, which regenerates the media, occurs during the inter-storm period. Biological uptake is discussed in greater detail in the Inter-Storm Treatment Processes section.

Inter-Storm Treatment Processes

Inter-storm treatment processes occur in the biologically active soil zone, which extends to approximately three feet in depth below the surface (38). These processes are responsible for the sustainability of the bio-treatment system by enabling long term retention of captured pollutants, removal of the pollutants from the media, and regeneration of some of the within-storm treatment removal mechanisms. Inter-storm treatment processes depend on biological uptake, oxygen levels, volatilization, soil processes, and routine maintenance (20).

Biological Uptake

Biological uptake is accomplished via microbial-mediated transformations, such as nitrification and denitrification. Biological uptake involves the transport of biosorbed pollutants from the cellular surfaces of the biomass into the interior of the cell, mainly by energy-consuming active transport, thus regenerating the biosorption capabilities of the biomass and biofilm (36). As nutrients are continuously removed from the biofilm via biological uptake, more nutrients are biosorbed onto the biofilm from the soil water. Thus the presence of water is important and a media that retains water is important. Removal of nutrients from the soil water via biosorption shifts the nutrient equilibrium between the soil water and the other sorption materials causing them to desorb nutrients into the soil water, thus regenerating their sorption sites for the next storm event.

The assimilation of nitrogen by plants, bacteria, algae, and fungi is an example of biological uptake and is part of the nitrogen cycle. The form of nitrogen needed for the production of biomass, amino acids and proteins, is ammonium (43; 44). Plants, bacteria, algae, and fungi are able to utilize nitrate/nitrite, ammonium, urea, and amino acids as nitrogen sources, although different species prefer different sources or combinations of sources of nitrogen; in general, plants prefer a mixture of ammonium and nitrate and will uptake a higher ratio of ammonium to nitrate (44; 45). Plants, bacteria, algae, and fungi respond to the presence of nitrate in the soil by altering their metabolic pathways. The presence of nitrate will trigger the activation of genes that encode transporters to uptake nitrate from the soil and the production of the enzymes nitrite reductase and nitrate reductase. These enzymes will convert nitrate into ammonium within the cell (45).

Oxygen Levels and Aerobic & Anoxic Zones

Common examples of microbial-mediated transformations include nitrification and denitrification (39). Nitrification and denitrification are part of the nitrogen cycle. Nitrification is a two step, energy-yielding reaction that occurs under aerobic conditions. Nitrification results in the oxidation of ammonia to nitrate. The first step is the conversion of ammonia to nitrite by nitrosobacteria. This is followed by the conversion of nitrite to nitrate by nitrobacteria (40).

Denitrification occurs under anoxic conditions and involves the oxidation of organic substrates using nitrate or nitrite as the electron acceptor (40). Denitrification results in the reduction of nitrate or nitrite to gaseous forms of nitrogen: nitric oxide, nitrous oxide, and nitrogen gas. Under anoxic conditions the end product is nitrogen gas; however under fluctuating oxygen levels nitric oxide and nitrous oxide often form (39).

Which microbial-mediated transformations occur is dependent upon the availability of oxygen. Nitrogen removal is an important goal of bio-treatment systems and is accomplished, partly using nitrification and denitrification. As mentioned previously, nitrification requires aerobic conditions whereas denitrification requires anoxic conditions. The simultaneous presence of nitrification and denitrification in the bio-treatment system is explained by three possible mechanisms.

The first mechanism for the simultaneous presence of nitrification and denitrification processes within the bio-treatment system is due to the biofilm. As the thickness of the biofilm increases, oxygen is consumed faster than it can diffuse throughout the entire depth of the biofilm; as a result the biofilm is composed of an inner anoxic layer and an outer aerobic layer. Nitrification in the outer aerobic layer transforms ammonia into nitrate which then diffuses into the inner anoxic zone where it undergoes denitrification, as shown in (42; 37).

The second mechanism for the simultaneous presence of nitrification and denitrification processes within the bio-treatment system is the pockets of aerobic and anoxic conditions throughout the media or soil. Root zones, as well as the variable saturation of the media or soil, are responsible for creating these pockets of aerobic and anoxic conditions (20).

A third mechanism is the low dissolved oxygen concentration present in the soil water. Since the soil water is not continuously aerated, the dissolved oxygen concentration will be lower than optimal for nitrification and above optimal for denitrification. As a result, both processes will occur at the same time at lower than the fastest rate (42). The dissolved oxygen concentration should be higher and the moisture content should be lower near the surface of the media or soil. With increasing depth, the dissolved oxygen concentration should decrease and the moisture content should increase. This means that aerobic conditions will dominant near the surface and anoxic conditions will become more prevalent with increasing depth.

Volatilization

The process by which liquids and solids vaporize and escape into the atmosphere is known as volatilization. If a substance readily vaporizes at normal atmospheric pressure and temperature it is known as a volatile compound. Examples of volatile compounds include volatile organic compounds such as petroleum hydrocarbons and ammonia (20).

The volatilization of ammonia is part of the nitrogen cycle. A significant amount of ammonia leaves the soil by volatilization, in some cases 50% of what is applied. The volatilization of ammonia is controlled mainly by the dissociation constant of ammonium and the pH of the soil (46).

Soil Processes

Soil processes include weathering, plant activity, and animal activity; all of which aid in maintaining the hydraulic conductivity of the soil. Weathering of the soil is caused by evaporation, expansion and contraction of the media due to moisture content and temperature changes, among other physical processes. Thus weathering results in the breakup of the cake layer formed from straining (20).

Plant activity not only aids in maintaining hydraulic conductivity but also prevents erosion of the filter bed media and increases the amount of organic matter in the soil that functions as adsorbents. Both the roots and the stems of plants serve to sustain hydraulic conductivity. As the stalks of the plants move back and forth in the wind they break up the surface cake layer that has formed. As plant roots grow they create void spaces; additionally, plant roots will expand and contract depending upon the availability of water, this creates preferential flow paths for infiltrating water (20).

Animals also help with maintaining hydraulic conductivity and increasing the amount of organic matter. Worms living in the soil produce castings which as organic matter, serve as an adsorbent. Additionally, as worms move through the soil they create cavities and void spaces which serve to increase infiltration (20).

Routine Maintenance

Although bio-treatment systems are largely self-sustaining, some maintenance is needed. The bio-treatment system should be inspected at least annually for erosion. The system should be inspected twice annually for vegetation health and density; the vegetative cover of the system should be maintained at a minimum of 85% cover. Whenever possible, vegetation issues should be corrected without the use of fertilizers and pesticides (19). Periodic removal and replacement of the top of the bio-treatment system may also be necessary. This will result in the removal of accumulated sediment and pollutants that are deposited to the sediment and the top layer of media (20).

2.4 BOLD & GOLD™

Bold & Gold™ is a Biosorption Activated Media (BAM) developed and patented by the University of Central Florida Stormwater Management Academy. BAM is designed with four functions: rapid infiltration, inert filtration, reactive filtration, and to provide an ideal habitat for microbes. The Bold & Gold™ used in this research is specified for highway runoff and is composed of an un-compacted volume ratio of 75% expanded clay and 25% tire crumb.

Expanded Clay

Expanded clays are typically composed of an inert ceramic particle with a porous coating. Expanded clay is created by a process known as calcination, which involves exposing the clay to temperatures of up to 1200°C inside a rotary kiln. During calcination the organic matter in the clay expands resulting in a high porosity, low bulk density aggregate. Furthermore, the expanded clay has a higher hydraulic conductivity (aka permeability) than similarly sized gravels and sands (47).

The high porosity of expanded clays enables them to maintain relatively high moisture content. The combination of consistent high moisture content and large surface area makes the expanded clay an ideal habitat for microbes and helps to maintain healthy vegetation on top of the filter bed. A healthy population of microbes and vegetation is essential for rejuvenating the adsorption and ion exchange capacities of the medium.

Clay minerals are aluminum silicates composed of silica tetrahedrons and alumina octahedrons. Clay particles have a net negative charge on the surfaces due to negatively charged functional groups. This net negative charge is balanced by exchangeable cations, such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. Additionally, there are some positively charged functional groups located on the edges of the clay particles (48). These properties make clay an ideal adsorption medium. Furthermore, the sorption capacity of clay is increased even further by the process of calcination (49).

Expanded clays are commonly used adsorbents and anion exchange media for the removal of phosphorus, principally as phosphate (47). Phosphate adsorption to clay generally occurs by bonding to the positively charged particle edges and by anion exchange of phosphates for silicates in the clay (46). The phosphorus sorption capacity for expanded clays has been found to range between 0.037 to 2.90 g P/kg, depending on the origin of the clay (50).

According to the NSQD (13), the average pH of freeway runoff is 7.1. This means the dominant form of aqueous ammonia present is ammonium (NH4+) as shown in Figure 3 (41). As mentioned previously, clay has a net negative charge and is balanced by exchangeable cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. As a result, clay is effective at capturing ammonium via cation exchange (51).

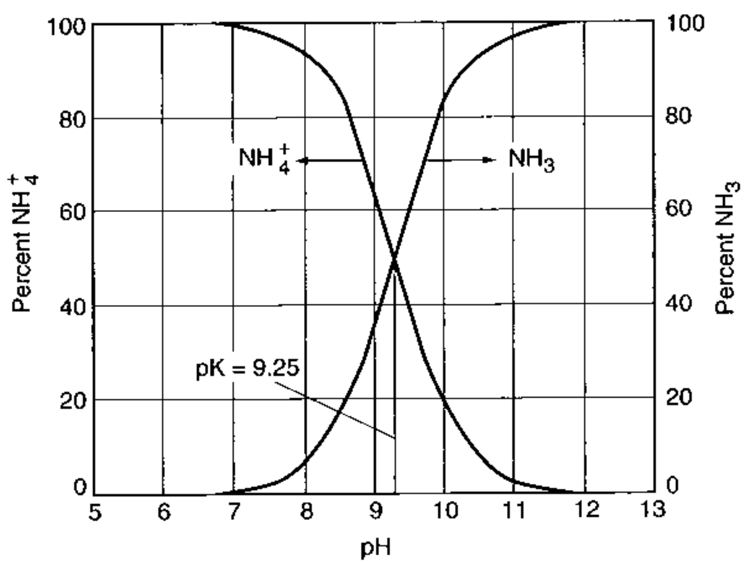

Figure 3. Distribution of ammonia and ammonium as a function of pH (41)

Tire Crumb

Automobile tires are generally composed of 27% to 33% carbon black by mass; carbon black functions similarly to activated carbon (52). Activated carbon has a large surface area to mass ratio, which makes it ideal for adsorption (53). Activated carbon is very effective in removing large organic molecules and nonpolar compounds. However, it is less effective on inorganic molecules such as: nitrate, phosphate, chloride, bromide, iodide, lead, nickel, titanium, vanadium, iron, copper, cadmium, zinc, barium, selenium molybdenum, manganese, tungsten, and radium (53).

The adsorption of polar adsorbates on nonpolar adsorbents, such as activated carbon, depends strongly on the pH of the solution. The solution pH affects the charge on the activated carbon, which tends to be negative at pH 7 and above, neutral from 4 to 5 pH, and positive below pH of 4 (30). This is due to the increasing number of positively charged sorption sites and the decreasing number of negatively charged sorption sites on the adsorbent. The resulting dominantly positively charged sorption sites on the activated carbon will favor the adsorption of nitrate ions due to the electrostatic attraction (54).

pH also has an effect on adsorption via activated carbon by affecting the form of the adsorbate. In the case of weak conjugated acids, such as phosphoric acid, the maximum adsorption is exhibited around the pH closest to the pKa of the acid. The more pKa values an acid has, the longer the pH adsorption plateau will be, thus the greater the pH range of effective adsorption (55).

CHAPTER 3 LINEAR ROADSIDE SWALE BIO-TREATMENT WITH HARVESTING OF HIGHWAY RUNOFF

3.1 INTRODUCTION

The data and information in this Chapter were used to compare effluent nutrient concentrations from the Bold & Gold™ BAM to concentrations from sandy soil using simulated highway runoff. Additionally, this material provides information for preliminary designs for a highway retention and biodetention system. For the example, the biodetention system uses Bold & Gold™ to remove nutrients and then the effluent from the system can be reused if desired (typically irrigation or rehydration of wetlands and other non-potable applications) or discharged with improved water quality. The improved water quality estimates can be used to meet TMDL program limits.

3.2 STATEMENT OF PURPOSE AND HYPOTHESES

Will a BAM media in a roadside swale bio-treatment configuration remove pollutants? An answer is provided by measuring the effluent nutrient concentrations from a bio-treatment system utilizing a BAM Bold & Gold™ media and comparing it to the effluent from a sandy soil. Various phosphorus and nitrogen species were the nutrients of interest including: total nitrogen, nitrate + nitrite, dissolved organic nitrogen, particulate nitrogen, total phosphorus, soluble reactive phosphorus (SRP), dissolved organic phosphorus, and particulate phosphorus. Turbidity, pH, total suspended solids (TSS), fecal coliform, and E. coli concentrations were also measured.

Additionally, a biodetention system is designed with the Biosorption Activated Media (BAM), called Bold & Gold™, with a below grade stormwater storage chamber before discharge to a surface water. The below grade storage is used to reduce the stormwater discharge rate and for non-potable reuse purposes such as irrigation.

The following hypotheses were formulated to reflect questions of concern when evaluating bioretention or biodetention systems:

- Bold & Gold™ media is superior to sandy soil (Type A-3) for capture of nitrogen and phosphorus species.

- Bold & Gold™ has a higher infiltration rate and permeability than Type A-3 sandy soil.

- Bold & Gold™ will have higher inter-storm moisture content, also known as field capacity, than Type A-3 sandy soil. This higher moisture provides better living conditions for the microbes and plants that sustain the pollutant capture mechanisms.

3.3 LIMITATIONS OF THE SWALE BIO-TREATMENT SYSTEMS

The experimentation was limited to the physical design configuration of the biodetention system and depth of Bold & Gold™. The simulated highway runoff is obtained by spiking stormwater pond water with ammonium carbonate, potassium nitrate, and potassium phosphate in order to approximately reach the average highway runoff concentrations for nitrogen and phosphorus species listed in the National Stormwater Quality Database.

3.4 METHODOLOGIES

Since pollutant removal and infiltration comparisons are made between the use of Bold & Gold™ and a Type A-3 sandy soil, adjacent test plots are used with the same highway runoff water. This comparison is performed using a field scale test bed split into sandy soil and Bold & Gold™ sides. The Bold & Gold™ used in this research is specified for highway runoff and was composed of an un-compacted volume ratio of 75% expanded clay and 25% tire crumb.

A nuclear density gauge was used to determine the wet and dry densities of the sandy soil and Bold & Gold™ in the test bed. A moisture content analysis was also performed on the test bed prior to each test run. Additionally, tests are performed on influent and effluent water for each test run.

Bench scale tests for specific gravity, permeability, maximum dry density, moisture content for maximum dry density, and particle-size are performed to determine the soil characteristics. Additionally, a bench scale column test was performed on both the sandy soil and the Bold & Gold™ without the sod present. The total porosities of the Bold & Gold™ and sandy soil were calculated based upon the density of water, the experimentally determined specific gravities, and the in situ dry densities in the test bed. An estimate of the vertical unsaturated hydraulic conductivity was calculated based upon an empirical relationship with the coefficient of permeability. Testing was done according to the American Society for Testing and Materials (ASTM) standards, as often as possible.

Test Bed Construction

The test bed represented a highway and an adjacent roadside swale, with a single 12 foot wide concrete traffic lane and a 2.0 foot wide concrete inside shoulder. A diagram of the test bed prior to being filled with Bold & Gold™ and sandy soil is displayed in Figure 4 to show the locations of the impermeable barriers. Wood was placed on the concrete lane and shoulder to approximately split the sheet flow equally into 4 foot long sections for each of the Type A-3 sandy soil and Bold & Gold™ sides.

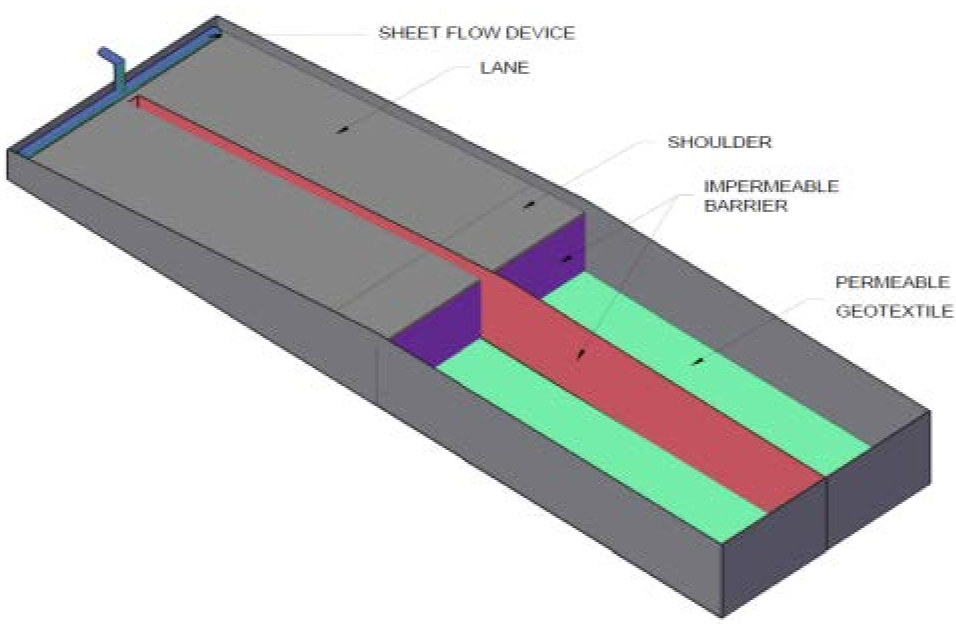

Figure 4. Diagram of empty test with location of impermeable barriers

A picture of the fully constructed test bed is shown in Figure 5.

Figure 5. Picture of the operational test bed

The Bold & Gold™ and sandy soil had equal depths of 2.7 feet. The depth of 2.7 feet was used because of the test bed geometric limitations and literature that indicated a depth of 3 feet as the maximum for effective bio-treatment (38). The St. Johns River Water Management District (SJRWMD) (56) (57) requires that detention with filtration systems for harvesting have a minimum filter media depth of 2.0 feet, thus the Bold & Gold™ and sandy soil depth of 2.7 feet was satisfactory to meet that regulation.

The traffic lane had a side slope of 2%, and the shoulder had a side slope of 5%. The roadside swale had a slope of 1:6, which was approximately 16.67% (58). The shoulder areas were compacted in five levels. The Bold & Gold™ and sandy soil were not wetted during compaction. Compaction was performed without watering. The roadside swale section of the test bed had a vegetative cover of Argentine Bahia. The

Argentine Bahia was placed on the test bed as sod and was allowed two months to establish prior to the start of testing. During the first month of sod establishment, the sod was watered every other day; during the second month, the sod was watered every four days.

Simulated Highway Runoff

The water used for the highway runoff was collected from a stormwater pond that receives runoff from both a two lane highway and a parking lot. It was desired to make the pond water concentrations more equal to actual highway runoff, thus the nitrogen and phosphorus species concentrations are adjusted to approximate the NSQD average values (13) for freeways, as shown in Table 4. To create simulated highway runoff, ammonium carbonate, potassium nitrate, and potassium phosphate were added to the pond water. Rainfalls of one, one and a half, and three inches of rainfall with duration of 30 minutes were simulated. Each rainfall was repeated three times.

Table 4. National Stormwater Quality Database Average Nitrogen and Phosphorus Species Concentrations for Freeway

NSQD Values for Freeways		
Units	**Name**	**Freeways**
Median Values in mg/L an N or P	NH_3	1.07
	TKN	2.0
	$NO_2^- + NO_3^-$	0.28
	Total Nitrogen	2.28
	Filtered Phosphorus (aka OP)	0.20
	Total Phosphorus	0.25

Collection of Influent and Effluent

Influent water quality was collected at the start of each of the 30 minute rainfall event. The influent was collected using a perforated PVC pipe lying along the interface of the concrete shoulder and the Argentine Bahia. The influent was collected at this location, as opposed to the influent source container, to include any changes or additions to the water chemistry that occurred as the runoff flows over the concrete lane and shoulder.

Effluent is defined as the water that has infiltrated through the soil in the test bed. The effluent drains from holes in the bottom of the test bed. The effluent was collected in 55 gallon barrels located underneath the test bed as shown in Figure 6. The effluent was collected for two hours after the 30 minute rainfall event had concluded. Two hours was used because the infiltrated water had almost stopped dripping at that time. Water samples for analysis were taken from the collection barrels at the completion of the two hour collection time. The collection barrels were scrubbed, rinsed with tap water, and allowed to dry prior to each test.

Figure 6. Effluent Collection

Water Quality Analysis

Turbidity and pH were determined at the test site using a 2100P Portable Turbidimeter by HACH® and an Accumet Research AR50 by Fisher Scientific®, respectively. An alkalinity, TSS, fecal coliform, E. coli, total nitrogen, nitrate + nitrite, ammonia, dissolved organic nitrogen, particulate nitrogen, total phosphorus, soluble reactive phosphorus (SRP), dissolved organic phosphorus, and particulate phosphorus analysis was performed by Environmental Research & Design, Inc., a National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory. .

All sample bottles, except the bacteria sample bottles, were acid washed using hydrochloric acid and rinsed with deionized water. The bacteria sample bottles were pre-sterilized by the manufacturer and will have a small white pill or white powder that will counteract any chlorine in the water. Five sample bottles each, from the influent, Bold & Gold™ effluent, and sandy soil effluent were transported to the laboratory on ice for analysis. Sulfuric acid was used to lower the pH to below two when needed for preservation and 0.45 µm syringe filters were used for filtering the samples when needed.

Moisture Content

As explained earlier, moisture content is critical to the operation of a bio-treatment system. The moisture content of the Bold & Gold™ and sandy soil in the test bed was determined using ASTM D 2216-98. Prior to each test run, core samples were taken over a depth range of six to eight inches at the three locations shown in Figure 7. The moisture contents from the three locations were averaged together to obtain the average moisture content of the soil.

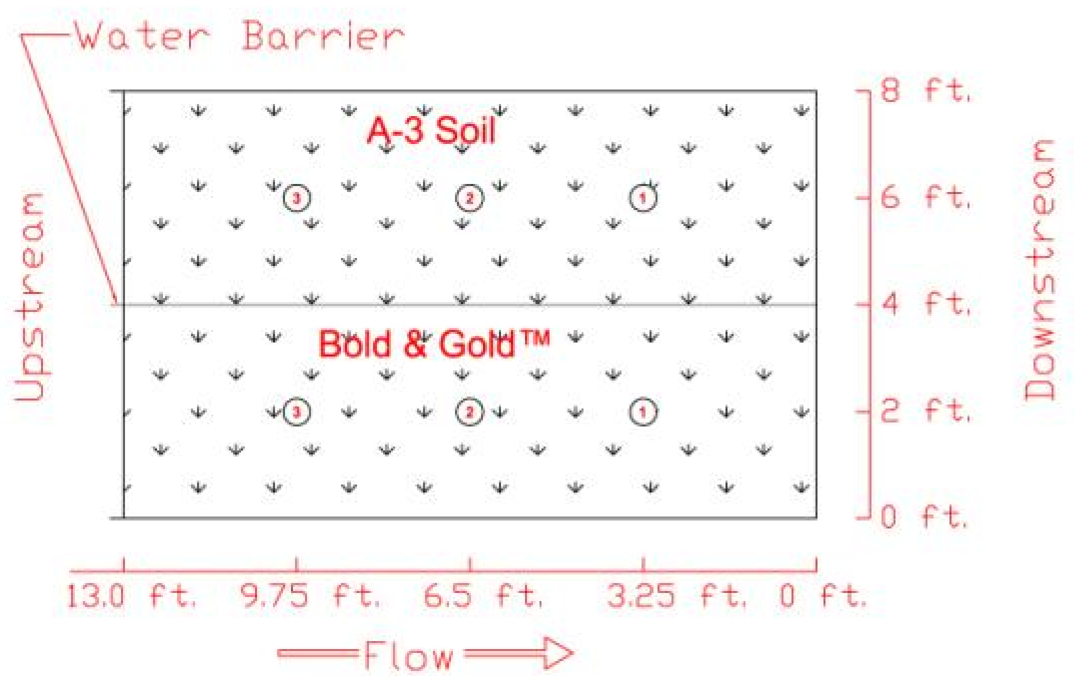

Figure 7. Testing Locations for Nuclear Density Gauge and Moisture Content

Specific Gravity

The specific gravity of the Bold & Gold™ and the sandy soil was determined using a water pycnometer, according to ASTM D 854-02. Oven dried soil samples were used for the experiment, thus Method B-Procedure for Oven-Dried Specimens was used.

Maximum Dry Density & Moisture Content at Maximum Dry Density

The maximum dry density and the moisture content at maximum dry density for the Bold & Gold™ and the sandy soil was determined using the standard Proctor test as described in ASTM D 698-00. The sandy soil was prepared using the Dry Preparation Method and testing was performed using Method A. The Bold & Gold™ was prepared using the Moist Preparation Method and testing was performed using Method B. A manual rammer was used for compaction.

Soil Classification

The sandy soil was classified using the Unified Soil Classification System, according to ASTM D 2487-00 and the American Association of Highway and Transportation Officials (AASHTO) system, as specified in AASHTO M 145-91. Classification was based solely upon particle size characteristics; the liquid limit and plasticity index were not considered. Particle size characteristics were determined using a sieve analysis as specified by ASTM C 136-01.

Particle Size Distribution

The particle size distribution was determined using a sieve analysis, as specified in ASTM C 136-01. The sieve test for the sandy soil was conducted with sieve numbers: 35, 45, 60, 70, 100, and 200. Additional sieves were used for the Bold & Gold™ since it is a composite of tire crumb and expanded clay; therefore there will be a broader distribution of grain sizes. The Bold & Gold™ sieve test was conducted with sieve numbers: 4, 8, 10, 16, 35, 40, 45, 50, 60, 70, 100, and 200.

Permeability

The permeability of the sandy soil and the Bold & Gold™ was determined using the constant head method. The standard method used is ASTM D 2434-68. A permeability cylinder having a diameter of three inches was used for permeability testing of both the sandy soil and the Bold & Gold™ due to their particle size distribution results, as specified in ASTM D 2434-68.

For both the Bold & Gold™ and the sandy soil, there were three series of tests, each time with a fresh soil sample. Each series included measurements at three separate head differences. For each head difference there were three measurements of the volume that were collected after a duration of 60 seconds. Coefficient of permeability (k) values were calculated for each of the volumes collected, resulting in three k values for each head difference and thus nine k values for each series. The k values were then corrected to 20°C, yielding the coefficient of permeability at 20°C (k20°C). The average k20°C for each series, as well as the overall soil, was then calculated.

The heads at which the constant head permeability test should be run are specified in section 7.2 of ASTM 2434-68. The standard discusses determining the head at which laminar and turbulent flow occur, and at what head intervals testing should be done in each of these regions. The actual procedure used for determining the heads to be tested differs from that of ASTM 2434-68. Since the focus of this research is on roadside swales, the chosen heads reflected a common depth range found in such swales. For this test, depth refers to the distance between the top of the soil in the permeability cylinder and the water level in the funnel, just as depth in a swale would refer to the distance between the water surface and the soil at the bottom of the swale. Depths of approximately 18 inches, 12 inches, and seven inches were used. Water depths greater than 18 inches are rarely seen in a swale because of safety reasons.

Unsaturated Vertical Hydraulic Conductivity (Vertical Unsaturated Infiltration)

An estimate of the vertical unsaturated hydraulic conductivity (k_{vu}) was calculated based upon an empirical relationship with the coefficient of permeability (k) (59), as shown using Equation (1).

$$\mathbf{K_{vu}=2/3*k} \qquad \textbf{(1)}$$

Total Porosity

Total porosity is the ratio of the volume of voids to the total volume of the soil. Equation (2) expresses the total porosity as a function of the density of water, the specific gravity of the soil, and the dry density of the soil. The dry densities of the Bold & Gold™ and sandy soil in the test bed were obtained using the nuclear density gauge. These densities, as well as the experimentally determined specific gravities, were used to calculate the total porosity of the medium in the test bed.

Total porosity=1-[(dry density)/((specific gravity)*(density of water))] (2)

Column Test

Column tests were performed on the Bold & Gold™ and sandy soil without sod present. Sod farms typically use fertilizer to increase production, thus it was reasonable to assume that the sod will leach nutrients into the Bold & Gold™ and sandy soil on the test bed, especially during the initial test runs. This presented a problem for analyzing nutrient removal rates since an unknown amount of nutrients were being added to the simulated highway runoff. As a result, the Bold & Gold™ and sandy soil test bed effluent concentrations were compared, not the percentage of removal. However, it was still desirable to have a general idea of what percentage of removal of the total phosphorus and total nitrogen were obtained by the sandy soil and Bold & Gold™. As a result, column tests without sod were conducted with Bold & Gold™ and sandy soil to obtain a percent removal.

The column test apparatus (see Figure 8) consisted of a 3.5 foot long clear PVC pipe with an inside diameter of six inches. There are eight inches of clean rocks at the bottom of the column and geotextile fabric separating the rocks from the media. The media was 2.7 feet deep. The effluent collection pipe was located within the rock layer.

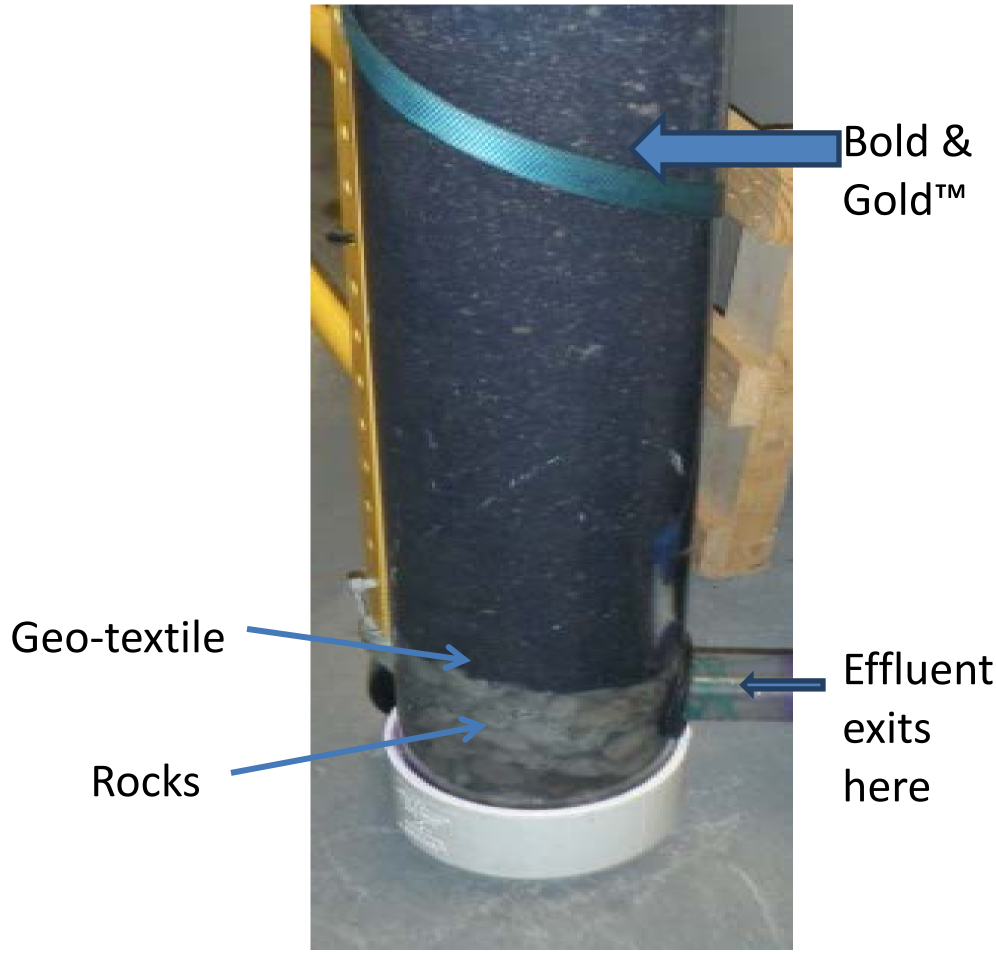

Figure 8. Column Test Apparatus

3.5 RESULTS AND DISCUSSION

Within this section, effluent nutrient concentrations of the soil amendment Bold & Gold™ are compared to those from sandy soil for simulated highway runoff with the ultimate goal of utilizing Bold & Gold™ in the design of bioretention or biodetention systems. In order to design a bioretention or biodetention system, media characteristics and media/water quality relationships were needed.

Media Characteristics and Results

The physical characteristics of the Bold & Gold™ and sandy soil present in the test bed were determined through tests done in the test bed, bench scale tests, and calculations based upon experimentally determined values. Bench scale tests for specific gravity, permeability, maximum dry density, moisture content of maximum dry density, and particle-size distribution were performed. The dry density of the in situ Bold & Gold™ and sandy soil located in the test bed was determined using a nuclear density gauge. Prior to each test run, core samples were taken from the test bed to determine the moisture content of the Bold & Gold™ and sandy soil. The total porosities of the Bold & Gold™ and sandy soil present in the test bed were calculated using the experimentally determined specific gravities and the in situ dry densities of the soils in the test bed.

Dry Density

A nuclear density gauge was used to determine the in situ dry densities of the sandy soil and Bold and Gold™ present in the test bed, according to ASTM D 6938-10. The dry densities of the soils were required for the subsequent permeability tests and porosity calculations. The dry density of sandy soil was found to be 85 pounds per cubic foot and the dry density of the Bold & Gold™ was found to be 39 pounds per cubic foot.

Inter-storm, In Situ Moisture Content (Field Capacity)

Field capacity is defined as the moisture content remaining in a media that has been wet and allowed to drain freely by gravity until drainage is negligible. By observation, drainage in the test beds was completed by gravity and typically occurs after two to three days, which is the same as reported elsewhere (60).

The moisture content data after complete gravitational drainage for the sandy soil and Bold & Gold™ are presented in Table 5 and Table 6, respectively. As shown in Tables 5 and 6, the moisture contents of both the sandy soil and Bold & Gold™ are relatively constant from test to test.

Table 5. Sandy Soil Moisture Content (Field Capacity) Data

Date	Upstream Moisture Content	Midpoint Moisture Content	Downstream Moisture Content	Overall Test Bed Average Moisture Content
8/11/2011	n/a	n/a	n/a	n/a
8/17/2011	6.84%	7.95%	n/a	7.40%
8/24/2011	6.01%	5.58%	5.82%	5.80%
8/29/2011	6.04%	5.95%	6.25%	6.08%
9/7/2011	4.23%	5.51%	5.34%	5.03%
9/12/2011	5.03%	5.14%	4.82%	5.00%
9/21/2011	6.19%	6.62%	6.69%	6.50%
9/26/2011	5.36%	4.87%	5.70%	5.31%
10/3/2011	6.98%	4.63%	5.63%	5.75%
Average of all test dates	5.83%	5.78%	5.75%	5.86%

Table 6. Bold & Gold™ Moisture Content (Field Capacity) Data

Date	Upstream Moisture Content	Midpoint Moisture Content	Downstream Moisture Content	Overall Test Bed Average Moisture Content
8/11/2011	n/a	n/a	n/a	n/a
8/17/2011	40.77%	40.27%	40.82%	40.62%
8/24/2011	40.36%	41.40%	42.40%	41.39%
8/29/2011	38.78%	39.34%	37.64%	38.59%
9/7/2011	38.47%	37.36%	38.56%	38.13%
9/12/2011	40.23%	39.20%	39.50%	39.64%
9/21/2011	42.47%	41.26%	40.50%	41.41%
9/26/2011	41.55%	40.98%	41.49%	41.34%
10/3/2011	40.54%	n/a	39.67%	40.11%
Average of all test dates	40.40%	39.97%	40.07%	40.15%

Since the measurements were taken after water had drained from the media, the overall average moisture content for all test dates were considered to be the field capacities. The field capacity of the Bold & Gold™ was 40.15% and the field capacity of the sandy soil was 5.86%. The higher field capacity of the Bold & Gold™ indicated that biological activity was more probable with the Bold & Gold™ than the sandy soil.

Particle-Size Distribution & Soil Classification

The particle distribution curves for the sandy soil and Bold & Gold™ are shown in Figure 9 and Figure 10, respectively. D_{10}, D_{30}, and D_{60} are the particle diameters corresponding to 10%, 30%, and 60% finer by mass on the distribution curve. The formulas for the uniformity coefficient (Cu) and the coefficient of gradation (Cc) are shown in Equation (3) and Equation (4), respectively. The D_{10}, D_{30}, and D_{60} values, as well as the uniformity coefficients and coefficients of gradation for the sandy soil and Bold & Gold™, are presented in Table 7and Table 8, respectively.

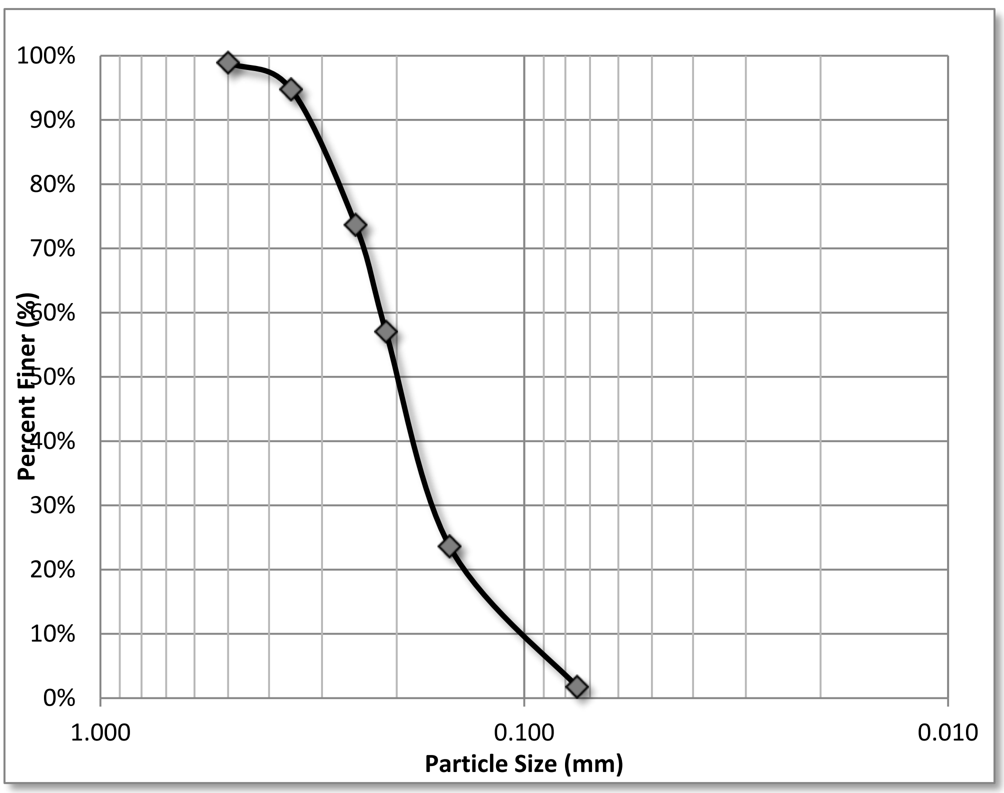

Figure 9. Particle Size Distribution Curve for the Sandy Soil Present in the Test Bed

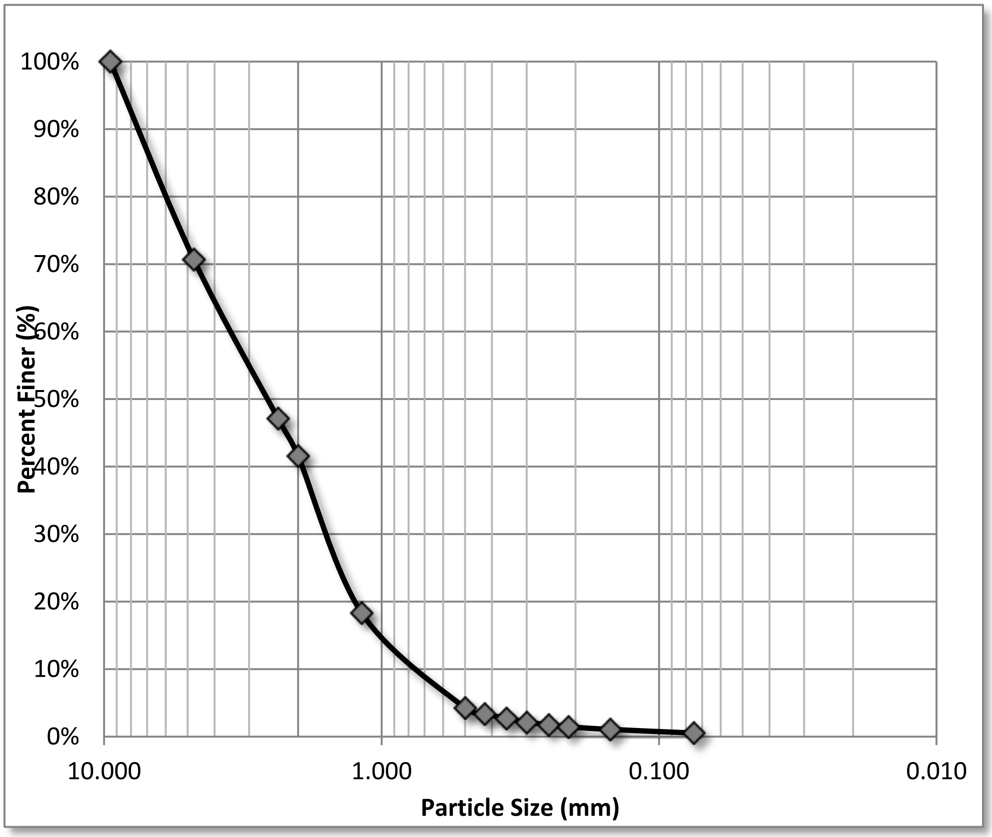

Figure 10. Particle Size Distribution Curve for Bold & Gold™

The formulas for the uniformity coefficient (Cu) and the coefficient of gradation (Cc) are shown in Equation (3) and Equation (4), respectively.

$$C_u = D_{60}/D_{10} \quad (3)$$

$$C_c = (D_{30}^{\wedge}2)/(D_{60} * D_{10}) \quad (4)$$

where D_{10}, D_{30}, and D_{60} are the particle diameters corresponding to 10%, 30%, and 60% finer by mass on the distribution curve.

Table 7. Uniformity Coefficient and Coefficient of Gradation for the Sandy Soil

D_{60}	0.22	mm
D_{10}	0.1	mm
D_{30}	0.18	mm
Uniformity Coefficient (C_u)	2.20	unitless
Coefficient of Gradation (C_c)	1.47	unitless

Table 8. Uniformity Coefficient and Coefficient of Gradation for Bold & Gold™

D_{60}	2.3	mm
D_{10}	0.7	mm
D_{30}	1.5	mm
Uniformity Coefficient (C_u)	3.29	unitless
Coefficient of Gradation (C_c)	1.40	unitless

Soil Classification

Soils are a composite of gravel, sand, silt, and clay; AASHTO and the Unified Soil Classification System have different grain size ranges for these components as shown in Table 9. The AASHTO system bases soil classification on particle size distribution, liquid limit, and the plasticity index. The Unified Soil Classification System utilizes the particle size distribution, liquid limit, and plasticity index just as AASHTO does, but also uses the grain type composition percentages, uniformity coefficient (Cu), and the coefficient of gradation (Cc).

Table 9. Grain Type Size Ranges

	Grain Diameter (mm)			
Name of Organization	Gravel	Sand	Silt	Clay
AASHTO	76.2 to 2	2 to 0.075	0.075 to 0.002	< 0.002
Unified Soil Classification System	76.2 to 4.75	4.75 to 0.075	Fines (silts & clays) < 0.075	

The composition of the sandy soil, according to the AASHTO Classification System grain type size ranges shown in Table 9, are presented in Table 10. Classification of the sandy soil according to the AASHTO system was based upon the particle distribution curve shown in Figure 9. As shown in Figure 9, more than 51% of the sandy soil passes the #40 sieve and less than 10% passes the #200 sieve, therefore the AASHTO classification of the sandy soil was A-3.

Table 10. AASHTO System: Grain Type Composition of the Sandy Soil

Gravel	0%
Sand	98.23%
Silt & Clay	1.77%

The composition of the sandy soil, according to the Unified Soil Classification System grain type size ranges shown in Table 9, are presented in Table 11.

Table 11. Unified Soil Classification System: Grain Type Composition of the Sandy Soil

Gravel	2.00%
Sand	96.23%
Fines	1.77%

Classification of the sandy soil according to the Unified Soil Classification System, is based upon the particle distribution curve in Figure 9, the composition percentages in Table 11, the uniformity coefficient, and the coefficient of gradation. The D_{10}, D_{30}, and D_{60} values, as well as the uniformity coefficients and coefficients of gradation for the sandy soil, are presented in Table 9. Based upon these parameters, the Unified Soil Classification System designates the sandy soil in the test bed as “Poorly Graded Sand”.

Specific Gravity

The specific gravity of soils (GS) is defined as the ratio of the dry density of soil solids to the density of water. Specific gravity is an important parameter in soil mechanics and was used for calculation of the various weight-volume relationships (61). The dry densities of the soils were required for the subsequent porosity calculations. At 20°C, the specific gravities were found to be 2.69 for the sandy soil and 1.22 for the Bold & Gold™.

Maximum Dry Density & Moisture Content for Maximum Dry Density

In order to better understand the compaction characteristics of the sandy soil and Bold & Gold™, a standard Proctor test was performed on each to obtain the maximum dry density and the moisture content for maximum dry density. The moisture content for maximum dry density is the moisture content of the medium at which the maximum dry density is achieved. The maximum dry densities and moisture contents for maximum dry density of the sandy soil and Bold & Gold™ were determined using a standard Proctor test, as described in ASTM D 698-00. The details of the tests and the results are presented by Hood (21).

The sandy soil had a maximum dry density of 103.4 lb/ft3 and moisture content for maximum dry density of 13.8%. The Bold & Gold™ had a maximum dry density of 43.1 lb/ft^3 and moisture content for maximum dry density of 40.2%.

Permeability

The results of the sandy soil and Bold & Gold™ permeability tests are shown in Hood (21). The coefficients of permeability for each sandy soil test, as well as the overall average coefficient of permeability, are presented in Table 12. The coefficients of permeability for each Bold & Gold™ tests, as well as the overall average coefficient of permeability, are presented in Table 13. The overall coefficients of permeability at 20°C for sandy soil and Bold & Gold™ were 0.0107 cm/second and 0.0409 cm/second, or 15.10 in/hr and 57.96 in/hr, respectively. Thus, the Bold & Gold™ had a coefficient of permeability 284% greater than that of the sandy soil. Nevertheless, both of the media were expected to drain at a relatively fast rate.

Table 12. Sandy Soil Permeability: Overall Coefficient of Permeability

Sandy Soil Test Series #	Average k at 20°C (cm/second)	Average Void Ratio (unitless)
1	0.010832687	0.809767138
2	0.012090602	0.719130061
3	0.00903978	0.725000282
Overall Average of Series	**0.0107**	**0.751**

Table 13. Bold & Gold™ Media Permeability: Overall Coefficient of Permeability

Bold & Gold™ Test Series #	Average k at 20°C (cm/second)	Average Void Ratio (unitless)
1	0.072147482	1.02275757
2	0.024054567	0.873764354
3	0.026486628	0.832986572
Overall Average of Series	**0.0409**	**0.910**

Unsaturated Vertical Hydraulic Conductivity (Vertical Unsaturated Infiltration)

An estimate of the vertical unsaturated vertical hydraulic conductivity was calculated based upon an empirical relationship with the coefficient of permeability (k) (59). Additionally, the design of a retention basin, assuming unsaturated vertical flow, was calculated using the media's unsaturated vertical hydraulic conductivity (59) (28). The estimates are shown in Table 14.

Table 14. Estimate of Unsaturated Initial Vertical Hydraulic Conductivity Based on an Empirical Relationship

	cm/second	in/hour
Bold & Gold™	0.02726	38.64
Sandy Soil	0.00710	10.07

Total Porosity

Total porosity is the ratio between the soil's volume of void spaces and total volume. The total porosities of the Bold & Gold™ and sandy soil present in the test bed are functions of the experimentally determined specific gravities of the soils, the in situ dry densities of the soils in the test bed, and the density of water. The total porosities of the sandy soil and Bold & Gold™ were 43% and 49%, respectively.

Water Quality Characteristics and Results

Water quality data were used to compare effluent nutrient concentrations of the soil amendment Bold & Gold™ to that from the Type A-3 sandy soil for simulated highway runoff. In addition to the comparison of effluent concentration, influent analyses and column tests were also performed. The complete data set for all water quality parameters and for all tests is found in the thesis of Andrew Hood (21).

Influent

The NSQD average values for freeways are shown in Table 15. The means, medians, standard deviations, and coefficients of variation of the simulated highway runoff are shown in Table 16.

Table 15. Summary of Freeway Runoff Data from the NSQD (13)

	NH_3 (μg/L as N)	$NO_2^- + NO_3^-$ (μg/L as N)	Filtered Phosphorus (μg/L as P)	Total Phosphorus (μg/L as P)
Number of Observations	79	25	22	128
Median	1070	280	200	250
Coefficient of Variation	1.3	1.2	2.1	1.8

Table 16. Summary of Test Bed Highway Runoff Characteristics

	Mean	Median	Standard Deviation	Coefficient of Variation
Turbidity (NTU)	3.338	3.49	0.9338	0.2798
pH	7.737	7.77	0.1810	0.02340
Alkalinity (mg/L as $CaCO_3$)	68.27	66.4	10.82	0.1585
TSS (mg/L)	3.644	3.3	1.737	0.4767
Total N (µg/L as N)	1078	999	209.3	0.1942
$NO_3^- + NO_2^-$ (µg/L as N)	306.2	280	74.73	0.2440
NH_3 (µg/L as N)	475.8	528	150.5	0.3162
Dissolved Organic N (µg/L as N)	169.3	68	190.8	1.127
Particulate N (µg/L as N)	126.6	60	165.2	1.305
Total P (µg/L as P)	189.2	197	16.78	0.08866
SRP (µg/L as P)	164.3	166	24.48	0.1490
Dissolved Organic P (µg/L as P)	7.444	6	5.940	0.7978
Particulate P (µg/L as P)	17.44	13	15.09	0.8652
Fecal Coliform (cfu/100 mL)	1019	362.5	1220	1.198
E. Coli (cfu/100 mL)	21.60	17	25.63	1.187

Column Test

Sod farms typically use fertilizer to increase production, thus it was reasonable to assume this sod would leach nutrients into the soils on the test bed, especially during the initial test runs.

A column test was performed on the Bold & Gold™ and sandy soil without sod present to determine what removal efficiencies of total phosphorus and total nitrogen were obtained by the Type A-3 sandy soil and Bold & Gold™ media without the influence of nutrient leaching from the sod. A single column test was performed on the sandy soil and Black & Gold™. The water quality testing was performed by the NELAC certified ENCO Laboratories, Inc. The results of the column test for sandy soil and Bold & Gold™ are presented in Table 17 and Table 18.

Table 17. Column Test Results Sandy Soil with no Sod

	Influent	Effluent	Removal
Total Nitrogen (mg/L as N)	1.2	1.4	-17%
Total Phosphorus (mg/L as P)	0.21	0.18	14%

Table 18. Column Test Results for Bold & Gold™ with no Sod

	Influent	Effluent	Removal
Total Nitrogen (mg/L as N)	1.7	1.7	0%
Total Phosphorus (mg/L as P)	0.21	0.085	60%

Total phosphorus removal was greater for Bold & Gold™ media. As expected with the short residence times, there was no removal of nitrogen during an event.

Effluent Comparisons

The water quality data of the effluent from the sandy soil were compared to the Bold & Gold™ effluent. The nutrient parameters of interest are the phosphorus and nitrogen species, since these are associated with the majority of impaired waters in Florida. In addition to nutrient concentrations, total suspended solids, turbidity, fecal coliform, E. coli, and alkalinity were also compared. An analysis of variance (ANOVA) was used to compare the averages of each parameter to determine if there is a significant difference between the concentrations in Type A-3 sandy soil and BAM Bold & Gold™

effluents at an 80% confidence level; see reference (28) for details. If the difference is found to be significant at a confidence level of 80%, then the maximum confidence level of significance is stated. Bar graphs for each medium show a comparison between the overall average of the parameter for both the sandy soil and the BAM Bold & Gold™.

Leaching of nutrients from the sod may occur. As a result, negative removal efficiencies occur when comparing the influent concentrations to the effluent ones. Sod contribution trend plots were constructed to determine if leaching is occurring and if it is diminishing with time. The plots were made using the total nitrogen and total phosphorus removal values of the media from the column tests, as well as the influent total nitrogen, effluent total nitrogen, and total phosphorus concentrations from the field tests; the nutrient removal values from the column tests were used to represent the removal values in the test bed. Equation (5) represents the nutrient mass balance of the bio-treatment system; it is assumed that all water that enters the system exits via the effluent, thus the mass balance was performed using concentrations. Based upon the mass balance, Equation (6) was developed and was used to calculate the nutrient loading leaching from the sod. It was assumed that leaching from the sod on both the sandy soil and Bold & Gold™ sides of the test bed was approximately equivalent since the same supplier of the sod is used, however it is recognized that less or more nutrients can be present in some of the sod.

(Influent Nutrients + Leached Sod Nutrients) - Media Nutrient Removal =Effluent Nutrients (5)

Leached Sod Nutrients = Effluent Nutrients + Media Nutrient Removal -Influent Nutrients (6)

Total Nitrogen

At a confidence level of 89%, there was a significant difference in the total nitrogen concentration of the effluents. The Bold & Gold™ had a 41% lower average effluent concentration of total nitrogen than sandy soil. The average effluent concentrations of total nitrogen were 3,521 and 2,066 μg/L as nitrogen for sandy soil and Bold & Gold™, respectively; the relative percent difference between the average total nitrogen effluent concentrations was 52%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 11. The average data are listed in Table 19.

Table 19. Average Total Nitrogen Effluent Data from Type A-3 and BAM

Average Effluent Total Nitrogen = 3.521 mg/L from Type A-3 Sandy Soil
Average Effluent Total Nitrogen = 2.065 mg/L from BAM Bold & Gold Media

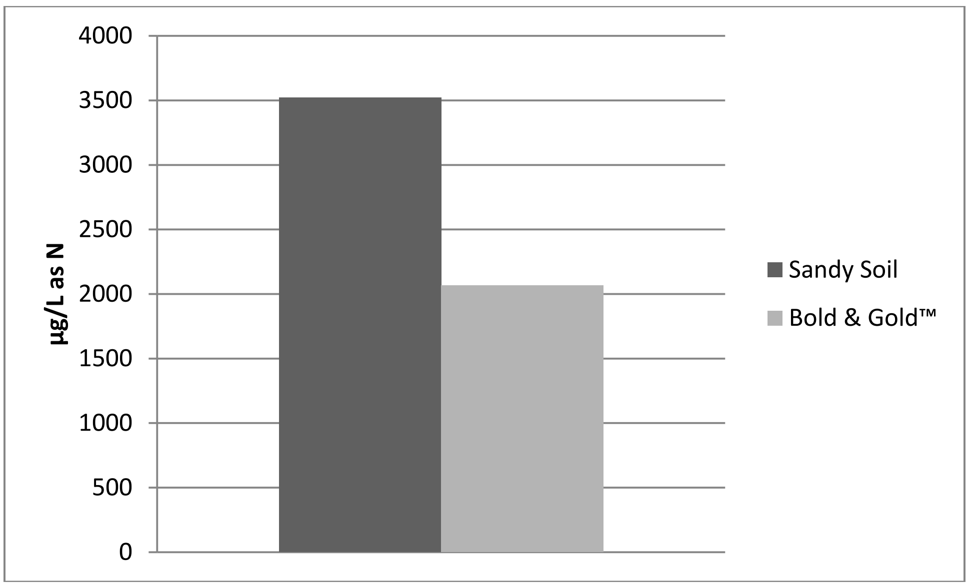

Figure 11. Average Total Nitrogen Effluent Concentrations

Total Nitrogen Leaching from Sod

Using the total nitrogen removal values for each medium from the column tests, and the influent and effluent total nitrogen concentrations from the field tests, the contribution of total nitrogen by the sod was approximated. The total nitrogen contributions by the sod with respect to time for the sandy soil and Bold & Gold™ systems are plotted respectively in Figure 11 and Figure 12. As shown in both Figures, the total nitrogen contribution by sod was decreasing with time and approaching zero, thus total nitrogen was being leached by the sod. Figure 11 was obtained using Equation (6) and shows that at the end of the trial period, there was a negative total nitrogen contribution by the sod in the sandy soil bio-treatment system. A result of negative total nitrogen contribution by the sod could be caused by one or a combination of the following explanations. The negative total nitrogen contribution by the sod could indicate that the total nitrogen removal value for sandy soil obtained in the column test is actually less than what occurs in the field scale tests. Another factor contributing to the negative total nitrogen contribution by the sod could be dilution of the simulated storm event water with preexisting moisture content in the media.

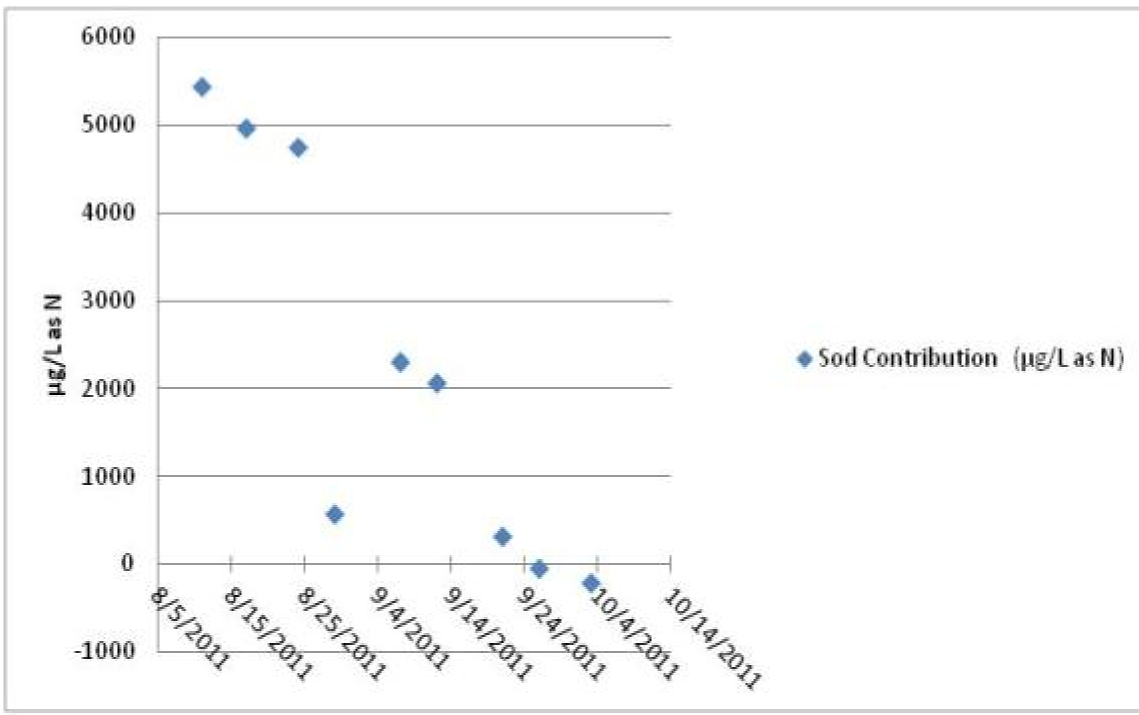

Figure 12. Leaching of Total Nitrogen from the Sod in the Sandy Soil System

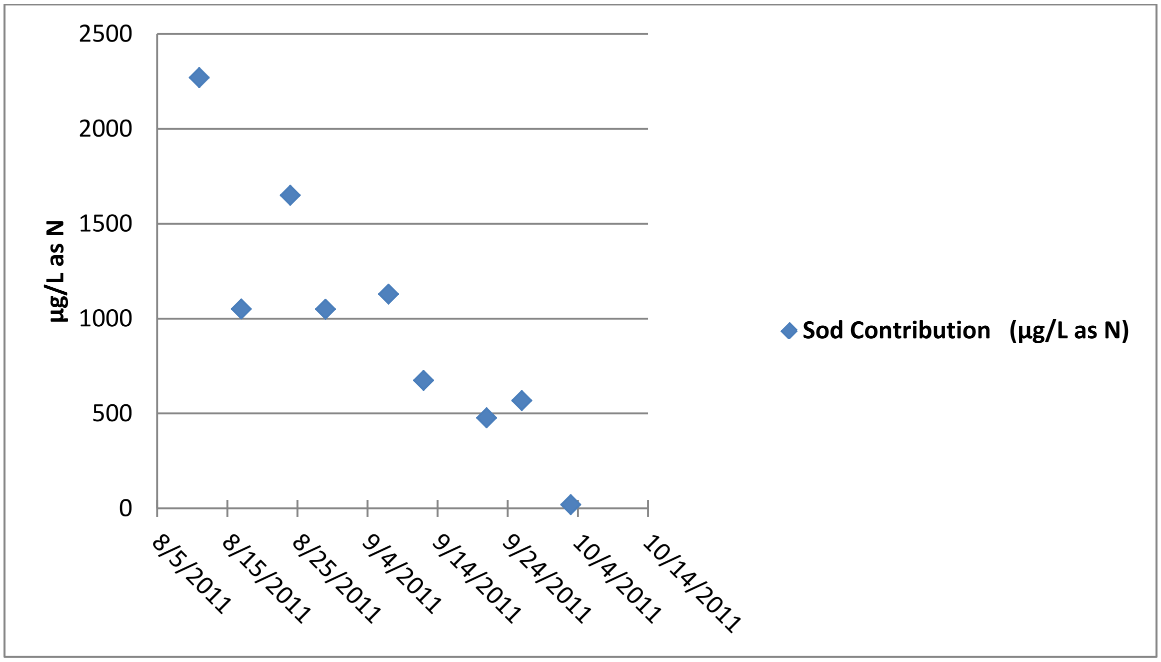

Figure 13. Leaching of Total Nitrogen from the Sod in the Bold & Gold™ System

Treatment processes that occur during the inter-storm periods, such as biological activity and vaporization, removed nutrients from the moisture stored in the media, thus lowering the concentration of nutrients in the moisture stored in the media to values below that in the highway runoff. However, the amount of water retained within media pore spaces is relatively small compared to the volume of water from the storm event, thus inter-storm treatment processes did not provide a significant contribution to pollutant removal in this swale configuration (20). To remove additional nutrients, a design configuration which stores a saturated amount of water within the media and is displaced is recommended. The curves for total nitrogen contribution by the sod have not reached a limiting or a consistent value by the conclusion of testing

Ammonia

At a confidence level of 80%, no significant difference in the ammonia concentration of the effluents was discovered. The Type A-3 sandy soil had a 15% lower average effluent concentration of ammonia than Bold & Gold™. The average effluent concentrations of ammonia are 107 and 125.6 µg/L as nitrogen for Type A-3 sandy soil and Bold & Gold™ respectively; the relative difference between the average ammonia effluent concentrations is 16%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 14.

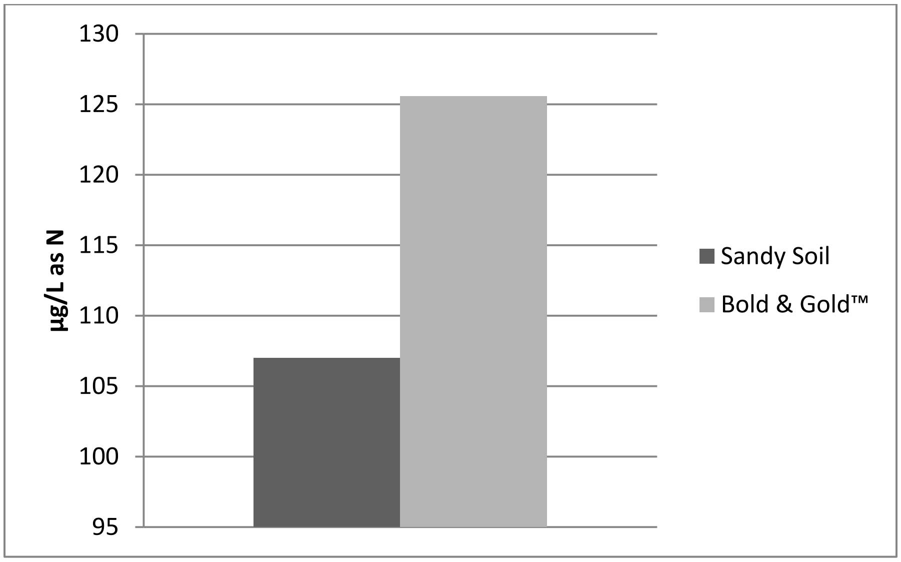

Figure 14. Average Ammonia Effluent Concentrations

Nitrate + Nitrite

At a confidence level of 92%, a significant difference exists in the nitrate + nitrite concentration of the effluents. The Bold & Gold™ effluent had a 49% lower average effluent concentration of nitrate + nitrite than sandy soil. Average effluent concentrations of nitrate + nitrite were 2629 and 1328 µg/L as nitrogen for Type A-3 sandy soil and Bold & Gold™, respectively. The relative difference between the average nitrate + nitrite effluent concentrations was 66%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 15.

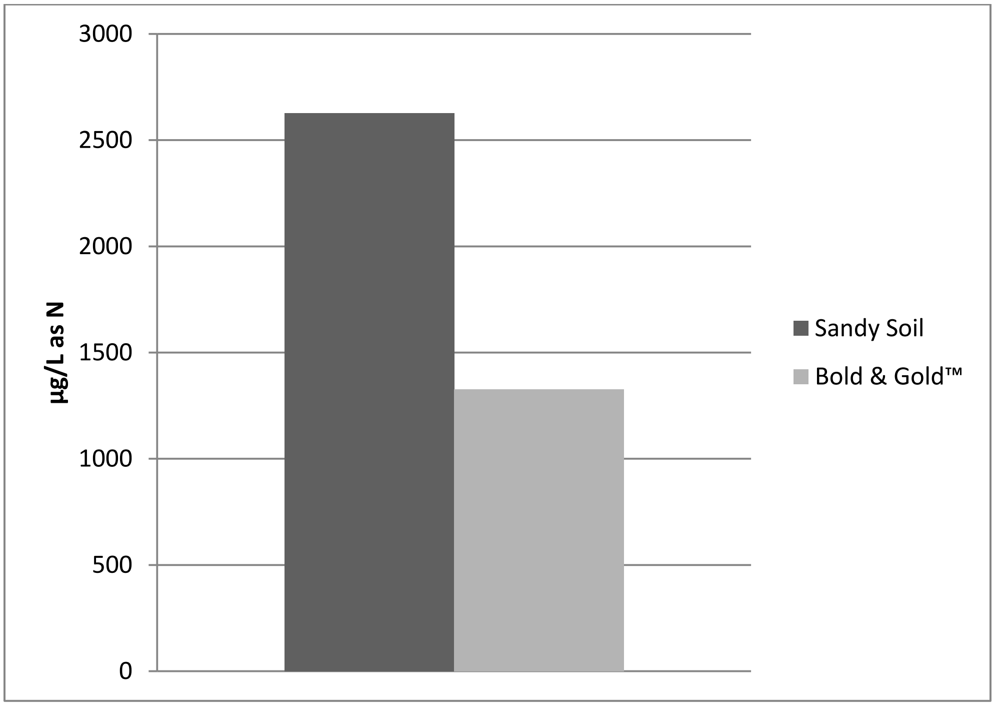

Figure 15. Average Nitrate + Nitrite Effluent Concentrations

Dissolved Organic Nitrogen

At a confidence level of 80%, there was no significant difference in the dissolved organic nitrogen concentration of the effluents. However, Bold & Gold™ had a 35% lower average effluent concentration of dissolved organic nitrogen than Type A-3 sandy soil. The average effluent concentrations of dissolved organic nitrogen were 613.4 and 397.4 µg/L as nitrogen for sandy soil and Bold & Gold™, respectively. The relative difference between the average dissolved organic nitrogen effluent concentrations was 43%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 16.

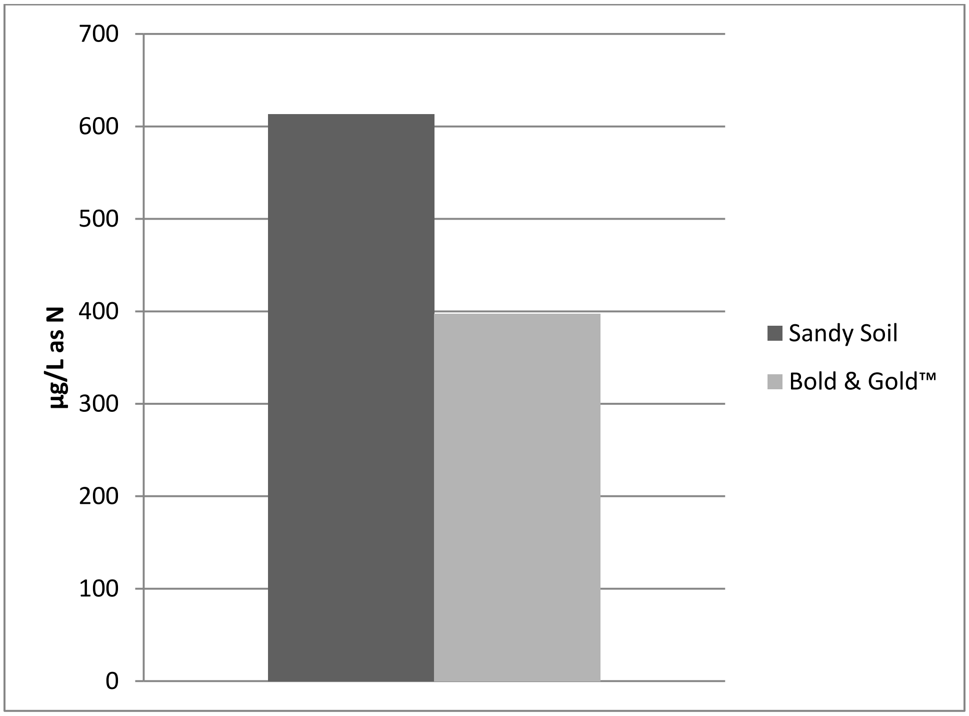

Figure 16. Average Dissolved Organic Nitrogen Effluent Concentrations

Particulate Nitrogen

At a confidence level of 85%, a significant difference exists in the particulate nitrogen concentration of the effluents. Also, the Type A-3 sandy soil had a 42% lower average effluent concentration of particulate nitrogen than Bold & Gold™. This is a case where the smaller diameter grain size of the sandy soil filters the particulate nitrogen while the large grain size of the Bold & Gold™ did not. Average effluent concentrations of particulate nitrogen were 141.6 and 245.1 µg/L as nitrogen for Type A-3 sandy soil and Bold & Gold™, respectively. The relative difference between the average particulate nitrogen effluent concentrations was 54%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 17.

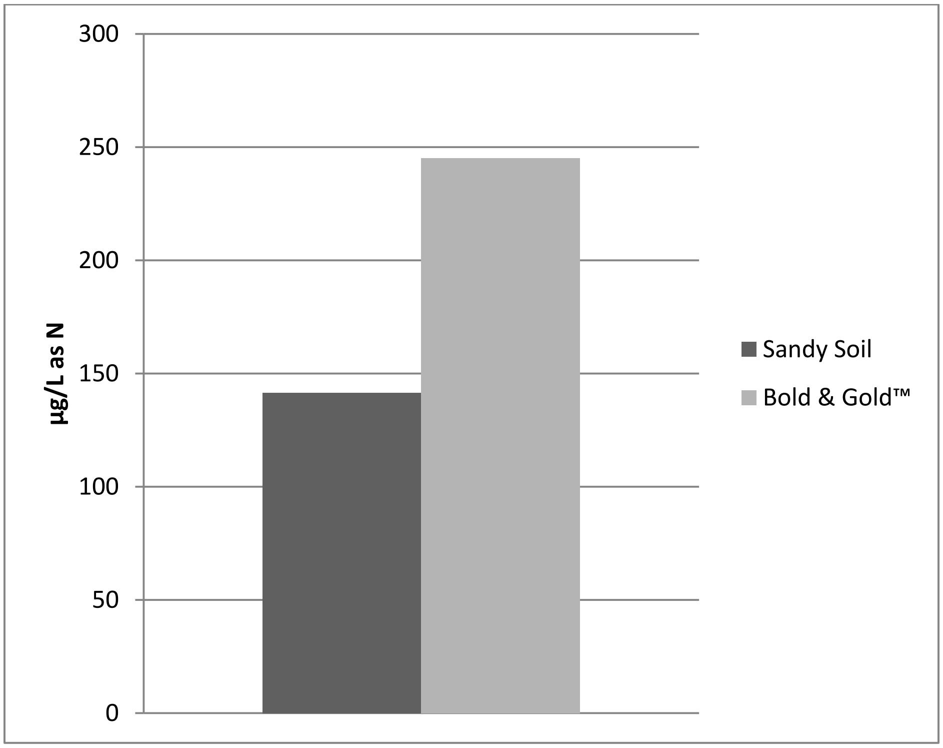

Figure 17. Average Particulate Nitrogen Effluent Concentrations

Total Phosphorus

At a confidence level of near 100%, there is a significant difference in the total phosphorus concentration of the effluents. The Bold & Gold™ had a 78% lower average effluent concentration of total phosphorus than Type A-3 sandy soil. Average effluent concentrations of total phosphorus were 302.6 and 66.22 µg/L as phosphorus for Type A-3 sandy soil and Bold & Gold™, respectively. The relative difference between the average total phosphorus effluent concentrations was 128%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 18. A similar mix of BAM Bold & Gold™ media was also effective in the removal of Phosphorus (11) in stormwater.

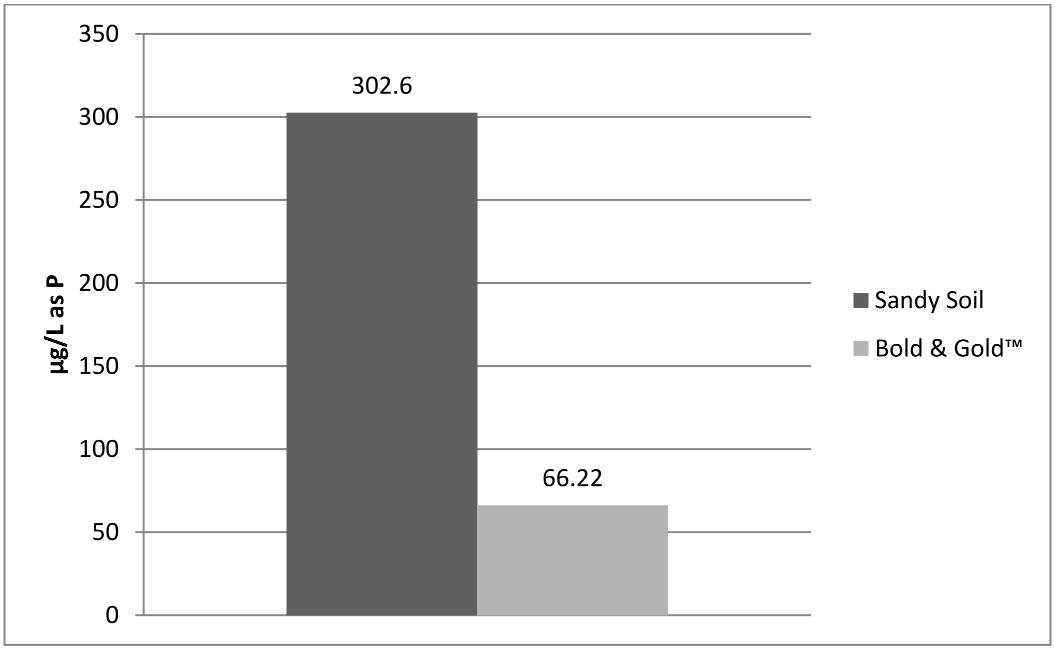

Figure 18. Average Total Phosphorus Effluent Concentrations

Total Phosphorus Leaching from Sod

Using the total phosphorus removal value of the Bold & Gold™ from the column test, and the influent and effluent total phosphorus concentrations from the Bold & Gold™ field tests, the contribution of total phosphorus by the sod was approximated. The data of Table 20 show the total phosphorus contributions by the sod using the Bold & Gold™ system for each trial. The total phosphorus contributions by the sod with respect to time for the Bold & Gold™ system are plotted in Figure 19. As shown in Figure 19, the total phosphorus contribution by sod was decreasing with time, thus total phosphorus was being leached by the sod but decreasing with time.

Table 20. Leaching of Total Phosphorus by Sod in the Bold & Gold™ System

Total Phosphorus removal based on column test (μg/L as P): 125

Date	Influent (μg/L as P)	Effluent (μg/L as P)	Sod Contribution (μg/L as P)
8/11/2011	159	87	53
8/17/2011	192	73	6
8/24/2011	165	92	52
8/29/2011	184	42	-17
9/7/2011	199	54	-20
9/12/2011	206	71	-10
9/21/2011	197	59	-13
9/26/2011	197	53	-19
10/3/2011	204	65	-14

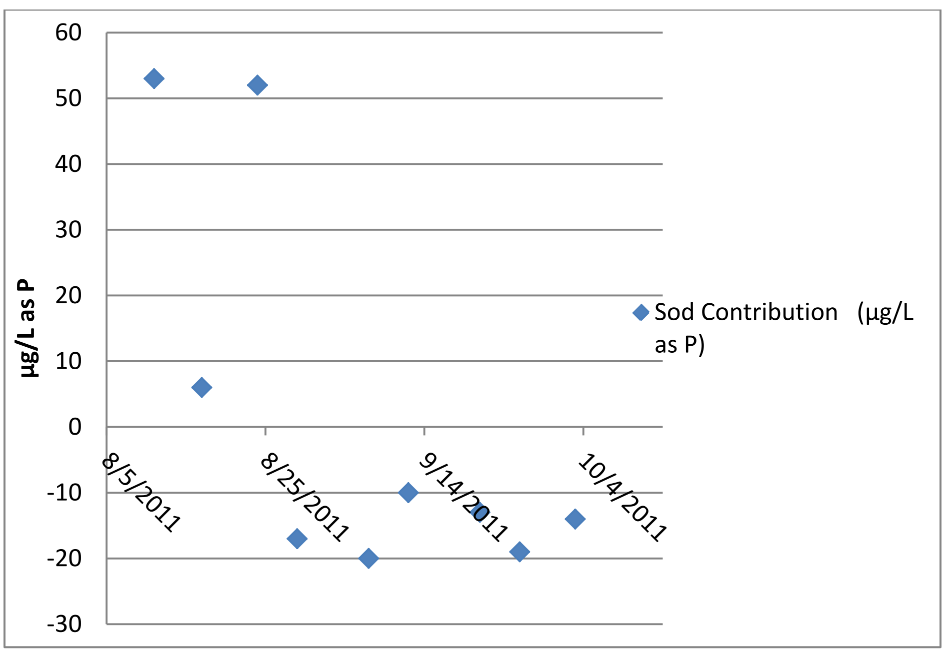

Figure 19. Leaching of Total Phosphorus from the Sod in the Bold & Gold™ System

The data points of Figure 19 were calculated using Equation (6) and show that there are negative total phosphorus contributions by the sod for the last six trials in the Bold & Gold™ bio-treatment system. The Calculations of negative total phosphorus contribution by the sod could be caused by one or a combination of the following explanations:

- dilution of the runoff water with pre-existing moisture contained in the media. Treatment processes that occur during the inter-storm periods, such as biological activity, remove nutrients from the moisture stored in the media thus, lowering the concentration of nutrients in the moisture stored in the media to values below that in the highway runoff. However, the amount of water retained within media pore spaces is relatively small compared to the volume of water from the runoff storm event, therefore inter-storm treatment processes do not provide a significant contribution to pollutant removal (20).

- The total phosphorus removal value obtained in the column test is actually less than what occurs in the field.

Figure 19 also shows that the negative total phosphorus contribution by the sod in the Bold & Gold™ system was relatively consistent indicated that the sod was no longer significantly leaching total phosphorus. By using the percent removals of total phosphorus for these dates, the actual in situ total phosphorus removal efficiency for the Bold & Gold™ bio-treatment system was calculated as 71%, as shown in Table 21.

Table 21. Total Phosphorus Removal Efficiencies of Bold & Gold™ after Leaching

Date	Influent (μg/L as P)	Effluent (μg/L as P)	Removal Efficiency
8/29/2011	184	42	77%
9/7/2011	199	54	73%
9/12/2011	206	71	66%
9/21/2011	197	59	70%
9/26/2011	197	53	73%
10/3/2011	204	65	68%
Average	-	-	71%

Soluble Reactive Phosphorus

It is worth repeating that soluble reactive phosphorus represents phosphorus that is readily available to plants and algae, and is composed of dissolved inorganic and dissolved organic phosphorus species (62). At a confidence level of near 100%, there was a significant difference in the soluble reactive phosphorus concentration of the effluents. The Bold & Gold™ had a 96% lower average effluent concentration of soluble reactive phosphorus than the effluent from the Type A-3 sandy soil. The average effluent concentrations of soluble reactive phosphorus were 180 and 7.655 µg/L as phosphorus from the Type A-3 sandy soil and Bold & Gold™, respectively. The relative difference between the average soluble reactive phosphorus effluent concentrations was 184%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 20.

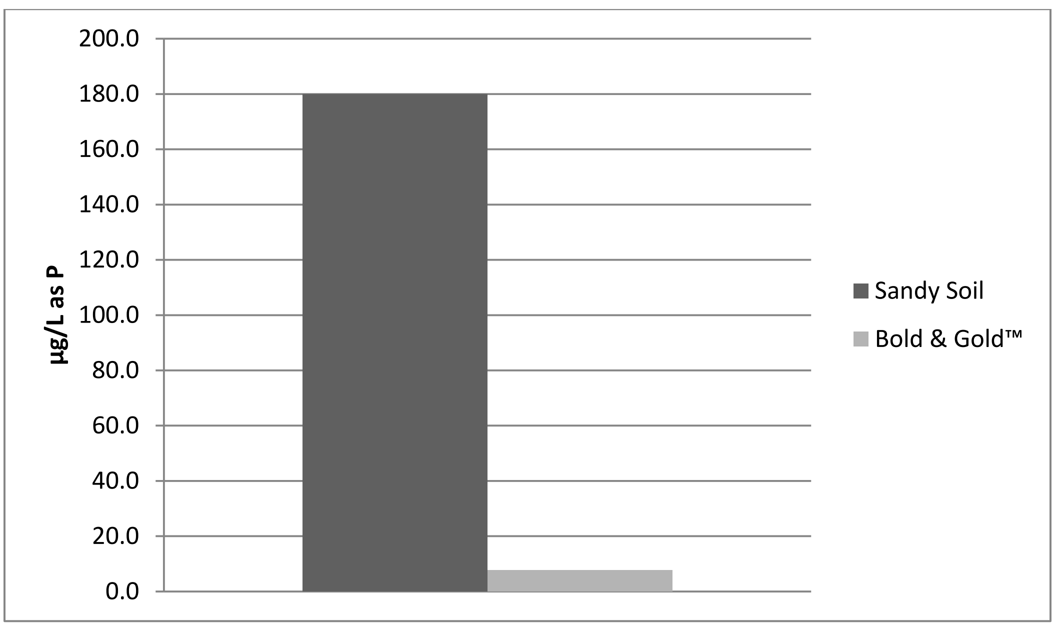

Figure 20. Average Soluble Reactive Phosphorus Effluent Concentrations

Total Suspended Solids

Total suspended solids (TSS) are particles in water that are removed by a 2.0 µm filter (63). At a confidence level of 99.85%, there was a significant difference in the total suspended solids concentration of the effluents. The Bold & Gold™ effluent had a 73% lower average concentration of total suspended solids than the sandy soil. Particulate nitrogen is a part of suspended solids but there are other constituents that make up the solids and thus the removal of solids is expected to be different that the removal of particulate nitrogen. The average effluent concentrations of total suspended solids were 9.433 and 2.5 mg/L for sandy soil and Bold & Gold™, respectively; the relative difference between the average total suspended solids effluent concentrations is 116%. A bar graph showing a comparison of the average effluent concentrations is shown in Figure 21.

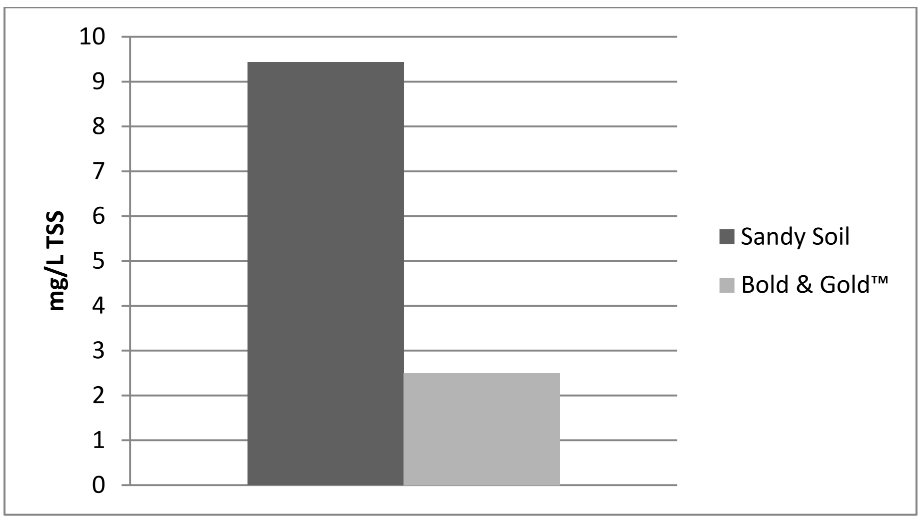

Figure 21. Average Total Suspended Solids Effluent Concentrations

Turbidity

Turbidity is a measurement of the light-transmitting properties, or clarity, of water. Turbidity is caused by suspended particles and is measured in nephelometric turbidity units (NTU) (64). At a confidence level near 100%, there was a significant difference in the turbidity of the effluents. The Bold & Gold™ had a 92% lower average effluent turbidity than sandy soil. The average effluent turbidities were 62.53 and 5.192 NTU for sandy soil and Bold & Gold™, respectively; the relative difference between the average effluent turbidities was 169%.

Fecal Coliforms

Fecal coliform are a group of bacteria whose presence in water is indicative of mammalian fecal contamination (65). At a confidence level of 80%, there was no significant difference in the fecal coliform concentration of the effluents. The sandy soil has a 16% lower average effluent concentration of fecal coliform than Bold & Gold™. The average effluent concentrations of fecal coliform were 1165 and 1385 cfu/100 mL for sandy soil and Bold & Gold™, respectively.

E. Coli

E. coli is a type of fecal coliform and its presence in water is indicative of mammalian fecal contamination (65). At a confidence level of 80%, there was no significant difference in the E. coli concentration of the effluents. The sandy soil had a 49% lower average effluent concentration of E. coli than Bold & Gold™. The average effluent concentrations of E. coli are 6.175 and 12.06 cfu/100 mL for sandy soil and Bold & Gold™, respectively.

Alkalinity

Alkalinity is a measure of a water's capacity to neutralize acids; the greater the alkalinity, the greater the buffer capacity of the water. At a confidence level of 98.94%, there was a significant difference in the alkalinity concentration of the effluents. The average effluent alkalinity of the Bold & Gold™ is 26% greater than the sandy soil. The average effluent alkalinities were 144.3 and 182.4 mg/L as calcium carbonate for sandy soil and Bold & Gold™, respectively.

pH

An important characteristic which affects adsorption chemistry is pH. There was no significant difference in the pH in the effluent from the Type A-3 sandy soil and the

Bold & Gold™. Table 22 shows the mean, median, and standard deviation values for the pH of the effluent from the Type A-3 sandy soil and Bold & Gold™ media, as well as the influent.

Table 22. Effluent pH Statistics

	Sandy Soil	Bold & Gold™	Influent
Mean	6.89	6.92	7.74
Median	6.92	6.83	7.77
Standard Deviation	0.218	0.253	0.181

CHAPTER 4 STORMWATER HARVESTING AND ASSESSMENT FOR REDUCTION OF POLLUTION (SHARP)

4.1 INTRODUCTION

A limiting consideration for harvesting from wet detention ponds is the possible effect the withdrawal will have on the water table adjacent to the pond during withdrawal of water and the drying up of the pond. Thus, a safe yield is defined as that rate of water withdrawal for harvesting that is within pond supply and acceptable water table decreases. Furthermore, natural terrains, such as flat topography and a high water table, significantly affect the performance of stormwater ponds. These terrains pose difficulty to stormwater quality treatment and flood control, as is evident in Central Florida (86 and 87). The problem is a result of the difficulty in separating the stormwater from groundwater; as the groundwater could either enter or leave the pond. In addition, too much groundwater input would result in shorter flow paths, lower residence times, and possibly the need for higher treatment volumes. Limitation to expansion of the stormwater pond, the failure to achieve targeted detention times, the need to mitigate the negative environmental impacts, and the desire to reduce the amount of water discharged demands an alternative approach for more effective stormwater ponds. This would require a model that can predict the interaction among groundwater, pond water, rainfall, and runoff.

4.2 STATEMENT OF PURPOSE

The purpose is to present a model that is useful for predicting pond stage, as well as the effects on the groundwater table elevations. The model must incorporate the interaction of runoff and pond water, pond water and groundwater, and rainfall and groundwater. The model details are found in the dissertation of Ikiensinma Gogo-Abite (88). The model has been applied with success to three distinctly different groundwater conditions, namely one where the groundwater exchange with the pond is very slow (possibly silty soils), one where the groundwater input rate is slow (sand but low head differential), and another where the exchange is rapid (limestone aquifer). The information in this chapter focuses on the provision of a forecasting tool to estimate impervious runoff volume, pond storage volume, and the volume of harvested as required to control pond discharge. To predict the volume of water available for harvesting and the subsequent discharge volume, the model was developed to simulate the runoff volume, harvesting rate, and storage volume based on the hydrologic cycle of the watershed and the groundwater geology. The model was based on the determination of the watershed hydrologic cycle components such as rainfall, runoff condition, evapotranspiration, infiltration, groundwater flow, pond size, and discharge device. The model is called SHARP, for Stormwater Harvesting and Assessment for Reduction of Pollution. The SHARP model is capable of 1) assessing harvest safe-yield and flow from any pond in any geologic formation and 2) predicting effects on surrounding groundwater with harvesting from the pond. The model also predicts the percentage of runoff into a harvesting pond that was not discharged. It was applied to three different ponds in Florida; one with negligible groundwater input (Econ pond near Orlando), the other with significant input (I-75 at exit 7 near Miramar), and the third with moderate groundwater input (Briarwood Lakes in Sarasota).

The model used proven theories concerning the hydrologic and hydraulic processes of stormwater in a watershed, both in surface and subsurface phases. The SHARP model was designed to accept watershed data generally available in most watershed management and local authorities. The model was structured to reduce the number of calibrated parameters by the use of readily available measurable physical parameters. The development of the SHARP model was governed by mathematical deterministic relationships as conceptual components and, when appropriate, empirical data available in literature.

4.3 DEVELOPMENT OF THE SHARP MODEL

The water dynamics in a catchment at the surface-subsurface interface and pond water-groundwater interface are critical in modeling their interaction. Determination of the saturated contributing surfaces and their evolution in time and space, and the relative contributions of the surface and subsurface to groundwater flow, and the input or withdrawal from a surface pond are important issues in stormwater harvesting. Richard's equation is frequently used to describe the water dynamics in the three physical domains of the land surface, vadose zone, and saturated zone with domain-dependent parameters. The contributing effects of these to the free-surface water (pond), which flow is dominated by the harvesting and discharge characteristics, were adopted to develop the model components. Richard's equation for vertical flow is expressed as a combination of Darcy's law and the principle of conservation of mass. Richard's equation was solved in lumped form for the different model components. The model components are developed to describe the hydrologic processes inherent in the movement of water on the surface and in the subsurface. The basic governing processes for the surface and subsurface movement are expressed in the combination of continuity and water budget equations for the pond storage (S_P), soil moisture storage (S_M), and groundwater recharge (S_{GW}).The hydrologic process involves interrelated sub-components of physical processes such as rainfall, irrigation, infiltration, surface runoff, subsurface water redistribution, and groundwater flow. Basically, the change in storage within the hydrologic components for surface, soil moisture, and saturated groundwater flows were expressed in volume units by Equations (7) through (9).

$$\Delta S_P = R + RO - H_{AR} - E - D \pm Q_{GW} \tag{7}$$

$$\Delta S_M = R + I_{IRR} - RO - AET - DP \tag{8}$$

$$\Delta S_{GW} = DP - Q_{GW} \tag{9}$$

Where: ΔS_P = change in surface storage; ΔS_M = change in soil moisture; ΔS_{GW} = change in groundwater storage; Q_{GW} = groundwater seepage; *AET* = actual evapotranspiration; H_{AR}= harvesting volume; I_{IRR} = irrigation volume; R = rainfall on pond; RO= runoff to pond; E = free surface water evaporation; D = pond discharge; DP = deep percolation. Generally, the SHARP model loops the hydrologic processes of a detention pond to the adjacent land surface and subsurface dependent of the climatic conditions in the watershed. Therefore, these three components constitute the core of the model, and mathematical expressions are developed for every sub-component. The sub-component equations are solved over a preselected time increment Δt .

The weather is what drives the entire system of hydrology, sedimentation, and harvested water in the model. The physical processes involved are rainfall or irrigation, meteorological data, solar radiation, and wind speed. Data for these sub-components were obtained from weather service agencies, city authorities, or by measuring instrumentation at the specific location. The principal sources for these data are the U.S. Geological Survey (USGS), National Weather Service (NWS), local authorities, and in certain conditions from instrumentation at the local sites. For missing or non-available data, formulas for estimation are available. The integrity of the model output are no better than the weather data upon which they are based. It is imperative that these data be checked for integrity and quality before being used in the model. There are other factors used to determine evaporation of free-water surfaces and evapotranspiration from the land surface and crops. Some of these data are measured directly at weather stations, while others are derived directly or related empirically from measured data. These data include solar radiation, air temperature, relative humidity, wind speed.

The generation of surface runoff is determined by the rainfall, surface cover, surface slope, soil type, and the soil-water content of the top soil surface. The estimation of surface runoff was calculated using water budget equations. Using water budget models, permeable and impermeable surface runoffs were computed by Equations (10) and (11), respectively.

$$RO = R + I_{IRR} - E - F \tag{10}$$

$$RO = R - I_a \tag{11}$$

where F = infiltration, and the initial abstraction (I_a) was assumed for most locations but can be calculated from local runoff data.

Infiltration is estimated based on the approximate method by the Green and Ampt model (1911), in which the computation for cumulative infiltration (F) was demonstrated by Equation (12).

$$F = \begin{cases} R & \text{for } i \le K_s \\ \dfrac{\psi \cdot M}{(f/K_s)-1} & \text{for } i > K_s \end{cases} \tag{1}$$

Where: f = infiltration rate; K_s = the hydraulic conductivity of the porous media; ψ is the effective suction at the wetting front; and M = difference between initial and final volumetric soil moisture content. Table 23 presents the conditions for infiltration and surface runoff after precipitation.

Table 23. Runoff and Infiltration Responses to Precipitation

Conditions	Runoff Potentials	Descriptions
$i < k_s$	$RO = 0$ and $\theta_s < 1$	*Rainfall infiltrates the soil; no runoff*
$k_s < i < f_p$	$RO = 0$ and $\theta_s \Rightarrow 1$	*Rainfall infiltrates the soil and the soil moisture increases to near surface saturation but no runoff*
$k_s < f_p \le i$	$RO = R - E - F$ and $S_e = 1$	*Infiltration rate attains full capacity and starts decreasing, the near surface soil is becomes saturated and then generates runoff*

where f_p = infiltration rate at ponding and S_e = effective saturation.

Evapotranspiration involves the calculation of potential evapotranspiration, *PET* from a reference surface, which is a function of the climatic parameters, and is expressed in Equation (13) for a hourly time step.

$$PET = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{37}{T_{hr} + 273} u_2 \left[e^o(T_{hr}) - e_a\right]}{\Delta + \gamma(1 + 0.34u_2)} \tag{13}$$

A crop evapotranspiration, ET_c, is then calculated under standard conditions, that is assuming disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Equation (14) demonstrated an expression for the adjustment of the potential evapotranspiration by combination of basal crop coefficient (k_{cb}) and evaporation coefficient (k_e) expressed in Equation (15).

$$ET_c = k_c \times PET \tag{14}$$

$$k_c = k_{cb} + k_e \tag{15}$$

The actual evapotranspiration (*AET*) is adjusted for nonstandard condition by a soil-water stress coefficient (k_s) for all kinds of stresses and environmental constraints. Evapotranspiration estimates were based on the FAO Penman-Montieth method and expressed in Equation (16).

$$AET = \left(k_{cb}k_s + k_e\right) \times PET \tag{16}$$

where PET = reference evapotranspiration (mm day^{-1}); R_n = net radiation (MJ m^{-2} hr^{-1}); G = soil heat flux density (MJ m^{-2} hr^{-1}); T_{hr} = hourly mean daily temperature at 2 m height (°C); u_2 = wind speed at 2 m height (m s^{-1}); e_s = saturation vapor pressure (kPa); e_a = actual vapor pressure (kPa); Δ = slope vapor pressure curve (kPa °C^{-1}); γ = psychrometric constant (kPa °C^{-1}); and ET_c = crop evapotranspiration (mm day^{-1}).

Penman approached the estimation of evaporation from a free-water surface by a combination of the energy-budget and mass-balance methods expressed in Equation (17).

$$E = \frac{\Delta R_n + \gamma(6.43)(1 + 0.536u_2)(e_s - e_a)}{\lambda(\Delta + \gamma)} \tag{17}$$

Soil-water above the field capacity in the root zone is lost by evapotranspiration and drainage to groundwater as deep percolation, and is governed by the soil characteristics. Flow is assumed as one-dimensional, so lateral flow in the vadose zone is ignored. An estimate for deep percolation is based on both steady and unsteady state flow processes in the soil during and after precipitation, respectively. The steady-state flow is expressed in Equation (18)

$$DP_{SS} = f \cdot t_d \tag{18}$$

where t_d = duration of the precipitation. Deep percolation from on steady-state flow is gravity driven and is calculated when the soil moisture content is equal or greater than the moisture content at field capacity of the root zone or unsaturated layer. The unsteady-state flow in the unsaturated zone is the Darcian velocity (flux rate) based on the rectangular soil-moisture redistribution profile, with the assumption that the initial soil-water content corresponds to the residual soil-water content (θ_r), or effective antecedent saturation (S_{ei}), and is expressed in Equation (19).

$$q = \frac{K_s}{\left(S_{ei}\right)^{-n} + \frac{nK_s t}{F}} \tag{19}$$

where q = flux rate; S_{ei} = initial soil saturation; and n = exponent related to the pore-size distribution index λ = (3 + 2/λ), for different soil characteristics. Deep percolation is computed as the combination of both steady-state and unsteady-state flow processes expressed in Equation (20) for the pervious area only.

$$DP = DP_{SS} + q \tag{20}$$

Soil moisture in the unsaturated zone is influenced by moisture losses from actual evapotranspiration within the root zone and deep percolation. The soil moisture content is estimated based on the mass balance of flow in the unsaturated zone for each layer of soil as expressed above by Equation (21).

$$\theta_i = \frac{S_{M,i-1} + R + I_{IRR} - RO - AET - DP}{T} \tag{21}$$

where T = unsaturated soil layer thickness. The estimated soil moisture content is substituted into Equations (22) and (23) for the corresponding negative pressure head, $h(\theta)$ and unsaturated hydraulic conductivity, $K(\theta)$.

$$h(\theta_i) = \frac{h_{cb}}{\left(\frac{\theta_i - \theta_r}{\theta_s - \theta_r}\right)^{1/\lambda}} \tag{22}$$

$$K(\theta_i) = K_s \left(\frac{\theta_i - \theta_r}{\theta_s - \theta_r} \right)^n \tag{23}$$

Where: h_{cb} = bubbling pressure head; θ_i = soil moisture content; θ_r = residual soil moisture content; and θ_s = saturated soil moisture content. The estimated hydraulic conductivity is a function of soil moisture and is used to compute the groundwater recharge based on the deep percolation formulation.

Recharge to the groundwater storage is by redistribution from deep percolation and seepage from adjacent water bodies. The flow of groundwater is influenced by the water gradient, which results in seepage losses. A water budget based on the inflow and outflow for groundwater storage is expressed Equation (24). The Groundwater seepage equation is based on Darcy's law for porous media flows and it is a function of the water gradient and soil characteristics. In this model, seepage is related to bank flow condition resulting in the rise and fall of stream stages. The rise and fall of the pond stage over time describes the flow to and return from the pond based on the relative water level difference between the groundwater and pond water, and reservoir storage. The flow Q to the pond at a distance x:

$$q_x = \frac{2HkD}{\sqrt{\pi}} \cdot \left(\frac{e^{\frac{x^2}{4\alpha t}}}{\sqrt{4\alpha t}} \right) \tag{24}$$

The flow q_o out of the banks at x = 0 at any time t per foot of bank length,

$$q_{x=o} = \frac{HkD}{\sqrt{\pi \alpha t}} \tag{25}$$

Equation (25) is expressed in volumetric flow units (L^3/T) per length of the reservoir bank. This is converted to volume expressed in length (L) unit to be consistent with other units of rainfall, irrigation, and runoff volumes by the multiplication of the perimeter (P_P) of the pond water surface level per the surface area (P_A), as expressed in Equation (26).

$$Q_{x=0} = q_{x=0}\left(\frac{P_P}{P_A}\right) \tag{26}$$

4.4 MODEL OPERATION

The SHARP model, driven by precipitation, simulates the flow interactions of land surface and subsurface vadose zones, and the free-water surface and saturated zones. The model can be applied to watersheds with a variety of soil characteristics, different soil cover and turf grasses, surface slopes, variable rainfall and irrigation rates, fluctuations in groundwater table levels, and water gradient. The relevance of the model is limited by the size of the watershed, as it is developed for pond catchment in a watershed. The model is a periodic loop of sequential computational processes of all the components in the hydrologic cycle. Preceding the loop are input parameters, boundary, and initialization conditions followed by the model interactions to produce simulated monthly or yearly hydrologic values and graphic outputs.

The SHARP model was developed on Microsoft Window-Excel interface to facilitate data entry, parameterization, characterization, and generation of numerical and graphical outputs. The model is composed of five modules, namely: ET, POND, INFIL, SEEP, and LAND. The ET module simulates the reference and crop evapotranspiration process by energy balance and turf grass needs. Inputs to the module are rainfall and meteorological parameters and it outputs the evaporation and evapotranspiration for use in the POND and INFIL modules, respectively. The ET module model the irrigation needs of the turf grasses, and schedule the irrigation quantity and timing from the available soil-moisture content and evapotranspiration.

INFIL module simulates the processes of infiltration, surface runoff, and soil water storage. Inputs to this module are rainfall, evapotranspiration, and soil characteristics, topography, and vegetation from the LAND module. Outputs from INFIL are used in SEEP and POND modules. POND module simulates the pond storage using outputs from ET, INFIL, and SEEP modules, and rainfall data. The SEEP module simulates the process of water movement in the soil subsurface by water redistribution, deep percolation, and seepage. The LAND module is the input unit that allows the user to specify watershed parameters, land uses and management, soil properties, and seasonal variations on weather data. Figure 22 demonstrates the general structure and operation of the SHARP model.

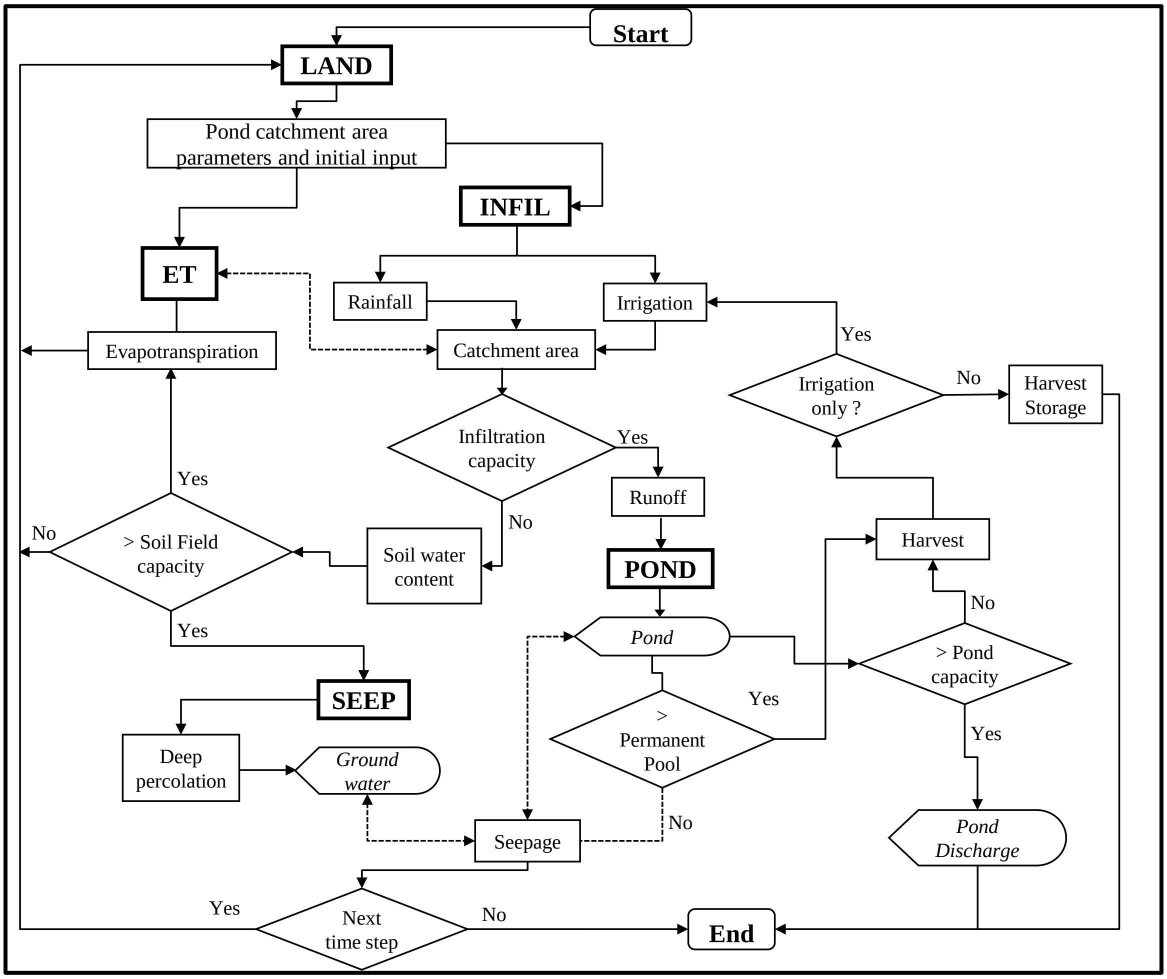

Figure 22. SHARP Model Flow Chart

Input and Output

The SHARP model is a continuous simulation model designed to perform simulation in response to the periodic needs for stormwater management. Outputs from the model consist of plots of rainfall and irrigation characterization, pond storage volume, harvesting storage volume, pond discharge volume, soil water volume, and groundwater volume. The SHARP model basic data inputs are used to develop periodic water storage in the pond, vadose (unsaturated) zone, and saturated zone to predict pond water harvesting volume availability and needs, total discharge volume, and percentage of surface runoff discharged. The movement of water in the watershed is synthesized from the model and input automatically within the model for specified time interval. The watershed characteristics and initial soil properties are used to set the initial boundary conditions of the model.

Model Parameters

The SHARP model requires the input of specific watershed parameters that provide the mechanism to adjust the simulation for the given catchment area topographic, hydrologic, soil, and landscape and management conditions. SHARP is designed to be used in a wide range of pond catchment areas, which must be evaluated for every model application. Some of these parameters could be evaluated from known watershed characteristics, while others that could not be precisely determined would be evaluated through calibration with existing data or laboratory analyses. These are categorized as system, meteorological, and control parameters.

System parameters are mainly composed of the watershed location, hydrology, land use, pond geometry and characteristics, topography, and soil type. The watershed or catchment location description provides the basis for the simulation. The location inputs are geographic data such as the longitude, latitude, and elevation, which helps in the identification of the watershed location and pond catchment area. This allows for the definition of appropriate boundary conditions for accurate simulation of water movement in the system. In addition, topographic description of the study area is relevant for selecting the hydrologic soil group that helps in identifying the soil types and defines the land use, percent imperviousness, urbanization level, slope, and vegetative cover and type.

Meteorological parameter categories are essentially measured data such as rainfall volumes, temperature and wind speed, among others. When they are not available, they are estimated from relevant formulations available in literatures. These parameters are sourced from the National Weather Service (NWS) or local agencies. Finally, the control parameters are basically system management controls to regulate the irrigation process of frequency, volume, and type; turfgrass water needs; required harvest volume; and pond storage capacity. Other regulations may have to be incorporated into the model simulation.

The following parameters are defined by calibration, experimentation, or literature: hydraulic conductivity, porosity and void ratio, initial water content, residual water content, saturation water content, and the initial depth of groundwater table. Constants and exponential parameters are used to aid calculation of other model parameters through the simulation process. Data for the pond's sediment, permanent pool, harvesting volume, and overflow volumes are management decisions provided and adapted to simulate the pond storage over time

SHARP Model Calibration and Verification at I-75 and Exit 7 in Miramar, FL.

The model is applied to a high percolating limestone geological area. Simulation for SHARP model calibration and validation was performed on pond water level for year 2009 and 2008, respectively. The pond is located at the North West corner of the Miramar Parkway and Interstate 75 Expressway (25.98° N, 80.36° W and 7 feet elevation) in the City of Miramar, Broward County, Florida. The catchment area is an industrial and commercial zone of approximately 80 hectare (197 acre), and has a directly connected impervious area (DCIA) of 38 hectare (94 acre), as well as an irrigable area of 25.5 hectare (63 acre). The stormwater pond surface area is 16 hectare (40 acre),is at an elevation of 2.12 m (7.0 feet), and has an average pond bottom elevation at -2.12 m (-7.0 feet). The general soil profile is a top layer of silty sand with rock fragments, to sand from the ground surface to 1.2 m (4 feet) depth, and limestone below the top layer.

In this study, the rainfall and meteorological data for year 2008 and 2009 were obtained for the weather station at North Perry Airport (KHWO), Hollywood, Florida, (26.00° N, 80.24° W) having a 2.44 m (8 feet) surveyed elevation, which is about 11.23 km (7 miles) east of the experimental site in Miramar. The weather station records rainfall, temperature, relative humidity, wind speed and direction, atmospheric pressure, and sky cover for radiation analysis; the historical data were obtained from the Weather

Underground website (wunderground.com 2010). In addition, the South Florida Water Management District provided radar rainfall data at the location for the simulated period. Data from this site were used as inputs in both ET and INFIL modules of the SHARP model. The City of Miramar provided the pond water level elevations for the simulation year 2009 with start and end elevations of 0.82 m and 0.88 m (2.70 and 2.89 feet), respectively, at 10 minute intervals. The simulation period was from January 1, 2009, at 00:00 hours, to December 31, 2009, at 23:59 hours. Table 24 presents the model initial inputs and boundary parameters for the pilot study.

Table 24. Model Input Parameters and Boundary Conditions

Soil Hydraulic Properties			
Description	**Units**	**First Layer**	**Second Layer**
Soil type		Loamy Sand	Limestone
Initial water content prior, θ_i	cm/cm (in/in)	0.100	0.100
Residual saturation, θ_r	cm/cm (in/in)	0.030	0.020
Water content at saturation, θ_s	cm/cm (in/in)	0.300	0.200
Moisture content at field capacity, θ_{FC}	cm/cm (in/in)	0.170	0.180
Pore size distribution index, λ		0.553	0.165
Bubbling pressure, h_{cb}	cm (in)	14.20 (5.59)	1.00 (2.54)
Saturated hydraulic conductivity, k_s	cm/hr. (in/hr.)	6.11 (2.41)	12.70 (5.0)
Layer Depth, d	cm (in)	124 (48)	425 (168)

At this pond site, the harvest volume is set at 113.6 m^3 per day (30,000 gallons per day) for six days of the week in the year, except in the winter months (December through March) when only half of this volume is harvested. No harvesting was done when the catchment area receives rainfall above 12.7 mm (0.5 in.). The pond surface discharge mechanism was a pump set at a rate of 37,854 m^3 per day (10 million gallons per day) at a discharge elevation of 0.97 m (3.2 feet). Simulation was conducted at an hourly time step (Δt = 1 hr.).

Model performance was evaluated by qualitative considerations using graphic presentations of observed versus predicted and statistical formulations for error measurements in the estimation and validation periods. Error measures adopted are root mean square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2). These statistical formulas are commonly used in hydrologic models to verify a model performance in regard to prediction accuracy. The performance measurement for the model output is the pond water level elevation of the simulated condition against the measured for the actual pond at Miramar, Florida, in the year of 2009 and 2008 for calibration and validation of the model, respectively. Table 25 presents the results of the statistical analyses on the pond water elevation profile.

Statistical analyses reveal that the model explains about 72% of variability in the observed data and have a root mean square error (RMSE) of about 0.07, and mean absolute error (MAE) of 0.07, which are measures for differences between the observed and predicted values. These indicators satisfy the criteria for a model prediction acceptance, which are a coefficient of determination above 0.7 (minimum acceptable value for good fit), and both RSME and MAE approaching zero. The statistical measurement indicators for the simulation period of 2008 verify those obtained for the simulation period of 2009, as shown in Table 25.

Table 25. Statistical performance indicators of the observed and simulated pond water elevation

Efficiency Criteria Symbol				$\mu^{(a)}$ (m)	$s^{(b)}$ (m)	$C_v^{(c)}$	RMSE m (ft.)	MAE m (ft.)	d_{rel}
Yearly Observation	Jan - Dec, 2008 Validation		Observed	0.86	0.12	0.14	0.07 (0.24)	0.05 (0.16)	0.91
			Predicted	0.82	0.10	0.12			
	Jan - Dec, 2009 Calibration		Observed	0.87	0.14	0.17	0.08 (0.26)	0.06 (0.21)	0.92
			Predicted	0.87	0.14	0.17			
Seasonal Observation	2008 Validation period	Dry	Observed	0.81	0.08	0.09	0.021 (0.07)	0.018 (0.06)	0.98
			Predicted	0.81	0.07	0.09			
		Wet	Observed	0.93	0.14	0.15	0.12 (0.38)	0.10 (0.32)	0.85
			Predicted	0.93	0.14	0.15			
	2009 Calibration period	Dry	Observed	0.80	0.10	0.12	0.07 (0.24)	0.06 (0.20)	0.89
			Predicted	0.81	0.13	0.16			
		Wet	Observed	1.03	0.10	0.09	0.09 (0.30)	0.07 (0.24)	0.74
			Predicted	1.00	0.07	0.07			

Figures 23 and 24 present the graphical results of time series and scatter plots for the pond water elevations of the measured and simulated values for calibration. The charts reveal that the model simulation plots follow the same trend as the measured pond water elevation values even though the plots do not match. The difference may be attributed to the averaging of the initial parameters for the catchment area, soil properties, land covers, and slopes used in the model. In addition, the rainfall and meteorological data were obtained from the nearest weather station, about 13 km (8 miles) east of the catchment location. Other important influences could be attributed to the time it takes for the transient water to move from one source to the other and other sources for irrigation in the catchment area. The break in the observed pond water elevation plot in Figure 22 is due to missing data for the period (06/20/2009 to 08/14/2009).

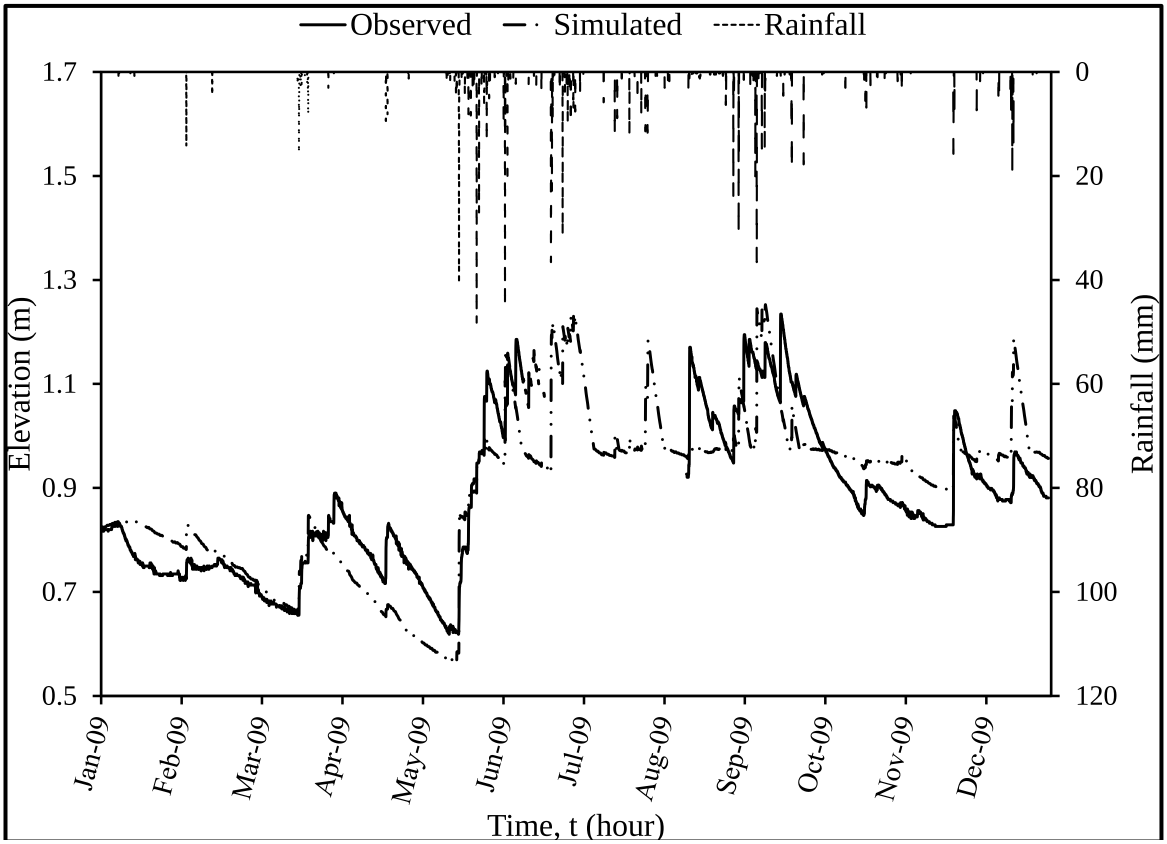

Figure 23. Observed and Predicted Pond Water Elevation Calibration During 2009

Figure 24 presents scatter-graph plotted for the pond water elevation between the observed values and predicted data for the calibration period. The plot showed the R^2 = 0.74 and the linear regression line equation with a gradient, b = 1.03. Value of 1.0 for R^2 means dispersion in prediction is equal to observation, and gradient b = 1.0 and intercept, a = 0 signifies perfect agreement.

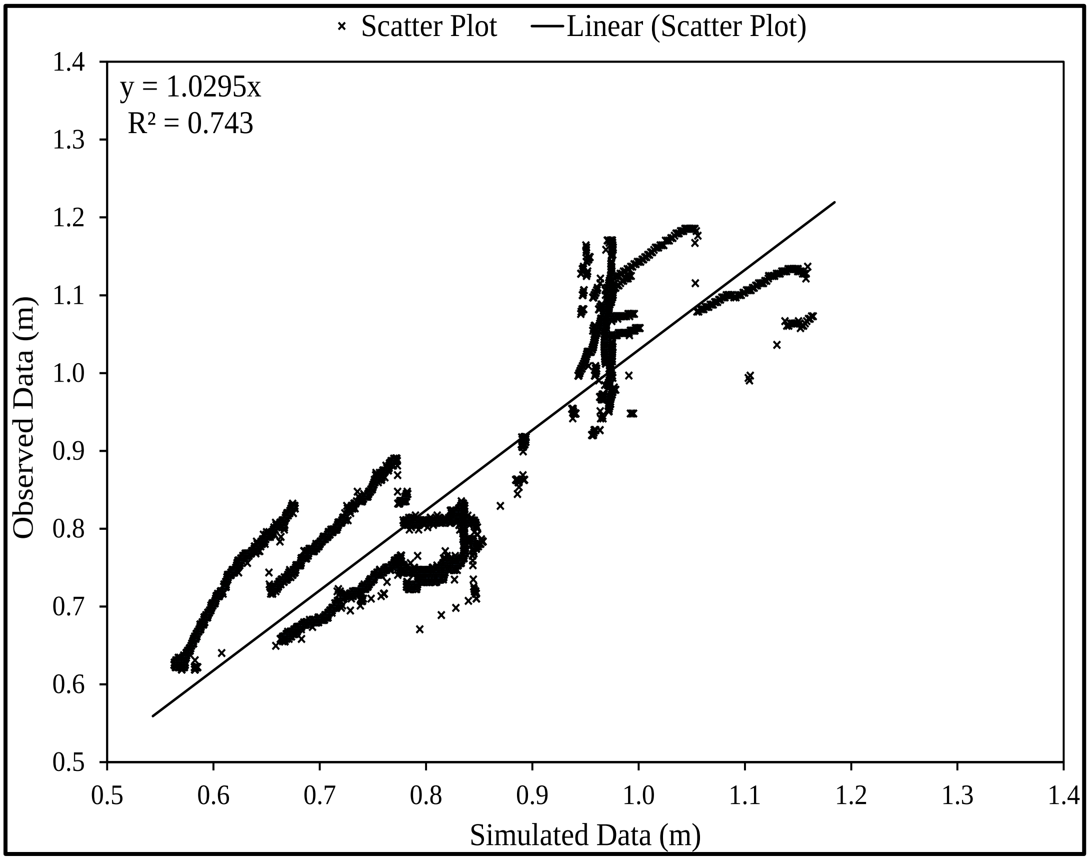

Figure 24. Scatter plot of observed versus simulated pond water level in 2009

Figures 25 and 26 present the time series and scatter plots for the pond water elevation of the measured and simulated values and between the observed values and predicted data for the validation period, respectively. Breaks in the observed pond water elevation are also noticeable for the validation period in Figure 24, from 08/20/2008 to 09/05/2008 due to the effect of tropical storm Fay in August 2008. The validation period showed that the model closely predicted the pond water elevations, especially during the dry months of January through May and November to December with efficiency criteria of *RMSE* = 0.02 m, *MAE* = 0.018 m, and d_{rel} = 0.98.

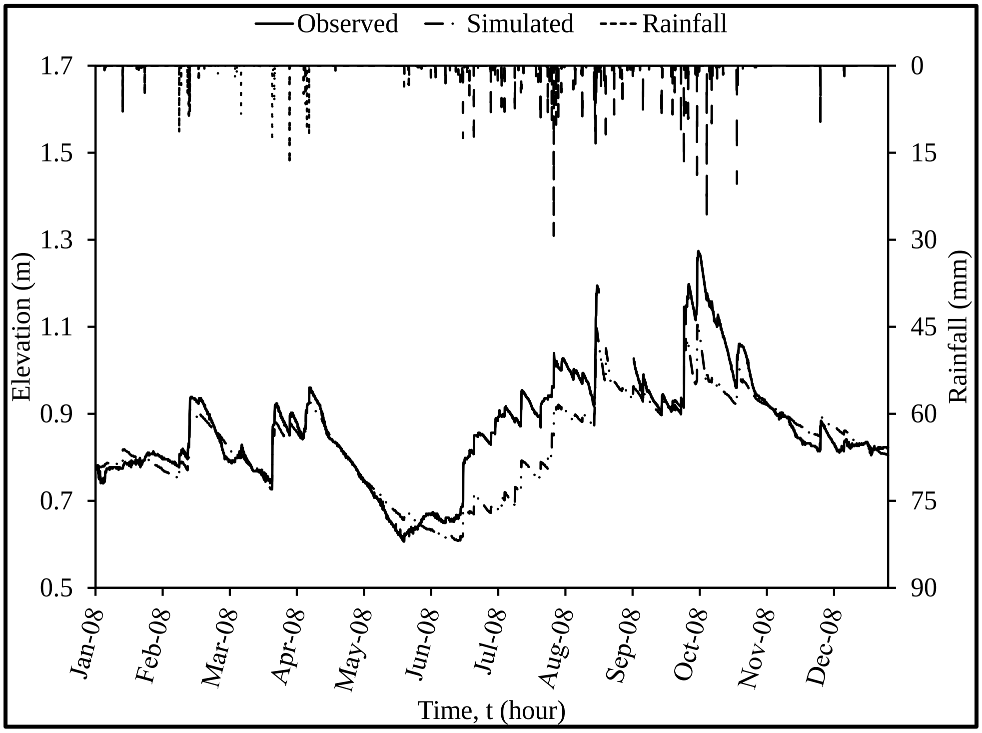

Figure 25. Observed and Predicted Pond Water Elevation Verification During 2008

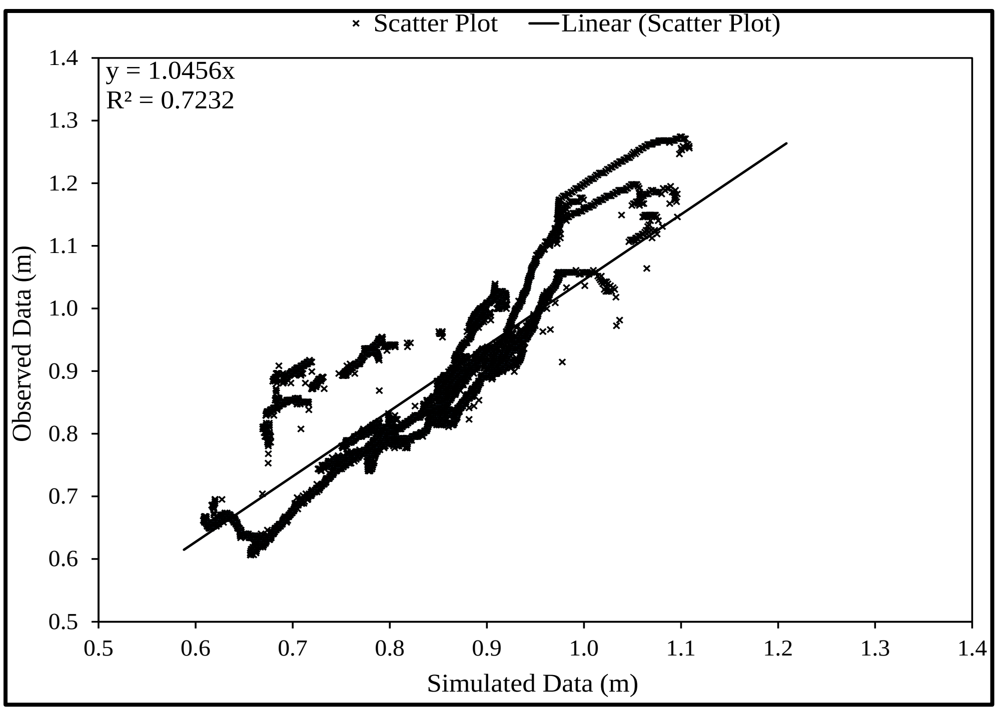

Figure 26. Scatter plot of observed versus simulated pond water level in 2008

The SHARP model has the additional capability to display graphically the effect of stormwater harvesting to the groundwater drawdown, pond discharge volume, and stormwater runoff contribution to harvesting. In Figure 27 is presented a plot of the percentage of runoff discharged against increase in the weekly harvesting volume for each simulation period of one year. The trend reveals an exponential decrease in percentage of runoff volume discharged with an intercept value equivalent to no harvesting.

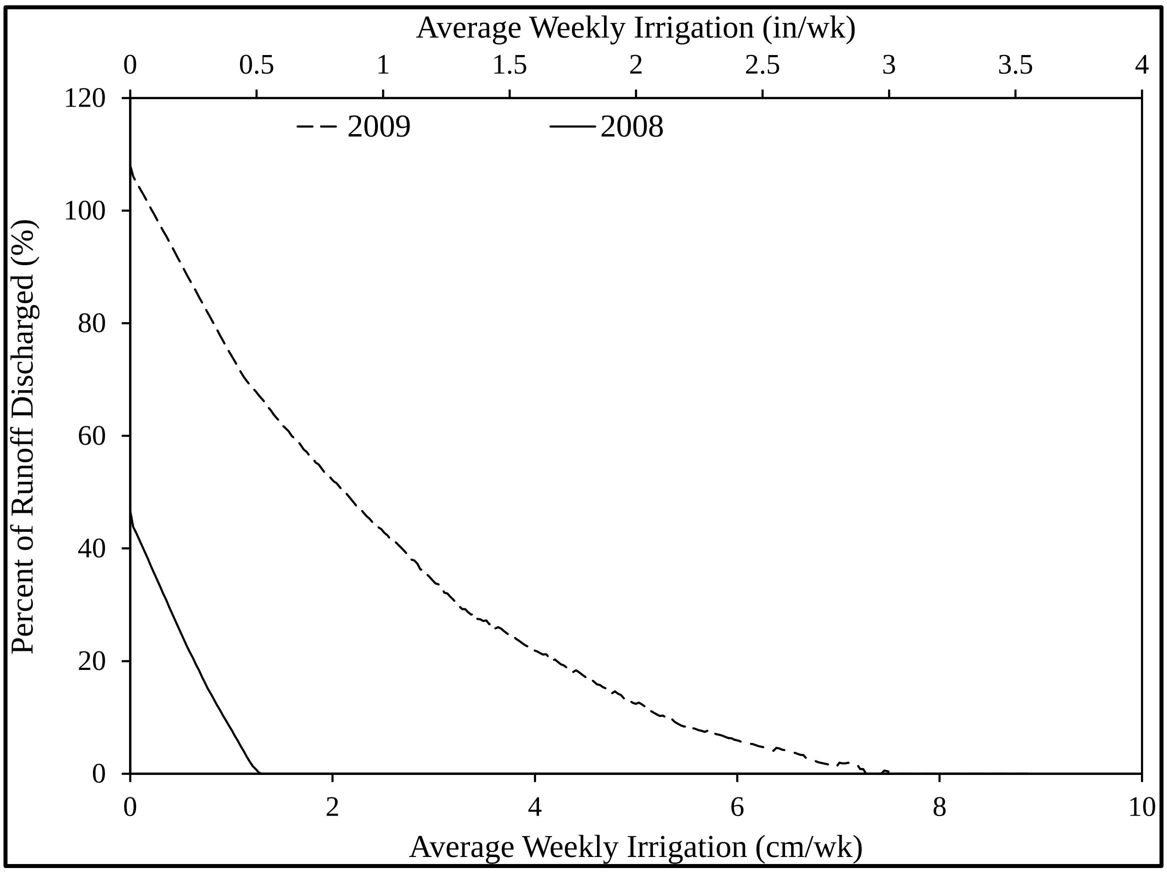

Figure 27. Percent of runoff discharged at permeability of 12.7 cm/hr. (5 in/hr.)

This explains that the discharge from the harvesting pond is about 108 percent of the runoff, or 8 percent more water than the runoff contribution is discharged for 2009. The source of this excess water could be attributed to groundwater seepage, direct rainfall on the pond, and equalization flow from adjacent ponds. However, for the year 2008, only about 48 percent of the runoff was discharged. Subsequent increase in the weekly harvest volume showed an exponential decline in the percent of runoff discharged, which eventually decreased to zero runoff volume discharged. This gives credence to the fact that stormwater harvesting will reduce the discharge from ponds to adjacent surface water, which in effect achieves reduction in the total maximum daily load (TMDL) by volume. The plots further reveal that harvesting can significantly reduce the quantity of pollutant discharged to receiving bodies by the reduction of the volume of discharge.

As the harvest volume is increased, the percent difference in pond storage increases negatively, that is, there is a net loss in the water available for harvesting, which also means more groundwater seepage to the pond. Figure 28 shows the groundwater elevation around the perimeter of the pond, and the safe yield level for the catchment area.

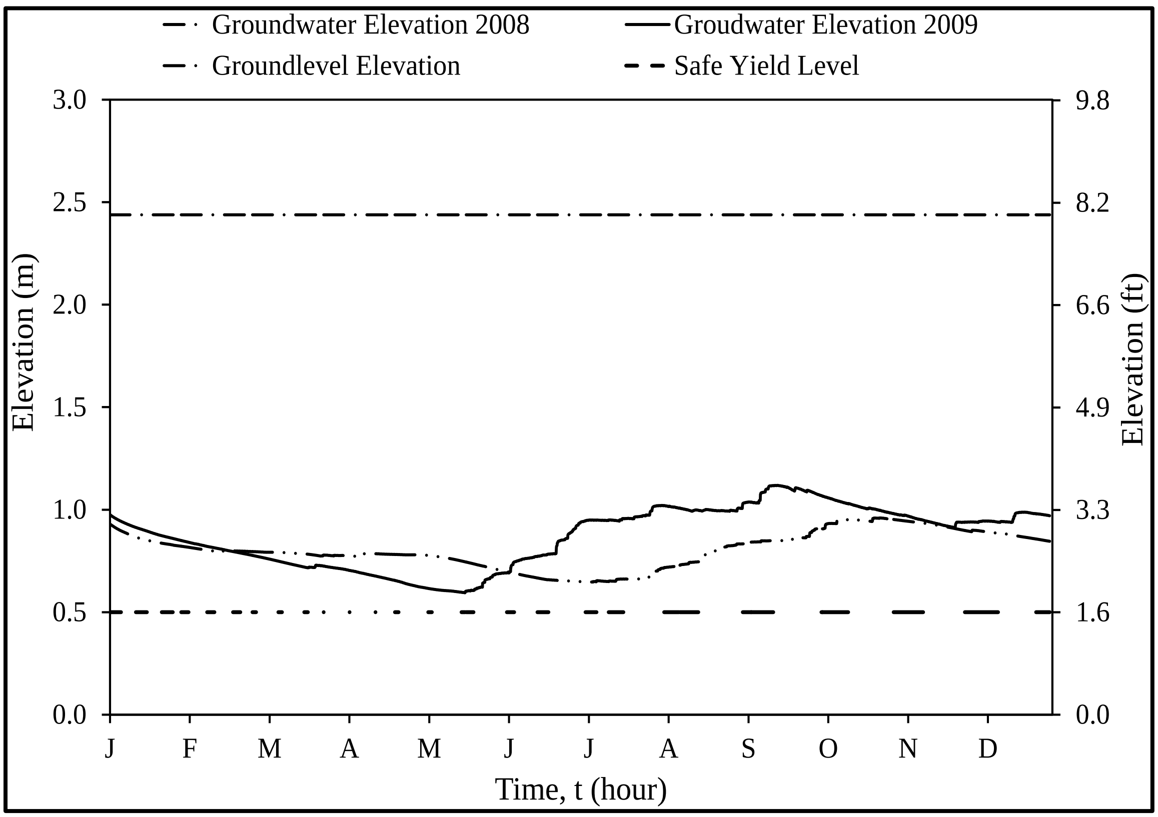

Figure 28. Groundwater elevations for the calibration and validation periods

As a check on mass balance consistency on the pond storage volume computation based on the pond surface area, the annual cumulative volumes of the factors in Equation 18 are presented in Table 26, which shows the inflow and outflow from the pond.

Table 26. Pond Inflow and Outflow Parameter Depths over the Pond Area for the Simulated Period

Year	**Parameter**	**Input, mm (in.)**	**Output, mm (in.)**
2008 (Validation period)	Rainfall (*R*)	1119.63 (44.08)	-
	Runoff (*RO*)	1250.95 (49.25)	-
	Harvest (*H*)	-	24.24 (0.95)
	Evaporation (*E*)	-	1897.54 (74.71)
	Discharge (*D*)	-	548.08 (21.58)
	Seepage (*Q*)	341.47 (13.44)	210.44 (8.28)
2009 (Calibration period)	Rainfall (*R*)	1611.88 (63.46)	-
	Runoff (*RO*)	1880.70 (74.04)	-
	Harvest (*H*)	-	22.96 (0.9)
	Evaporation (*E*)	-	1779.27 (70.05)
	Discharge (*D*)	-	1995.03 (78.54)
	Seepage (*Q*)	601.8 (23.69)	163.17 (6.42)

In the calibration period, net in-flow and out-flow for the pond is 133.96 mm (5.27 in.), which equals the difference between starting and ending pond water elevations of 2956.56 mm and 3090.42 mm (116.40 in. and 121.67 in.), respectively. Similarly, for the validation period, net in-flow and out-flow for the pond was 26.92 mm (1.06 in.), which equals the difference between starting and ending pond water elevations of 2910.84 mm and 2938.30 mm (114.60 in. and 115.68 in.), respectively.

CHAPTER 5 DEMONSTRATION OF HARVESTING WATER FROM WET DETENTION PONDS

5.1 INTRODUCTION

An up-flow filter was demonstrated as part of an FDOT research contract (90). The results indicated that two feet deep filters can remove solids and achieve nutrient removal from wet detention ponds. Two feet of soil is suggested by other reports to improve the water quality before distribution (90). In this report, both biological and chemical indicators were measured and the results showed that the treated water met the standards for human contact. Removal of the wet pond water through soils may be done using horizontal wells, pipe-in-pipe filters that are filled with media, or the use of other filters. To demonstrate the operation of a horizontal well, one was constructed adjacent to the shore line of a 15 acre regional pond. The well consistently produced a flow rate needed for the irrigation demand (500 gpm), and of a quality that meets public access irrigation quality standards. Thus, it will not be necessary to continue work with a horizontal well, but a more cost effective solution is being sought. This solution continues the use of natural material filters, but should also include disc type filters.

5.2 STATEMENT OF PURPOSE AND HYPOTHESES

The purpose of the information in this chapter is to identify, using column tests, the removal effectiveness of select media mixes, and then apply these media to demonstrate, by sampling and measurement, the effectiveness. The demonstration site filters used are a down-flow filter, a disc filter, an upflow filter, and a mobile or pipe-in-pipe filter. All units are resident in some form of commercially available pipe to make their use most cost effective.

5.3 COLUMN TESTING FOR MEDIA SELECTION

Several materials were examined to determine their potential as a filter medium. Column testing was carried out, and several parameters were examined. The parameters examined were: ammonia, nitrate+nitrite, total nitrogen (TN), ortho-phosphate, total phosphorus (TP), pH, alkalinity, turbidity, and total solids. The materials examined were selected based on several criteria, namely, filtration rate, capital cost or economic considerations, availability, pollutant removal potential, and clogging potential.

As discussed in Chapter 2, the parameters of interest for this study have been shown to be removed by physical, chemical, and biological processes supported by media filtration. The materials examined in this study are: less than 3/8 inch diameter expanded clay, 3/8-1/2 inch diameter expanded clay, tire crumb, washed mason sand, cedar sawdust, and #89 limerock. All materials have been examined in the literature either individually or in some combination (23, 28, 31, 33, 34, 48, 49, 50, 52, 54, & 89).

In Table 27, the permeability of several different materials examined for this project is shown. The permeability varies for each material type and is an important factor in ensuring proper contact time. The higher the permeability, the more medium required to maintain the same contact time as a medium having a lower permeability.

Table 27. Measured Permeability of Different Materials

Material	Permeability [in/hr]
Tire Crumb	43.33
Expanded Clay (small size)	19.6
Expanded Clay (large size)	128
Mason Sand	5.44
#89 Limerock	16.4

It can be seen from Table 27 that each of the materials examined has a different permeability. Often times it is desirable to use a combination of materials to maximize pollutant removal capabilities while maintaining a flow rate. For this reason several mixes of materials were examined. Table 28 shows the results of the column testing completed for this study. It can be seen that all of the mixes examined showed potential for removing the pollutants of interest.

Table 28. Column Testing Results

	Parameter [Average Percent Removal]					
Media Mix	Ammonia [%]	Nitrate [%]	Total Nitrogen [%]	Ortho-Phosphate [%]	Total Phosphate [%]	Turbidity [%]
60% Expanded Clay, 30% Tire Crumb, 10% Saw Dust	15%	27%	45%	100%	81%	No Data
50% Expanded Clay, 50% Tire Crumb	45%	17%	10%	46%	22%	40%
100% Tire Crumb	51%	27%	30%	65%	44%	57%
25% Tire Crumb, 75% Sand	-15%	75%	83%	82%	86%	91%
15% Tire Crumb, 50% Sand, 35% Expanded Clay	1%	65%	26%	31%	36%	37%

From the column test data shown in Table 28 which were based on the quality of the water to be treated and the desired contact time, the media selected was the one with the highest total nitrogen removal. The media is 25% tire crumb and 75% sand and is called a Bold & Gold mix. The 15 % increase in ammonia is most likely due to the conversion of organic nitrogen, which is considered a positive result. A longer holding time in the media will further convert the ammonia. Ammonia nitrogen is then converted to nitrate and is removed by biological means. The next best mix was expanded clay, tire crumb and saw dust in terms of total nitrogen removal. These two mixes had excellent total phosphorus removal (86% and 81% respectively). The sand mix has a tendency to clog thus replacement using expanded clay and tire crumb may be used.

5.4 DOWN-FLOW FILTERS FOR WATER FROM A WET DETENTION POND

A 29 year-old wet detention pond on Harbor Island in Tampa, FL, was selected to build a full scale down-flow filter to treat the water. The pond was cleared of bottom muck 3 years before the filter application. About 324 cubic yards of pond bottom mud (organics) was removed. It was a requirement of the permit that an additional 25% TN reduction be achieved before discharge from the pond. From Table 29 it can be seen that 86% of the TN in the pond is inorganic, or ammonia and nitrite+nitrate. As stated in Chapter 2, ammonia will be in the form of ammonium and thus potentially removed via adsorption with clay, adsorption with tire crumb, volatilization, or nitrified to nitrate via nitrifying bacteria. The nitrite+nitrate can only be removed via denitrification. This requires specific conditions within the filter media, namely denitrifying bacteria must be present and the environment must be anoxic. From Table 29 it can also be seen that the TP concentrations are also slightly elevated. The ortho-phosphate represents 77% of the TP, and is readily removed via adsorption to the tire crumb, as shown in Chapter 2.

Table 29. Wet Pond Water Quality

Ammonia [mg/L as N]	NO_2+NO_3 [mg/L as N]	Total Nitrogen [mg/L as N]	Orthophosphate [mg/L as PO_4]	Total Phosphorus [mg/L PO_4]	pH	Alkalinity [mg/L as $CaCO_3$]
0.481	0.94	1.65	0.8	1.04	7.39	208

A Harbor Island pipe filter was installed in the pond side embankment, as shown in Figure 29, and was named the Hillsborough Filter. Space was somewhat of a concern but there was sufficient space to allow a slower flowing filter medium.

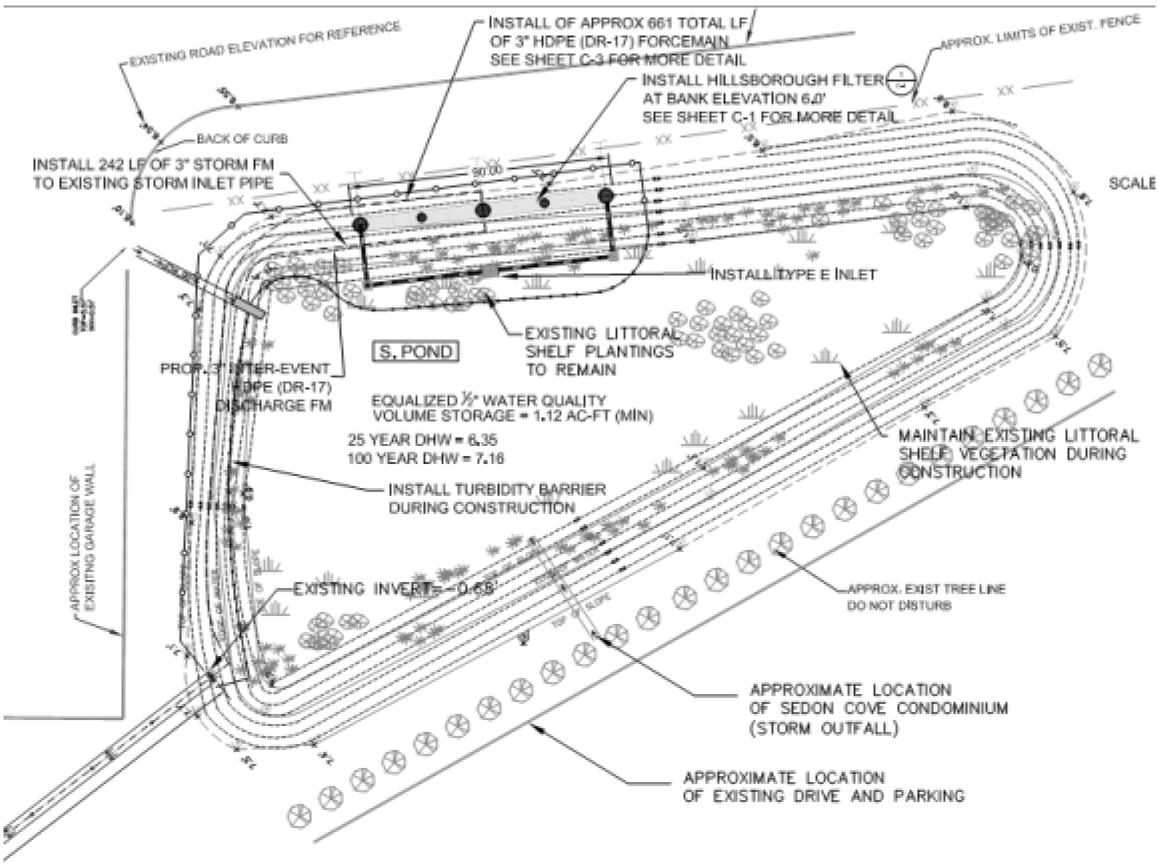

Figure 29. Pond Schematics and Filter Location (Watermark Engineering Group)

The size and characteristics of the watershed are shown in Figure 30. The size of the basin is 26.8 acres with 95% imperviousness. The imperviousness in the basin includes hotels and condominiums, as well as parking lots and roadways. Parking lot and road surfaces account for approximately 40% of the basin. The effective impervious area was calculated as 15.5 acres, and the pond was designed to store 0.5 inches of rainfall over the effective impervious area. The pond was designed as a wet detention pond with a residence time of 21 days during the wet season.

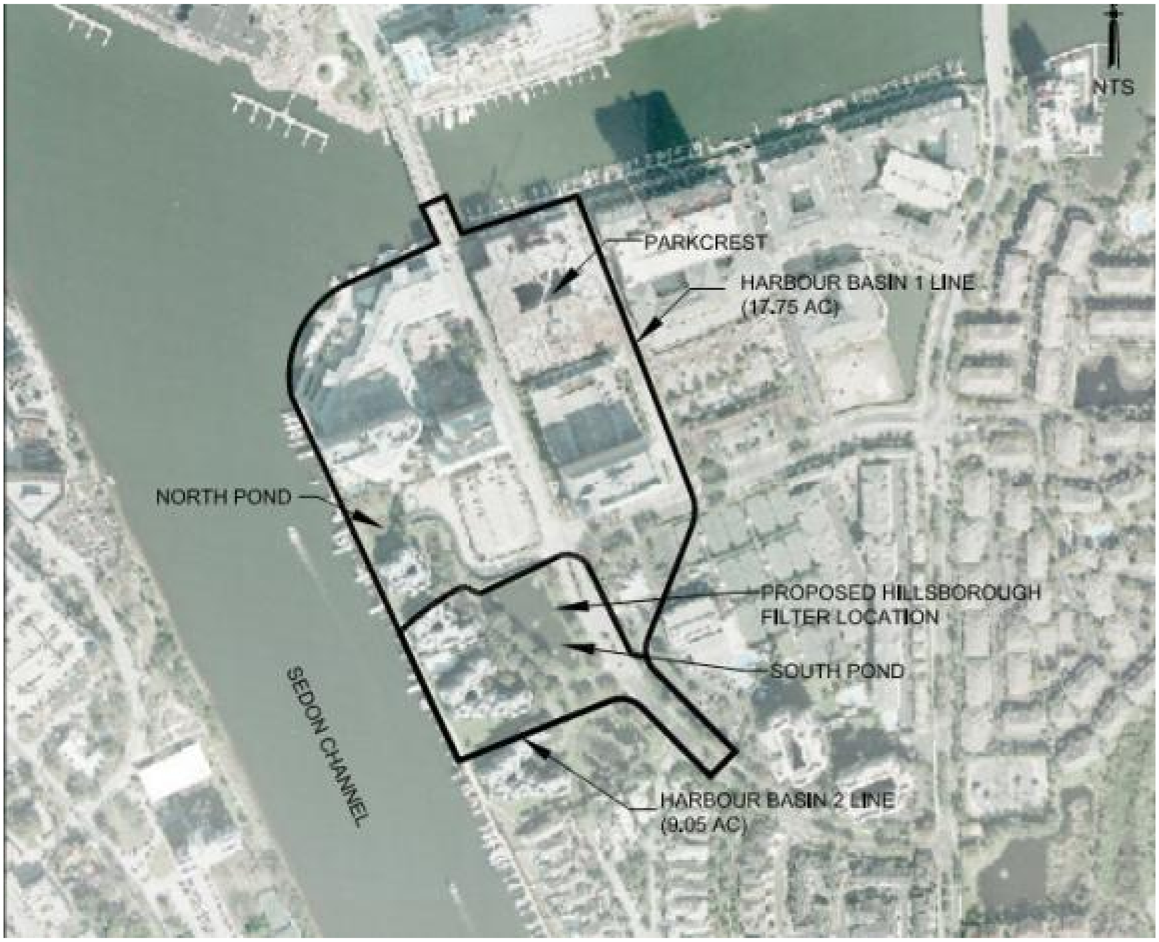

Figure 30. Aerial Photo of the Drainage Basin

The proposed filter design is shown in Figure 31. It was designed by Mark Flint of Watermark Engineering Group from Apollo, Florida. It is a down-flow filter with backwash functioning capabilities. Water is distributed via spray heads over the media and then filters through the media. The effluent is collected in an under drain pipe into a wet well where it is pumped back to the pond. A backwash mechanism is also in place to maintain and rejuvenate the filter media. The filter has been in operation for over two years when this report was written.

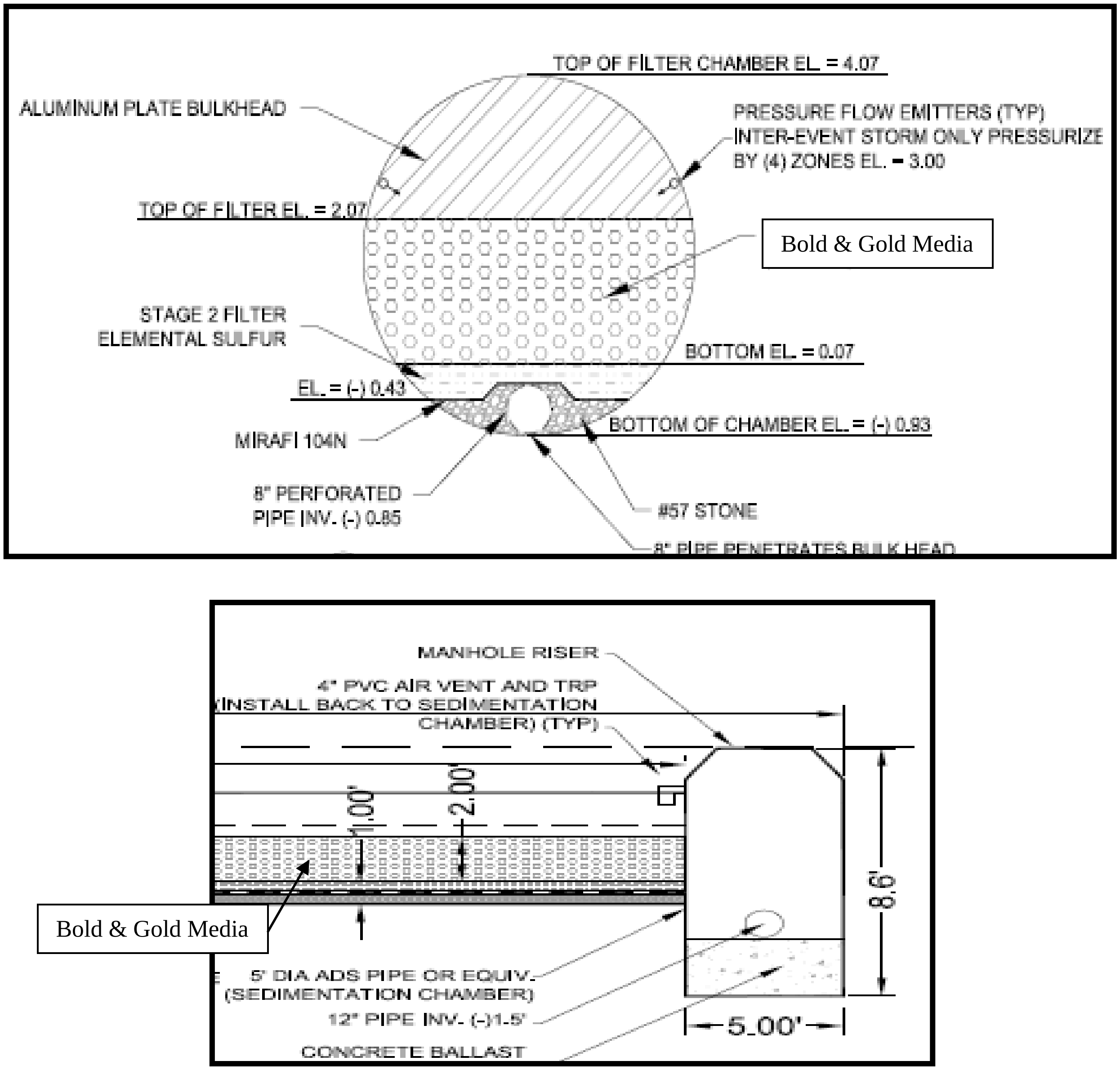

Figure 31. Down-flow Filter Section and Side View Design Drawings

The initial selected media for experimental purposes included 10% limestone, 25% tire crumb and 65% sand mix, however it had excessive clogging. Thus the mix from the laboratory column testing (see Table 28) was used. Figure 32 below shows a particle size distribution of the selected media mix. It can be seen that the media is poorly graded sand based on the Unified Classification System with particle diameters ranging from 0.1 mm to 0.5 mm. This indicates that the media mix will readily infiltrate clean water. It should also be noted that due to the small particle size of the media mix, clogging could potentially occur at a faster rate than for a media with a larger particle size.

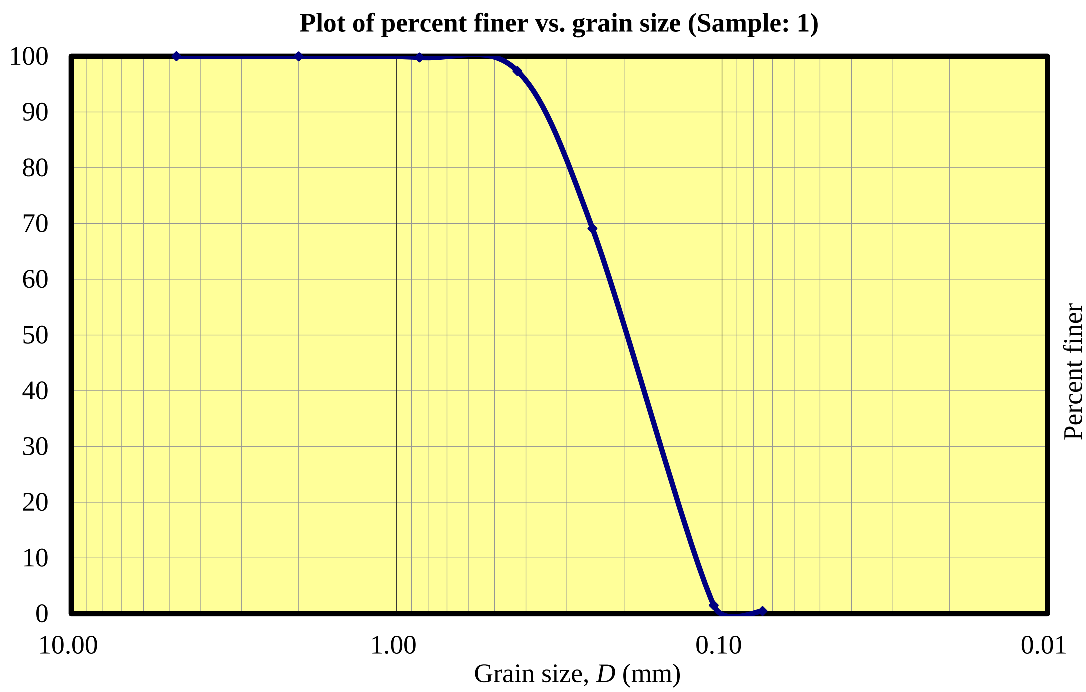

Figure 32. Particle Size Distribution Graph for the First Media at Harbor Island

This filter was installed on September 27th, 2010. Sampling began shortly after construction was completed. Including sampling of the wet detention pond prior to the filter construction there were 12 sampling events. Several field parameters were measured on site, and samples were collected to analyze for nutrients. The parameters measured by field sampling methods in the pond are shown in Table 30. These were measured for every sampling event. All of the values recorded are typical of in-land surface waters in central Florida, except conductivity. The conductivity measured was higher than most wet detention ponds. The higher conductivity is likely due to the wet detention pond being in close proximity to Tampa Bay indicating potential saltwater intrusion into the pond. Also, the closer the pond water is to the Bay, the higher the conductivity.

Table 30. Field Parameter Results

	pH	Alkalinity [mg/L as CaCO3]	Turbidity (NTU)	DO (mg/L)	Conductivity (µS/cm)	Temp (°C)
Average	7.72	48.40	5.14	7.42	461.00	25.55
Median	7.79	47.00	5.21	7.15	437.00	29.60
Std. Deviation	0.50	5.46	2.57	1.63	213.59	11.39

The field pond monitoring for nutrients shows that all forms of nitrogen and phosphorus are reduced after the installation of the down-flow media filter. Presented in Table 31 is the water quality comparison based on measurement before and after the Bold & Gold filter media. The reduction in ammonia was expected as the residence time in the filter was increased and could be due to volatilization, nitrification, or adsorption. The nitrate was likely denitrified by denitrifying bacteria that colonized in the media. Straining and/or depth filtration likely removed any particulate pollution, including nitrogen and phosphorus. The orthophosphate was likely removed through adsorption to the tire crumb and bioaccumulation.

Table 31. Water Quality Comparison of Pre-Filter and Post Filter Water

	Ammonia [mg/L as N]	Nitrate+Nitrite [mg/L as N]	Total Nitrogen [mg/L as N]	Ortho-Phosphate [mg/L as PO_4]	Total Phosphorus [mg/L as PO_4]
Pre-Filter	0.481	0.94	1.65	0.8	1.04
Post Filter	0.29	0.14	0.98	0.23	0.25
% Change	40	85	41	71	76

It should be noted that in the time period around September 28th, 2011, a significant decrease in flow through the filter was observed. Upon inspection of the filter media, it was observed that a thin layer of highly concentrated low permeability organic material sealed off the top of the filter. The organics were identified by microscope detection. The filter organic material was the same as that found in the bottom materials of the pond. Based on the presence and accumulation of this material, the decision was made to remove the existing filter media and install a media mix with a larger particle size. The new mix installed was 80% of coarse (large size) expanded clay and 20% tire crumb. Column tests on this blend also show a removal of TN of over 80%. No other parameters were measured. Figure 33 below shows the particle size distribution curve for the new media mix. The new media mix has a larger particle size than the old media mix. According to the Unified Soil Classification System, this media mix is classified as poorly graded sand with gravel. The larger particle diameter of this media mix is intended to reduce clogging, and increase the effectiveness of backwashing while achieving nutrient reduction.

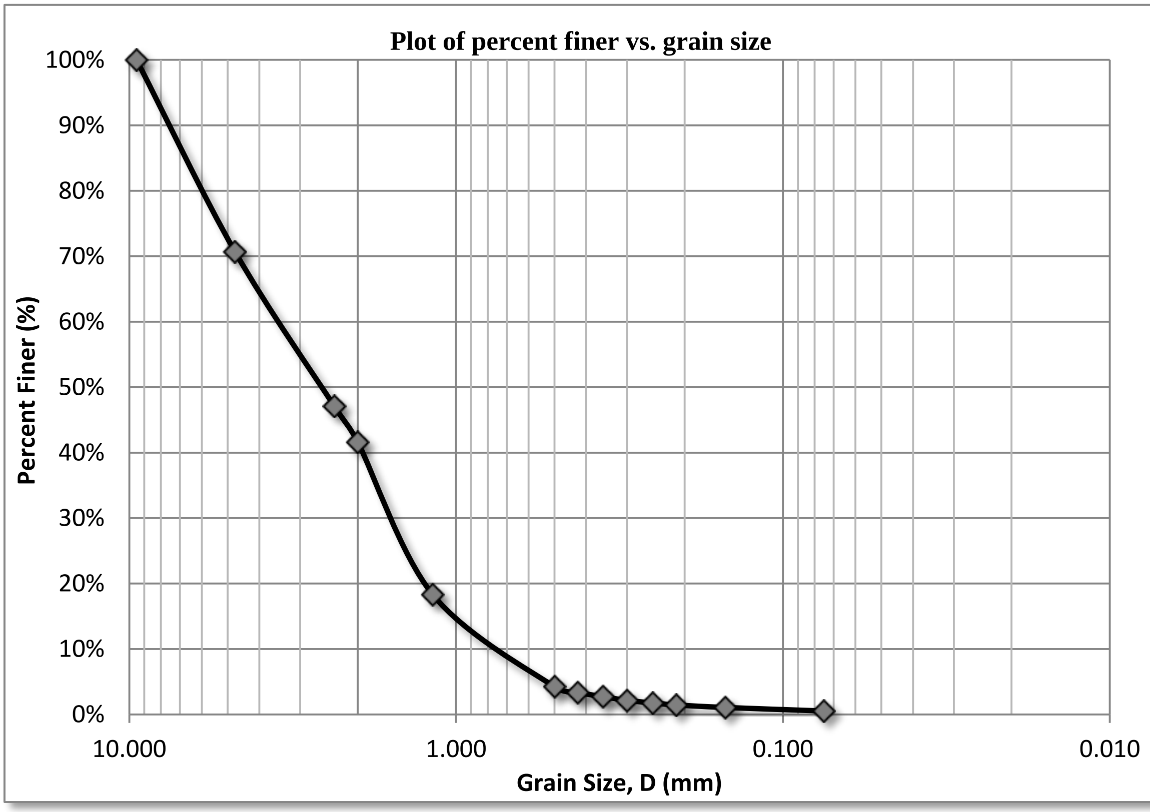

Figure 33. Particle Size Distribution for the New Media Mix for Harbor Island

The water quality was monitored for both the old media mix and the new media mix at Harbor Island and using average influent values that were about the same. The comparison under these conditions is shown in Table 32.

Table 32 below shows the pre filter and post filter or effluent concentration of the nutrient parameters of interest. The average effluent total nitrogen and nitrate+nitrite concentration data for the new media mix as shown in Table 32 was significantly less than the old media mix ($\alpha=0.05$). There was no significant difference in the ammonia concentrations. The total nitrogen removal could be due to increased biological activity or better filtration with depth found in the new media mix. The old media mix was clogging at the surface. Also, there was no significant difference for ortho-phosphate measurements between the old media mix and the new media mix but there was a significant difference for total phosphorus ($\alpha=0.05$) using the data as shown in Table 32.

.

Table 32. Old Media Vs. New Media Effluent Concentrations

	Ammonia [mg/L as N]	Nitrite+Nitrate [mg/L as N]	Total Nitrogen [mg/L as N]	Ortho-phosphate [mg/L as PO_4]	Total Phosphorus [mg/L as PO_4]
Old Media Effluent	0.29	0.21	1.23	0.21	0.35
New Media Effluent	0.29	0.09	0.67	0.26	0.18
% Difference	none	57	45	19	49

These results show that a down-flow filter using a filter media is an effective way to reduce both TN and TP concentrations in wet detention ponds. The old media achieved a 41% reduction of TN and a 76% reduction of TP, compared to the pre-filter water condition. The new medium achieved a 54% reduction of TN and a 90% reduction of TP. It should also be noted that the prior to using the filter, pond water quality had a higher inorganic component for both nitrogen and phosphorus species, compared to the post filter installation condition. This could indicate conversion into biomass when using the filter.

Overall, both the old media mix and the new media mix met the requirements of the permit for this project. TN and TP concentrations were reduced. As demonstrated in the field application of filter media, the clogging potential needs to be considered in the design of a media mix. In applications with a high clogging potential, a media mix should be selected with a larger particle diameter. This reduces the clogging potential and increases the effectiveness of backwashing.

5.5 MOBILE PIPE-IN-PIPE FOR WATER HARVESTING

The ability to temporarily treat waters is a common occurrence in practice. It is for this reason that a mobile, pipe-in-pipe filter application was examined. The site selected for this project was selected based on convenience of location and therefore, ease of sampling. The pond selected was located on the main campus of the University of

Central Florida in Orlando, Florida. The basin contains roadways, parking lots, dormitory buildings, as well as maintenance and storage facilities. The pond selected is part of a larger pond system on the main campus of UCF and therefore, connected to several other ponds in series. The water quality parameters of interest are as follows: pH, temperature, turbidity, ammonia, nitrate+nitrite, total nitrogen, ortho-phosphate, and total phosphorus. Initial sampling of the pond provided the water quality presented in Table 33 below.

Table 33. Initial Water Quality of Pond

pH	Temperature [^{o}C]	Turbidity [NTU's]	NH_3 [μg/L]	NO_x [μg/L]	Total N [μg/L]	SRP [μg/L]	Total P [μg/L]
7.32	25.1	1.54	85	282	412	5	16

As shown in Table 1 (presented in Chapter 2), the pH is in the common range of stormwater runoff from highways. The nutrient parameters, on the other hand, are all lower than national averages. Such low concentrations may be difficult to remove and make it difficult to quantify any removal.

The design used for this project involved a large diameter, perforated, outer pipe that housed a smaller diameter, perforated, inner pipe which was filled with an 80% coarse expanded clay and 20% tire crumb media mix. This mix was selected based on the performance of the Harbor Island down-flow filter. The outer pipe was 80 feet long and installed from the edge of the pond towards the center of the pond (See Figure 34 below). It was anchored in place by two sets of rope with bricks on the end and a metal wire anchored to opposite shores of the pond.

Figure 34. Installation of the Outer Pipe for the Mobile Pipe-in-pipe Filter

The inner pipe section came in four five foot sections totaling 20 feet in length. These five foot sections were filled with the media mix and sealed off with a rubber end cap. A two inch diameter screen pipe ran through the center of the filter media and rubber end caps and was fitted with quick release fittings to attach all the sections together. The section closest to the shore of the pond was connected to 40 feet of two inch diameter pipe which connected to the suction end of a pump. The inner pipe was pieced together and installed into the outer pipe as shown in Figure 35 below.

Figure 35. Inner Pipe Installation for the Mobile Pipe-in-pipe Media Filter

The filtered effluent is pumped back to the pond away from the zone of influence for the influent. This system was designed to run for eight hours several times a week at 110 gallons per minute. The inaugural run of the system showed that the pumping rate was only 60 gallons per minute. However, it was observed that prior to measuring the flow rate there was a significant reduction in flow. Two sampling events occurred during this time, one on March 21st, 2012 and one on March 26th, 2012. The average water quality measured for these two events is presented below in Table 34.

Table 34. Parameter Average Value for the First Two Sampling Events

	pH	Turbidity [NTU's]	NH_3 [μg/L]	NO_x [μg/L]	Total N [μg/L]	SRP [μg/L]	Total P [μg/L]
Pond Water Average	7.455	2.505	70.5	258	394	2.5	43
Filter Effluent Average	7.035	2.705	88.5	242	380	3	19.5

Based on the data presented in Table 34, there was no significant difference (α=0.05) between the pond water average and the filter effluent average. Total nitrogen and total phosphorus are both lower for the filter effluent but due to the low concentrations, it is difficult to quantify. After the second sampling event on March 26th 2012, the flow rate was still below what was required. Upon examination of the system, it was determined that the reason for the reduced flow was that the fines in the media had clogged the screen pipe. The inner pipe was removed from the pond and the media was removed from the inner pipe. A new media mix was made and sieved to retain all particles 6.35 mm and larger. The new media mix was installed into the inner pipe which was subsequently installed back into the outer pipe in the pond. Pumping operations resumed at that time and flow rates remained at or above 110 gallons per minute for the duration of the project.

Once the new media had been installed, sampling resumed. A total of five sampling events occurred with the new media mix. After 3 more sampling events, it was observed that the nutrient concentrations were still low, making it difficult to quantify the filter performance. Table 35 below shows the average values of the pond water and filter effluent for three sampling events that occurred on March 28th, March 29th, and April 13th, 2012. For the parameters examined, there was no significant difference (α=0.05) between the pond water average and the filter effluent average.

Table 35. Pond and Filter Effluent Average Values Prior to Fertilizer Spike

Sample Location	pH	Turbidity [NTU's]	NH_3 [μg/L]	NO_x [μg/L]	Total N [μg/L]	SRP [μg/L]	Total P [μg/L]
Pond Average	7.2	2.3	51.7	198.3	376.7	5.0	19.7
Filter Effluent Average	7.4	2.0	60.7	191.3	407.3	7.0	22.3

As previously stated, nutrient concentrations in the pond and filter effluent have been low for the duration of this project, making performance difficult to quantify. For this reason, toward the end of the project on April 17th, 2012, the pond was spiked with about 5 lbs of 10-10-10 (N-P-K) fertilizer. The fertilizer was allowed to dissolve in a 5 gallon bucket of water over night before applied to the pond. The dissolved fertilizer was then applied directly above the end of the filter and mixed in with the pond water. A sample was then collected from the area above the filter at that time. Shortly after the application of the fertilizer spike, a sample was collected from the filter effluent. The system was allowed to run for four more hours before another sample was collected. Table 36 below shows that average concentration for the nutrients measured.

Table 36. Pond and Effluent Average Value After the Fertilizer Spike

Sample Location	pH	Turbidity [NTU's]	NH_3 [μg/L]	NO_x [μg/L]	Total N [μg/L]	SRP [μg/L]	Total P [μg/L]
Pond Average	6.9	1.6	121.0	159.5	465.0	138.0	261.5
Filter Effluent Average	7.0	4.4	214.5	158.0	525.0	40.5	89.0

It can be seen from Table 36 above that there was no total nitrogen reduction. There is however, a significant ortho-phosphate and total phosphorus reduction. This shows the effectiveness of both the tire crumb and expanded clay at adsorbing phosphorus species. The lack of a reduction in nitrogen species indicated that either the flow rate through the media is not allowing a sufficient contact time with microbes or that microbes have not yet fully established on the media.

The results of this study showed that a mobile pipe-in-pipe treatment system can be an effective way to reduce phosphorus species in stormwater. Due to the time limitations of this study, it could not be determined whether sufficient colonization of the media took place to achieve nitrogen removal in high-flow through filter applications. In theory, given enough time and the proper conditions, nitrogen removal should be possible, but it was not able to be quantified in this study.

There were several observations that should be noted at this time. First, it was observed that the metal fittings used in this project to connect the inner pipe sections together tended to rust, and develop a slime layer making them difficult to work with when needing to perform maintenance. It is recommended that different techniques be examined to ease maintenance activities and moving the system. There was also an incident where the metal cable anchoring the system to the shores of the pond broke. This did not cause any significant issues but it is recommended that a thicker cable be used or a different material all together. In addition, one of the screen pipes broke when working to remove the media from one of the inner pipes; this should be replaced with a stronger material so as to prevent breakage.

5.6 DISC FILTRATION FOR WATER FROM A WET DETENTION POND

Location

An FDOT designed wet detention pond on Interstate 75 at exit 7 in Miramar was being considered as a possible source of irrigation water for nearby residential and commercial properties. The pond has an area of 40 acres. The location is shown in Figure 36. Also, Figure 37 is an aerial photo showing the commercial watershed and the roads system, as provided by GAI Consultants, Inc.

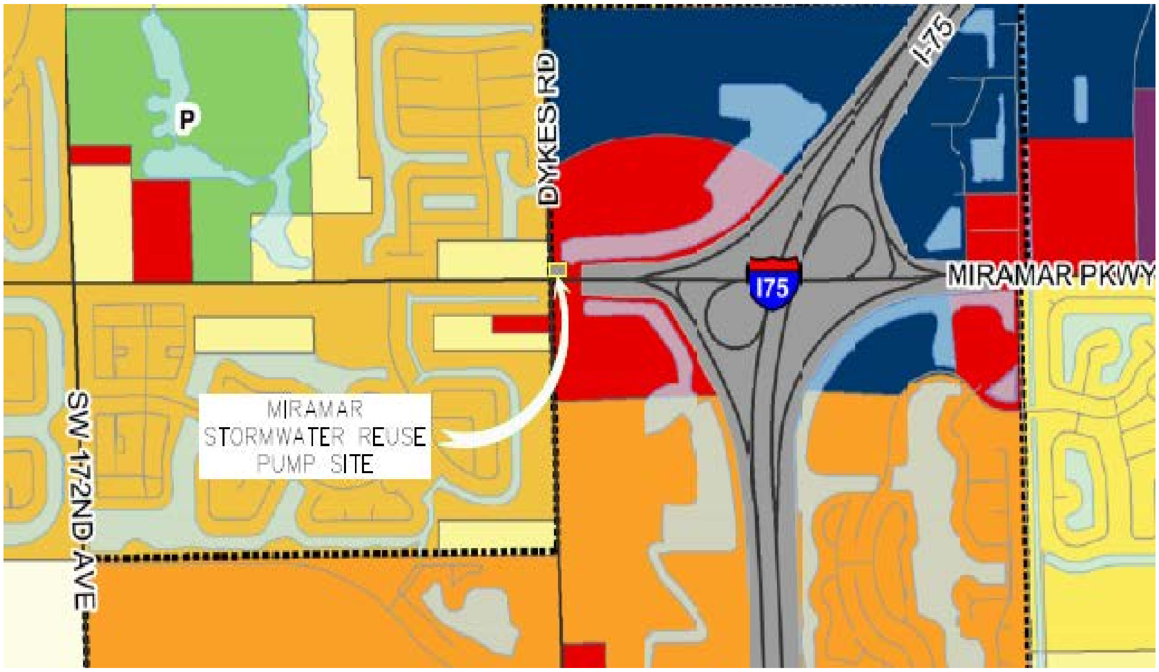

Figure 36. FDOT and City of Miramar Pond Location

Stormwater sampling inlets, from left to right, shell, chase, and north

Pump and Disc Filter location

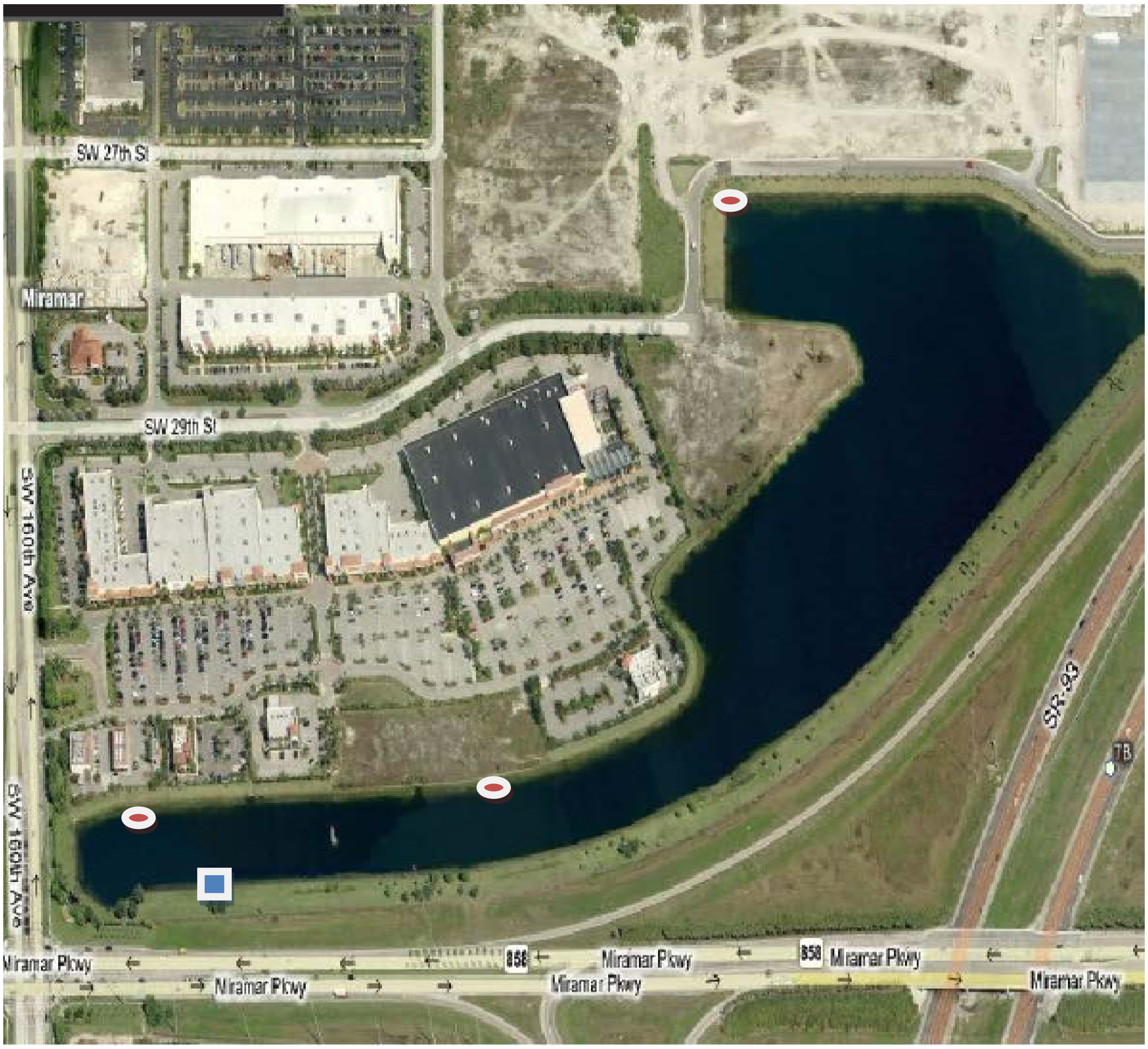

Figure 37. Aerial Photo, Sampling Location, and Land Use

Stormwater Quality

Seven samples from the stormwater inlets to the wet detention pond were sampled and analyzed. Gross solids were excluded from the water matrix. The water quality data are shown in Table 37. Averages are tabulated as shown. The values are characteristic of stormwaters with infiltration of ground water noted and judged by measured pH values greater than 7.5. The changes in the average values from 11/3/10 to 6/28/11 were not significant and thus, the averages are tending to converge to representative ones.

Table 37. Stormwater Inlet Water Quality Data, Detection Limits, and Averages

Location Parameter	Units	Chase 7/23/10	Shell 7/23/11	North 7/23/12	Chase 9/29/10	Chase 11/3/10	Chase 4/6/11	Chase 6/28/11
BOD_5	mg/L	15.9	U	4.02	U	6.5	2.85	3.62
Fecal Col.	CFU	2400	6000	3400	1160	1240	300	1900
S. Cond.	uS/cm	-	-	-	40.3	157	243	123
Ammonia	mg/L	U	U	U	0.056	0.01	0.185	U
NO_x	mg/L	U	U	U	0.046	U	U	U
pH	#	-	-	-	8.93	6.9	8.11	8.16
Temp.	^oC	-	-	-	25.6	26.8	25.4	26.9
TKN	mg/L	1.58	0.592	0.285	0.22	2.5	1.69	1.69
T. Solids	mg/L	115	105	69	20	101	158	76
TP	mg/L	0.078	U	U	0.266	0.457	0.329	0.152
TSS	mg/L	3	27	2	2	2	6	4
Turbidity	NTU	2.12	1.01	2.08	1.96	5.90	6.27	5.03

Parameter	Units	DL	11/3 AVG	4/6 AVG	6/28 AVG
BOD_5	mg/L	2.3	5.74	5.26	5.03
Fecal Col.	CFU	2	2840	2417	2343
S. Cond.	uS/cm	0.432	98.7	146.8	140.8
Ammonia	mg/L	0.011	0.017	0.045	0.039
NO_x	mg/L	0.022	0.018	0.017	0.016
pH	#	0.069	7.9	7.98	8.025
Temp.	^oC	1	26.2	25.9	26.2
TKN	mg/L	0.738	1.035	1.145	1.222
T. Solids	mg/L	0.1	82	95	92
TP	mg/L	0.063	0.267	0.199	0.192
TSS	mg/L	1.534	7.2	7.0	6.6
Turbidity	NTU	0.01	2.61	3.22	3.48

DL – Detection Limit, U – Below Detection Limit

Pond water quality data at the outlet show low nitrogen, phosphorus, turbidity, and total suspended solids (TSS). The data and the average of the sampling events are shown in Table 38. The very low phosphorus was favorable for the use of the pond for irrigation since fertilizer sold in the state is now mandated to have zero phosphorus. TSS is below the standard of 5 mg/L set for irrigation quality water. Fecal coliforms have been significantly reduced relative to the stormwater inputs. The concentration of total solids, pH, and specific conductance over time in the pond indicated that groundwater is infiltrating into the pond.

Table 38. Pond Water Quality at the Outlet and Average Data

Parameter	Units	5/13/10	8/17/10	12/21/10	1/31/11	3/31/11	5/5/11	5/26/11	6/30/11
BOD_5	mg/L	U	2.8	U	U	U	U	U	U
Fecal Col.	CFU	352	400	350	80	200	U	80	140
S. Cond.	uS/cm	410	354	480	493	484	427	448	421
Ammonia	mg/L	U	U	U	U	U	U	U	U
NO_x	mg/L	U	U	U	U	U	U	U	U
pH	#	7.78	7.63	7.8	7.95	7.98	7.63	8.14	8.06
Temp.	^oC	28	33	18.4	19.4	26.8	24.7	29	29.1
TKN	mg/L	1.35	0.509	0.014	0.12	2.54	1.14	U	1.17
T. Solids	mg/L	278	196	231	290	276	250	277	247
TP	mg/L	U	U	U	0.134	0.162	0.062	0.115	0.11
TSS	mg/L	2	2	3	4	2	2	4	2
Turbidity	NTU	0.812	0.676	0.54	0.86	1.00	1.38	0.73	2.59

Parameter	Units	DL	12/21 avg	1/13 avg	5/5 avg	5/26 avg	6/30 avg
BOD5	mg/L	2.3	1.7	1.6	1.5	1.4	1.4
Fecal Col.	CFU	2	367	296	276	244	229
S. Cond.	uS/cm	0.432	415	434	441	442	440
Ammonia	mg/L	0.011	U	U	U	U	U
NO_x	mg/L	0.022	U	U	U	U	U
pH	#	0.069	7.74	7.79	7.80	7.84	7.87
Temp.	^oC	1	26.5	24.7	25.1	25.6	26.1
TKN	mg/L	0.13	0.624	0.498	0.946	0.946	0.978
T. Solids	mg/L	0.1	235	249	254	257	256
TP	mg/L	0.063	U	0.128	0.078	0.081	0.085
TSS	mg/L	1.534	2	3	3	3	3
Turbidity	NTU	0.01	0.68	0.72	0.88	0.86	1.07

The average values were calculated using a value for the below-detection reading equal to half of the detection limit (DL), except for parameters where measurements were all below detection limits. The running averages for each parameter indicated a stable and consistently acceptable water quality of the pond and water that can be used for irrigation purposes.

A disc filter was used to further remove pollutants and to provide a backup in case there were high levels of particulate matter. Water quality assessment for the performance of the filter from samples taken before and after the filter indicated acceptable irrigation quality water because the TSS was less than 5, specific conductance was less than 1000, and turbidity and fecal coliforms were low. The data and averages are shown in Table 39. The importance of the filter for removal of TSS was shown in the TSS data of 3/31/2011 when TSS was reduced from 13 to 4, and in the filter discharge sampling with time, which showed an improved water quality with time (see Table 40). The filter also provided for an additional level of treatment for those water quality conditions where there may be other unacceptable irrigation quality measures in the pond. The water quality data show the reliability of the filter for redundant effectiveness. The sampling of the water quality, as shown in Table 39, indicated marginal changes in the pollutants, which was expected since the quality of pond water is excellent.

Table 39. Comparison of Water Quality Before and After Filtration

(a) Before Filtration

Parameter	Units	5/13/10	8/17/10	12/21/10	1/31/11	3/31/11	5/5/2011	5/26/11	6/30/11
BOD_5	mg/L	U	U	U	U	U	U	U	U
Fecal Col.	CFU	432	520	50	40	440	U	80	460
S. Cond.	uS/cm	394	333	1220	421	459	427	427	408
Ammonia	mg/L	U	U	U	U	U	U	U	U
NO_x	mg/L	U	0.332	U	U	U	U	U	U
pH	#	7.94	8.06	9.36	8.35	8.15	7.63	8.33	8.09
Temp.	^oC	27.1	33.2	22.9	20.5	27.1	24.7	29.3	29.2
TKN	mg/L	0.738	0.323	U	0.34	1.22	1.14	U	0.924
T. Solids	mg/L	262	197	187	240	288	250	260	285
TP	mg/L	U	U	0.134	0.109	0.197	0.062	0.075	0.143
TSS	mg/L	2	3	2	2	13	2	3	22
Turbidity	NTU	1.03	1.05	1.36	1.21	2.51	1.38	0.86	1

U is undetected or Below Detection Limits (DL)

(b) After Filtration

Parameter	Units	5/13/10	8/17/10	12/21/10	1/31/11	3/31/11	5/5/2011	5/26/11	6/30/11
BOD_5	mg/L	U	U	U	U	U	U	U	U
Fecal Col.	CFU	248	480	350	U	260	20	40	20
S. Cond.	uS/cm	390	345	390	417	449	432	426	433
Ammonia	mg/L	U	U	U	U	U	U	U	U
NO_x	mg/L	U	1.23	U	U	U	U	U	U
pH	#	7.99	7.87	7.87	7.87	8.17	8.07	8.13	7.88
Temp.	^oC	27	32.8	20.2	22.6	25.8	27.7	27.9	27.4
TKN	mg/L	0.451	0.49	U	0.1	0.871	0.74	1.27	1.25
T. Solids	mg/L	267	196	215	248	256	250	251	248
TP	mg/L	U	U	0.081	0.095	0.104	0.065	0.051	0.091
TSS	mg/L	3	2	2	2	4	13	2	15
Turbidity	NTU	1.16	0.901	3.11	0.54	1.01	5.47	1	1.12

U is undetected or Below Detection Limits (DL)

Note: the only significant removal due to filtration was for TP, because the pond water quality was excellent or low in BOD, TSS, and nitrogen. The average TP in the intake to and the discharge from the filter was 0.120 mg/L and 0.081 mg/L respectively.

Table 40. Comparison of Filter Discharge Water Quality with Filtration Time

time from start			0 min	15 min	30 min
Parameter	Units	Inlet	6/30/11	6/30/11	6/30/11
BOD_5	mg/L	U	U	U	U
Fecal Col.	CFU	460	20	U	U
S. Cond.	uS/cm	408	433	405	407
Ammonia	mg/L	U	U	U	U
NO_x	mg/L	U	U	U	U
pH	#	8.09	7.88	8.17	8.19
Temp.	^oC	29.2	27.4	29.1	29.3
TKN	mg/L	0.924	1.25	1.38	0.873
T. Solids	mg/L	285	248	232	237
TP	mg/L	0.143	0.091	0.111	U
TSS	mg/L	22	15	U	2
Turbidity	NTU	1	1.12	1.16	0.81

The filter was operated over a 30 minute run time to detect if there were changes in water quality with filtration time, after the filter had not been in operation for more than a day. After the start of filtration, measurement with time was taken since during the first few minutes of filtration, filtered (discharge) water can have a higher concentration of some water pollution measures. The higher concentration results from a degradation of larger particulates on the filter and breakdown of some filter materials. Since all of the sampling for water quality up to this point was conducted after the filter was not operational for days, and the water quality was considered acceptable even at the start of filtration, additional samples were taken to document water quality changes with filtration run time. The results are shown in Table 40, and indicated, as expected, slightly higher concentrations at the start of the filter run for particulate constituents, such as TKN, TSS, and Turbidity. TKN is a measure for organic matter which can be particulate. Also noted was the significant decrease during this run time in fecal coliforms compared to inlet conditions. There was a relatively small decrease in total solids but that measure also includes the dissolved solids in suspension. Temperature at the start of filtration indicated the water was in a sheltered environment and not subject to the higher water temperatures of the pond. Thus, it is expected that the filter effectiveness with operation time will be greater than that reported in the filter sampling because the discharge from the treatment filter was sampled at the beginning of filter time operation. The disc filter is an option that should be considered for filtering wet detention pond water.

5.7 UP-FLOW FILTER

Location

The watershed location was chosen for demonstration because it had both state and local roads from which stormwater discharges into a large wet pond (better defined as a canal or lake) and there was a Department of Environmental Protection grant to test and construct methods for the reduction of nutrients and solids. In addition, there was an interest by Sarasota County to demonstrate a full scale up-flow filter with sorption media. The watershed was approximately 605 acres and included the 65 acre wet pond. There was only one discharge from the wet pond and sufficient room was available for treatment at the point of discharge. The drainage is into Alligator Creek in Sarasota County, Florida. A location map is shown in Figure 38.

Figure 38. Up-flow Filter Location in Sarasota County, Florida.

The UP-Flow Filter

The up-flow filter is part of a treatment train and is situated downstream of pre-treatment by anaerobic and aerobic ponds. The pre-treatment for the filter was necessary because of the form of the nitrogen. However, this pre-treatment is not always necessary and depends on the form of the nitrogen. The filter area included two (2) filter zones. First, the flow of water enters a submerged rock area that consists of an 8 FT deep coarse rock “pre-filter” that surrounds the up-flow filter (see construction photo is Figure 39). The rock filter area is constructed of No. 3 broken concrete and promotes a submerged flow of water, with higher flow bypass provided through the filter center rock channel. This area was designed to block large organic algal mats and other floating plant debris, but also functions as an “anoxic zone” that promotes denitrification processes as the water moves across and through the rock media.

Figure 39. Up-Flow Filter in a Pipe

The second portion of the up-flow filter is contained within four (4) 5 FT diameter pipes (see Figure 39). The up-flow filter contains a “robust” media (coarse media) system that operates on a very low filter surface application rate (0.16 to 0.50 GPM/SF), with a low pressure driving head (2-5 FT of hydraulic head). The interior of the up-flow filter includes a 12 inch depth of No 3 concrete rock and a 12 inch diameter pipe “plenum” area that is overlain by 24 inches of “Bold & Gold” sorption media.

The filter design features maximize media contact time and reduced clogging potential. It is important to understand that clogging of the up-flow filter is minimized by the characteristics of the media in the up-flow filter. The up-flow media is non-uniform 50% shredded tire and expanded 50% clay particles with a wet bulk density of about 61 Lbs/CF. The low bulk density allows for a “fluidization” of the media to further reduce clogging effects. The physical removal of solids is largely dependent upon capture of organic materials through physical sorption and pore blockage. As organic solids are captured in the void spaces of the filter, biological processes reduce the volume of volatile detritus materials along with the growth of bacterial and fungal biomass. Also, as the filter matures, the physical removal process will improve and filter effluent quality will improve.

Water Quality

Conclusions on water quality are based on seven samples. Four samples were taken during the wet and warm season (August-September), and three in the dry and cool season (January- February). The water quality of the wet detention pond reflected characteristic algal blooms in stagnant waters with high concentrations of organic nitrogen. The other forms of nitrogen were mostly below detection limits. The nitrogen form and elevated concentration level was more characteristic of a long residence time operating stormwater wet detention pond (or a highly eutrophic lake) than of stormwater itself. The average pond nitrogen levels for Total Nitrogen (TN) and Organic Nitrogen (ON) were 3.1 and 3.0, respectively. The ON was in a dissolved form. The nitrate plus nitrite concentration averaged 0.08 mg/L and were primarily below detection limits, while the ammonia concentration was always non-detectable. The average total phosphorus concentration was 0.24 mg/L, with less than 5% dissolved. The pH is over 8, with an average suspended solids and turbidity of 67 mg/L and 38 NTUs. These water quality conditions reflected why this pond water is difficult to treat for nitrogen removal.

The pre-treatment fermentation and aerobic ponds were not operational during the sampling period. One benefit of the non operation was to demonstrate removal during extreme loading conditions. When the fermentation (anaerobic) and aerobic ponds will be put in operation, the filter will reduce the nitrogen and solid levels further than they had without the pre treatment. The filter however, was not expected to remove organic nitrogen. The average water quality measures for the up-flow filter, based on seven samples and the conditions during the sampling are shown in Table 41. The % removal for suspended solids, turbidity, and total nitrogen was 40%, 47%, and 16%, respectively. There was no significant change in pH, total phosphorus and alkalinity. Average Total Phosphorus was less than 0.250 mg/L with 5% dissolved. The up-flow filter could be more effective once the pre-treatment fermentation and aerobic areas are in operation.

Table 41 Comparison of Water Quality Data for the Up-Flow Filter

	Suspended Solids (mg/L)	Turbidity (NTU)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Average Intake	66.7	38	3.1	0.24
Average Effluent	40.0	20	2.6	0.24
% Removal	40	47	16	none

5.8 RESULTS

Roadway runoff into wet detention ponds can be used and will meet irrigation water quality standards. A down-flow pipe media filter, pipe-in-pipe media, up-flow media filter, or disc filter can be used to improve water quality. In some cases, such as the pond on Interstate 75 at exit 7, the pond is a source of significant water supply. Cost data for the up-flow and down-flow filters shown an average cost to remove one pound of TN and TP to be around $115/day and $690/year using an interest rate of 4 % over 20 years (personal communication, Mark Flint with Watermark Engineering Group). Professionals from the City of Miramar, Watermark Engineering Group, GAI Consultants, and FDEP have all provided valuable assistance with these filters indicating the degree of interest within the profession.

CHAPTER 6 LINEAR SWALE DESIGN USING BIORETENTION AND BIODETENTION

6.1 INTRODUCTION

A swale is used to both infiltrate and transport runoff water. The swale is composed of an area adjacent to a roadway that infiltrates the runoff water and because of the need to protect the sub base of the roadway; the swale is dry in the surface layer. It remains dry more frequently than a retention pond which may contain water up to 72 hours after a runoff event. Once the water enters the bottom of the swale, the soil conditions are moist to wet. This wetness or ponding of water is typical provided there is no soil erosion problems caused by the slope of and soils in the transport ditch and swale, which results in an impermeable bottom. When runoff water is infiltrated along the slope of the swale and through the bottom, filtration helps in the removal of the solid fraction of the pollutants and when biosorption activated media (BAM) are used; additional particulate and dissolved fractions are removed. This filtered water can be used for irrigation and other reuse options.

6.2 APPLICATION OF A BIORETENTION AND BIODETENTION SWALE

To calculate a cost and estimate removals, an example application is used. In Chapter 3, it was shown the moisture content of a soil media can be enhanced and thus biological activity can be improved. The biological activity can result in a utilization of a pollutant provided the form of pollutant is available as an energy source and environmental conditions are suitable for the biological activity. In essence, removal of pollutants can be expected with higher moisture content. This enhancement of biological activity results in the use of the terms bioretention for high infiltrating areas and biodetention for low infiltration areas.

The results of the field and laboratory investigations presented in Chapter 3 are expanded to illustrate the concept and some calculations for design and pollution control credit. For convenience of demonstration, an example highway location has 1,000 feet of divided highway, without a median barrier, and is in Orange County, FL. The runoff discharges to a Class III receiving water body. The highway has three lanes in each direction for a total of six lanes; all runoff flows into a swale. BAM materials will be used in the bottom of the swale. In this example, without a median barrier present, it is required by design code to have a minimum median width of 60 feet (58). For this highway location, it is required for flood control purposes, that roadside and median ditches and swales be designed for a 10-year storm event (66). The swale system was designed as a trapezoidal shaped swale with a minimum slope for positive flow, meaning that the swale has a minimum longitudinal slope. A swale can be defined as detention with filtration (67). Section and plan views of the design are presented in Figure 40 and isometric views are shown in Figure 41. Note that these diagrams are actually drawings for the final design with some dimensions noted, and they are shown here to better illustrate the system.

The swale is to be composed of a swale bottom with Bold & Gold™ media, and an exfiltration drain pipe can be added for additional infiltration. A pipe can be added to promote the storage of runoff. Both the exfiltration system and the pipe or other storage system can discharge water during flood control conditions. If the water is stored after the pipe collection, it is assumed to irrigate seven acres of grass covered land. However, it should be noted that these areas are not specific or fixed, and any combination of storage and irrigation land can be used.

As a type of detention with a high moisture filer media, called BAM may be subjected to regulations for detention with filtration systems as used by the SJRWMD (67). It is assumed for this application, the treatment volume of stormwater is required to be detained in the basin, percolated through at least two feet of the natural or artificial treatment medium before entering the collection system, and then either discharged to a surface water body or reused. A minimum depth of two feet of media in detention with filtration systems is used and follows the requirement of the SJRWMD (67). The SJRWMD requires on-line detention with filtration systems, which discharge to Class III waters, to provide treatment for the first 1.5 inches of runoff from the total area or the first 3.0 inches from the impervious surface, whichever, is greater (68).

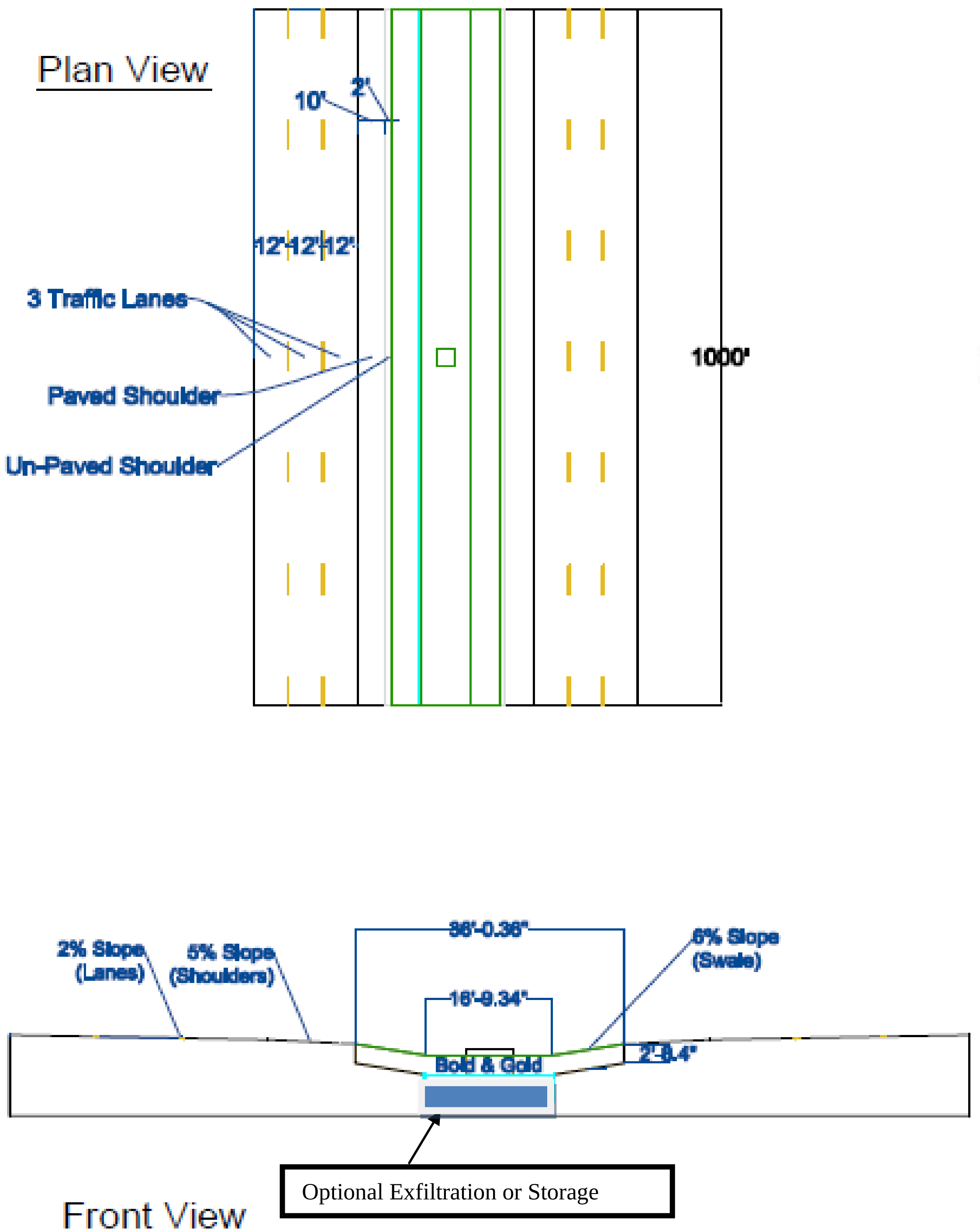

Figure 40. Section and Plan Views of Bioretention (Swale) and Biodetention (Reuse)

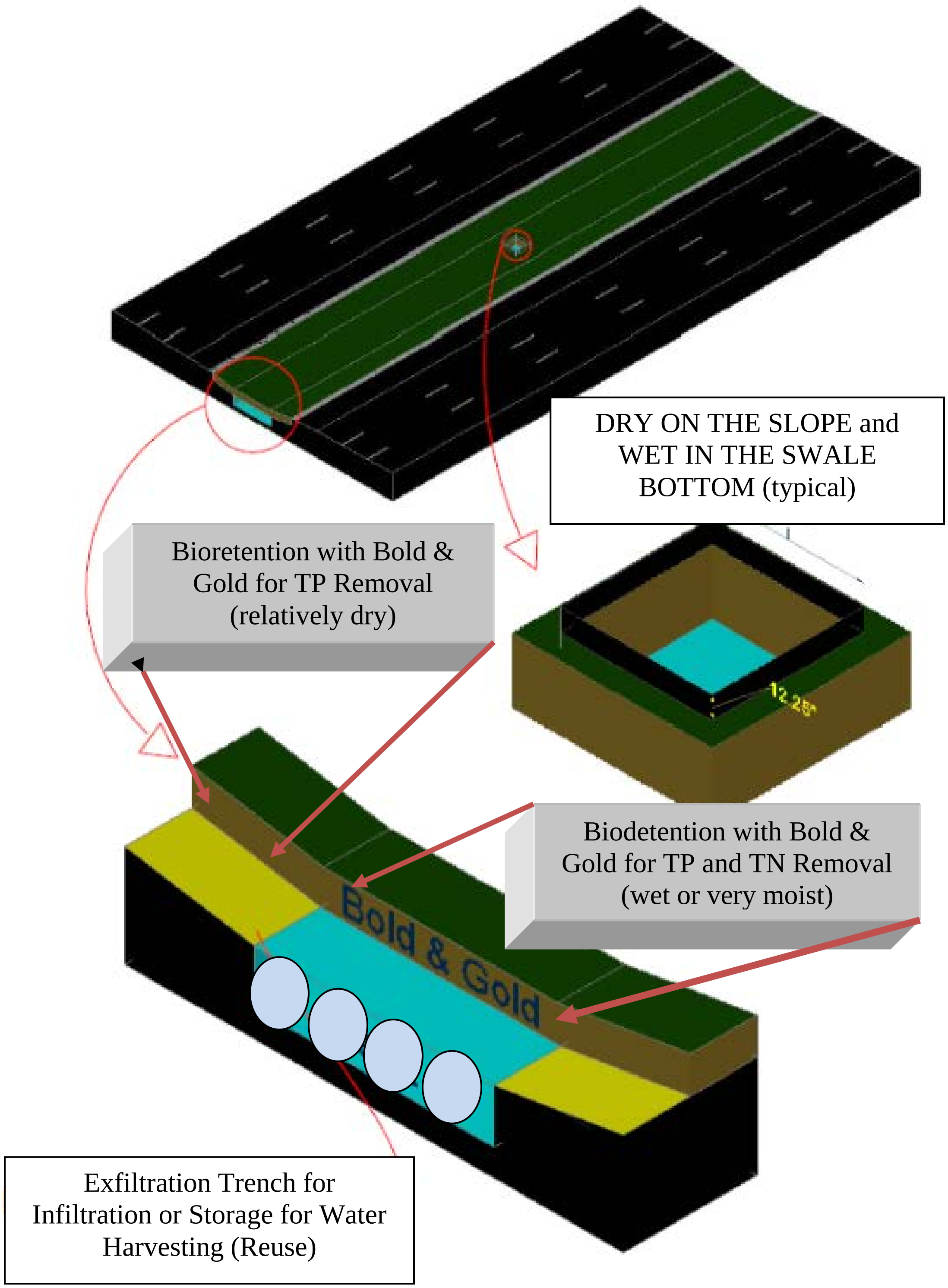

Figure 41. Isometric Views of a Bioretention and Biodetention Swale System

Designing the swale system dimensions for the roadway follows.

<u>Assumptions & Givens:</u>

- Bold & Gold™ media thickness: 2.7 feet (consistent with the depth in Chapter 3)

Note that in this design, the watershed is defined as the travel lanes, shoulders, and the swale itself.

- Trapezoidal shaped swale
  - Lies parallel to the roadway
  - Maintenance by commonly used equipment
  - Swale Freeboard (66): 0.5 feet
  - Side Slopes of Swale are the same as roadside slope: 1:6 (16.67%)
  - Maximum Recovery time is 72 hours
    - Use a Factor of Safety of 2
  - Unknowns:
    - Dimensions of Swale
    - Effectiveness
- Longitudinal Bed Slope of Swale (vertical/horizontal): 0%
  - The swale is designed for no positive flow and is a long narrow detention basin.
- The following roadway design characteristics are obtained from the Florida Department of Transportation <u>Plans Preparation Manual</u> (58).
  - Travel Lanes:
    - 3 lanes in each direction
    - Lane width: 12 feet
    - Cross slope of travel lanes (vertical/horizontal): 2%
  - Shoulder (note that only the shoulders adjacent to the median will drain to the swale)
    - Width of paved portion of shoulder: 10 feet
    - Width of unpaved portion of shoulder: 2 feet
    - Slope of Shoulder (vertical/horizontal): 5%

- Median:
  - The median width is the horizontal distance between the inside edges of the travel lanes of each roadway, thus the median includes the shoulders.
  - Required is a minimum median width of 60 feet for freeways that do not have a median barrier, with a design speed greater than or equal to 60 mph.
  - A design condition is that the width of the bottom of the detention basin had to be a minimum of 3 feet for maintenance purposes.
- Roadside and swale side slope (vertical:horizontal): 1:6 (16.67%)

6.3 DESIGN DETAILS FOR ESTIMATING COST AND EFFECTIVENESS

The design details for a roadway swale and collection are specified for calculating runoff rates and volumes in a publication by Hood (21). Highway dimensions were used to determine how much of the median is taken up by the shoulders and how much is available for the biodetention swale system. A summary is listed in Table 42.

Table 42. Highway Section Givens and Calculated Drainage Widths

Givens	
# of travel lanes	6
lane width (ft)	12
Cross slope of lanes	0.02
# shoulders adjacent to median	2
Width of paved portion of shoulder (ft)	10
Width of unpaved portion of shoulder (ft)	2
Slope of Shoulder	0.05
Median Width (ft)	60
Roadside Slope & Swale Wall Slope	0.167
Drainage Regions	**Width (feet)**
Travel Lanes "$D\_W_{travel\ lanes}$"	71.986
Paved Shoulders "$D\_W_{paved\ shoulders}$"	19.975
Unpaved Shoulders "$D\_W_{unpaved\ shoulders}$"	3.995
Bio-detention swale & harvesting System "$D\_W_{bio-detention\ swale}$"	36.030

The volume and intensity of runoff is important for design and estimation of flows and TMDLs, thus a summary is presented. The rainfall intensity for a 10-year, 1.35-hour storm in Orange County, FL is determined using the Florida Department of Transportation Intensity-Duration-Frequency (IDF) Curve for Zone 7. The rainfall intensity for the design storm event is shown in Table 43. A map of Florida IDF Curve zones and the IDF Curve for Zone 7 are presented, respectively, in Figure 42 and Figure 43.

Table 43. Intensities for the Design Storm Event

Design Storm	Design Intensity "i_D" (inches/hour)
10-year, 1.35 hour	2.6

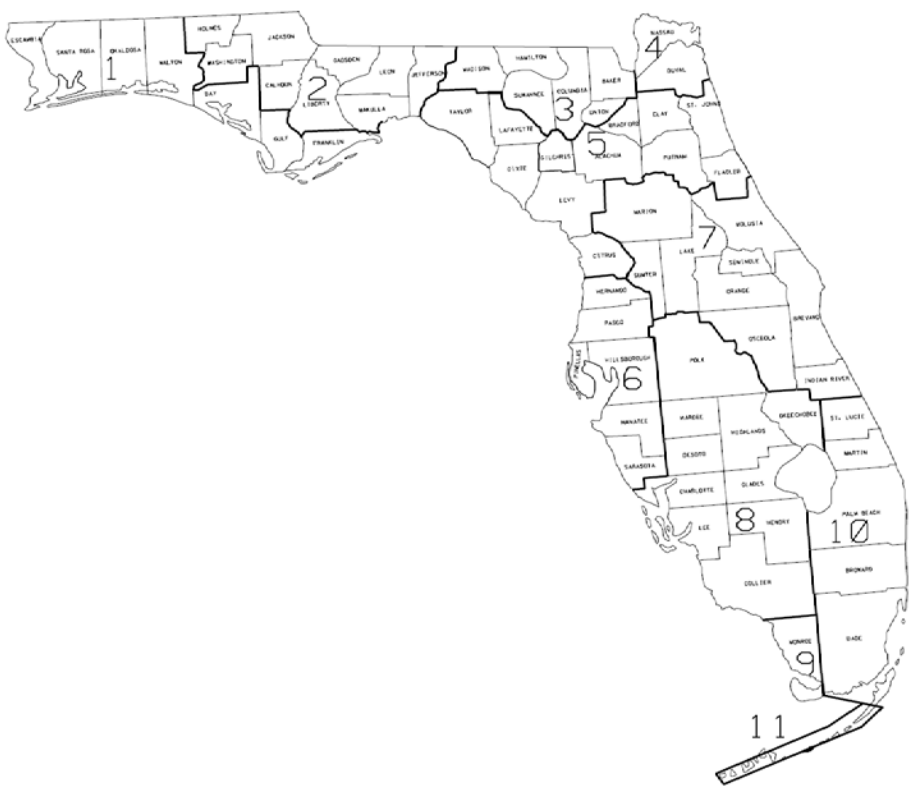

Figure 42. FDOT Zones for Precipitation IDF Curves (77)

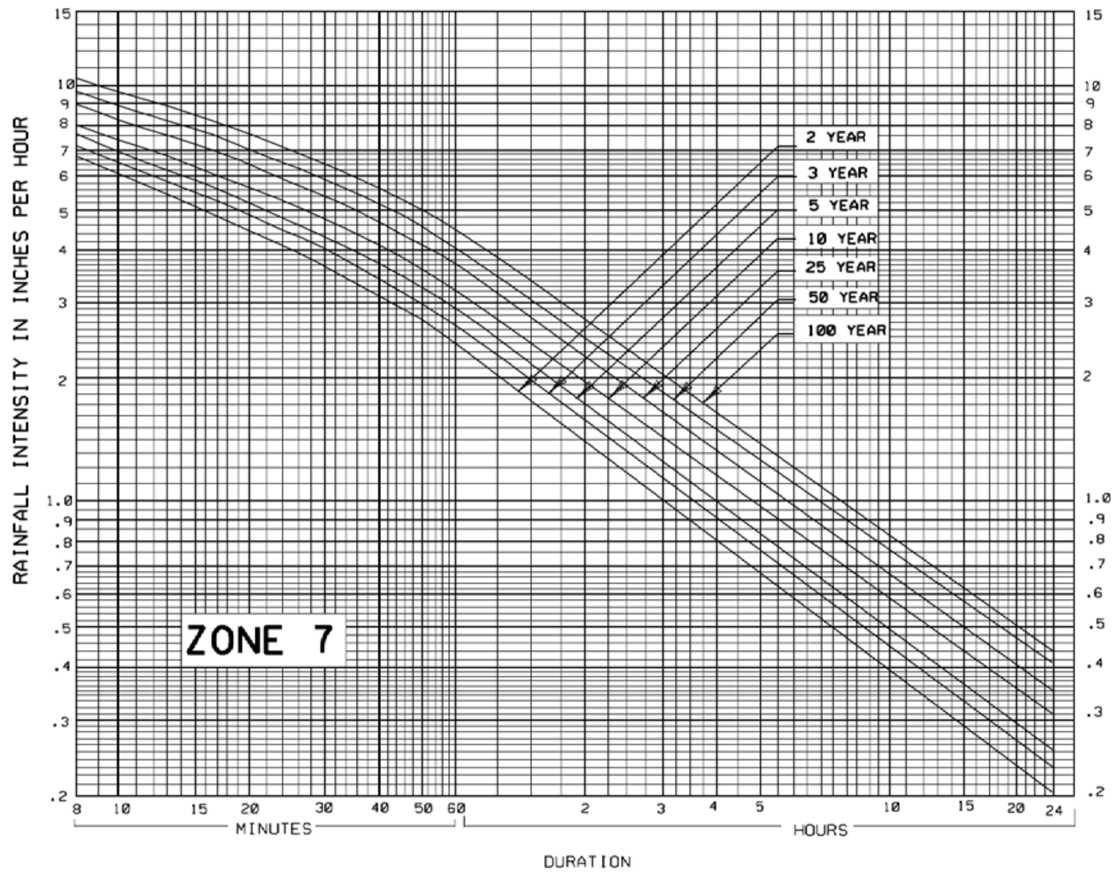

Figure 43. IDF Curve for Orange County, FL (77)

6.4 HARVESTING STORAGE VOLUME

In this example, water infiltrated must be reused. This situation results when there is a high water table or a reuse need. A water budget was used to determine the use rate and harvesting efficiency. The harvesting storage volume was found using the rate-efficiency-volume "*REV*" curve, the harvesting efficiency, and the use rate. The water budget was based upon the irrigation needs of 7 acres of land, and the additional total phosphorus removal needed to reduce the annual total phosphorus mass loading by 85%.

Equivalent Impervious Area for the REV Curve

The EIA is the equivalent impervious area that translates rain into runoff volume, thus creating water to be infiltrated or harvested. In the case of the biodetention swale system, the water harvested was created from runoff from the paved lanes, paved shoulder unpaved shoulder and all of the precipitation that falls on the biodetention swale, thus all of these regions shall be considered part of the EIA. This is because all of the precipitation that falls on the biodetention swale, neglecting the small amount that was stored in the media and evaporated, either initially infiltrates into the media and then travels through the media until entering the storage, or becomes runoff and is percolated through the media and into the storage as the treatment volume. Note that if a storm event exceeds the treatment volume, then the excess runoff is discharged via the swale. For the purposes of the harvesting design, the runoff exceeding the treatment volume was not considered since the first 3.0 inches of impervious runoff from a storm event is treated in the slope of the swale and is the treatment volume. The EIA of the biodetention swale system was calculated using Equation (27) and the resulting value is shown in Table 44.

$$EIA = (Length\ Roadway) * \left[(C_{travel\ lanes} * D\_W_{travel\ lanes}) + (C_{paved\ shoulders} * D\_W_{paved\ shoulders}) + (C_{unpaved\ shoulders} * D\_W_{unpaved\ shoulders}) + D\_W_{bio-detention\ swale} \right] \quad \textbf{(27)}$$

Table 44. Equivalent Impervious Area "*EIA*"

Knowns	
$D\_W_{travel\ lanes}$ (ft)	71.986
$D\_W_{paved\ shoulders}$ (ft)	19.975
$D\_W_{unpaved\ shoulders}$ (ft)	3.995
$D\_W_{bio-detention\ swale}$ (ft)	36.030
$C_{travel\ lanes}$	0.950
$C_{paved\ shoulder}$	0.950
$C_{unpaved\ shoulder}$	0.230
Length of Roadway (ft)	1000.000

Calculated	
Equivalent Impervious Area "EIA" (ft^2)	124311.415

Irrigation Rate

A seven acre turf grass requires irrigation of one inch per week (12). The irrigation rate was calculated using Equation (28) and was 3630.00 ft^3/day, see Table 45.

$$Irrigation\ Rate = (irrigation\ demand) * (Area\ to\ be\ irrigated) \quad \textbf{(28)}$$

Table 45. Irrigation Rate

Knowns	
irrigation demand (inch/week)	1
Area to be irrigated (acres)	7

Calculated	
Irrigation Rate (ft^3/day)	3630.00

Use Rate

The use rate is the volumetric rate at which the stormwater is used. The use rate is expressed as inches per day over the equivalent impervious area "*EIA*". The use rate is equal to the irrigation rate, assuming that the irrigation rate meets or exceeds the use rate needed to obtain the harvesting efficiency "*E*" needed for the required pollutant mass loading reduction. Thus the *REV* curve use rate is equal to the irrigation rate divided by the *EIA*, see Equation Error! Reference source not found.. The required use rate was 0.35 in/day for the *EIA* (Table 46).

$$Use\ Rate = \frac{Irrigation\ Rate}{EIA} \quad \textbf{(29)}$$

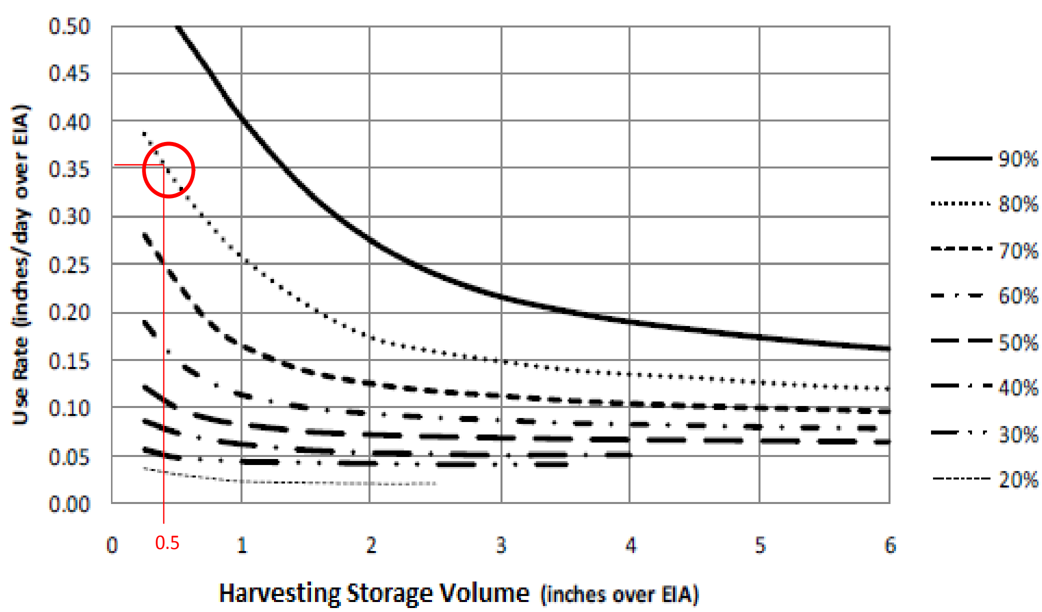

Figure 44. Rate-Efficiency-Volume Curve for Orange County, FL (76)

Table 46. Use Rate

Knowns	
Irrigation Rate (ft^3/day)	3630.00
Equivalent Impervious Area "EIA" (ft^2)	124311.415

Calculated	
Use Rate (ft/day on area equal to EIA)	0.029
Use Rate (in/day on area equal to EIA)	0.35

Determine the Harvesting Efficiency "*E*"

The biodetention swale system example design problem must reduce the annual total phosphorus mass loading by 85%, thus only 15% of the original mass of total phosphorus may be discharged. The Bold & Gold™, however, was expected to remove 71% of the total phosphorus from the stormwater entering the system. A mass balance was performed to determine the minimum harvesting efficiency "*E*" needed to achieve the required reduction in total phosphorus loading to the surface water body. The harvesting efficiency is the percentage of stormwater that is harvested and not discharged. The mass balance to obtain the minimum harvesting efficiency is shown in Figure 45 and was performed using Equations (30), (31), (32). The minimum harvesting efficiency "*E*" required to meet the pollutant removal requirement was found to be 49%. It should be noted that this is the minimum harvesting efficiency required to meet the 85 % pollutant removal criteria. A greater harvesting efficiency will be needed for a greater pollution removal. In this design, the 1,000-foot segment of biodetention swale was used to irrigate seven acres of grass-covered land. Upon inspection of the *REV* curve, see Figure 44, it was determined that a harvesting efficiency of 80% at a use rate of 0.35 in/day results in a minimum storage volume of 0.5 in/EIA. Since 80% is greater than 49%, the biodetention system achieved greater than 85% mass removal.

a)
$$\begin{aligned} Mass\ loading\ of\ \ pollutant\ discharged &= Concentration_{Influent} * Q_{Influent} * (1-0.85) \\ &= Q_{discharged} * Concentration_{Influent} * (1-0.71) \end{aligned} \quad \mathbf{(30)}$$

b) $$Q_{discharged} = \frac{(1-0.85) * Q_{Influent}}{(1-0.71)} \qquad \textbf{(31)}$$

c) $$Q_{harvested} = Q_{Influent} * \left[1 - \frac{(1-0.85)}{(1-0.71)}\right] \qquad \textbf{(32)}$$

In addition to swale retention, exfiltration pipes that add water to the ground can also be used. A mass balance flow diagram for options is shown in Figure 45.

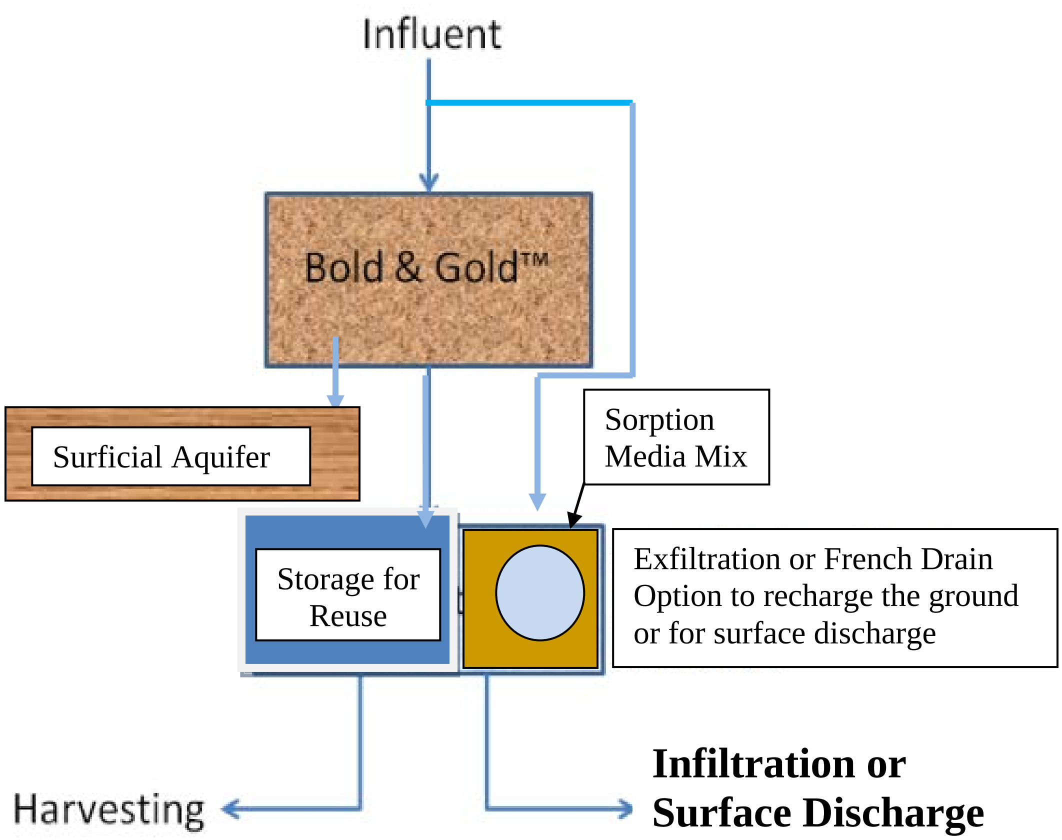

Figure 45. Mass Balance Options for Bioretention or Biodetention Swale System

6.5 HARVEST STORAGE VOLUME

The reuse of harvesting storage volume is the volume of water in storage for beneficial purposes. On the *REV* curve, the harvesting storage volume is given in units of inches over the equivalent impervious area. The harvesting storage volume is found using the *REV* curve, the harvesting efficiency, and the use rate. In the previous section, it was determined that a 0.5 in./EIA harvesting storage volume will be used. This is considered to be the lowest storage volume and thus will lower the cost of treatment. A lower volume may be possible and should be checked with the reviewing agency. The storage volume is about 5180 cubic feet, and is a 30 foot wide by 3 foot deep and about 60 foot long rectangular storage. The required harvesting volume in units of cubic feet is shown in Table 47.

Table 47. Harvesting Volume

Equivalent Impervious Area "EIA" (ft^2)	124311.4146
Use Rate (in/day on area equal to EIA)	0.350
Harvesting Efficiency	80%
Harvesting Volume (inches on area equal to EIA)	0.5
Harvesting Storage Volume (ft^3)	5179.642

6.6 SUMMARY OF BIORETENTION AND BIODETENTION DESIGN

Based on column tests, Bold & Gold™ used in the swale is expected to remove 71% of the total phosphorus concentration from the stormwater entering the swale. The phosphorus removal occurs either along the slope or in the bottom of the swale. Harvesting of the stormwater provides additional pollutant mass removal. A summary of important design dimensions and values for the particular site conditions of this problem are in Table 48. Section and plan views of the design were presented previously in Figure 40. Isometric views were shown previously in Figure 41

6.7 NOTES FOR MAINTENANCE

Sediment build up over time is likely to occur in storage, thus maintenance will be required periodically to remove the sediment. Access to the storage for maintenance should be considered when designing the biodetention swale with reuse system.

Maintenance of the swale system should use tractors that are as light weight as possible. Also, the weight of the tractors must be considered since the storage structure will have to support their weight. Furthermore, tractors used in bio-treatment systems should be equipped with turf tires in order to prevent damage to the vegetation.

Table 48. Design Summary

Roadside and Swale Side Slope	1 V : 6 H
Freeboard	6 inches
Media thickness	2.7 feet
Vertical distance from shoulder to bottom of basin	20.25 inches
Bio-detention swale & harvesting System "$D\_W_{bio\text{-}detention\ swale}$"	36 feet & 0.36 inches
Length of Swale Segment	1000 feet
# of travel lanes	6
lane width	12 feet
Cross slope of lanes	0.02
# shoulders adjacent to median	2
Width of paved portion of shoulder	10 feet
Width of unpaved portion of shoulder	2 feet
Slope of Shoulder	0.05
Median Width	60 feet
Harvesting Storage Volume	5179.642 ft^3

6.8 POUNDS REMOVED AND COST

Using the laboratory results for nutrient removal with Bold & Gold media, two systems for the removal of pollutants from a roadway are considered within this section, namely (1) bioretention area in a swale, and (2) biodetention using some form of storage for harvesting.

Using the highway example location and design section presented within this Chapter, the loading (pounds/year) of total phosphorus and total nitrogen and annual cost are estimated. For the estimation of runoff TN and TP loading, the EMCs were 1.64 mg/Land 0.22 mg/L respectively. Using 48 inches for average yearly runoff from the highway in the example of this Chapter and one side of the roadway (3 lane highway with a 10 feet shoulder) and for a 1000 feet long section of highway results in an average loading of about 19 pounds per year of TN and 2.5 pounds per year of TP. This loading is the discharge average annual loading without treatment.

Using the swale design procedure of the SJRWMD Applicants Handbook (75) and an infiltration rate of 2 inches/hour without any B&G, the annual average capture of the swale is 27%. Using B&G as a bioretention area and an infiltration rate of 5 inches per hour, (38.64 inches/hour was the initial infiltration rate shown in Table 14) the average annual capture is 54.5%. Thus the bioretention swale removes about 50% more than a regular swale constructed with A3 soil. In the actual testing presented in this Chapter, the B&G removed 100% more. However, if there were no concentration reductions caused by the bioretention of the swale, then the pounds removed by infiltration per year for TN and TP are 10.3 and 1.4 respectively. Note the infiltrated water also shows an additional phosphorus concentration decrease noted as 71% in Table 21. Also if the soil can maintain moisture and be saturated some time of the year, total nitrogen concentration reduction due to the BAM media should be at least 50% (91).

The cost of the B&G media for a bioretention area per 1000 feet is calculated assuming labor cost for installation is 50% more than the media cost. The depth of the media is 2.0 feet and the width of application in the swale is 4 feet. The product and installation cost per 1000 feet of highway for the BAM is estimated at $20,650. The yearly cost over 20 years with a 3 % interest rate is $1400. The cost per pound of TN and TP removed per year is about $135 and $1000 respectively. If additional total nitrogen concentration reduction is assumed at 50% (91) and phosphorus concentration reduction at 71% (table 21), then the TN average yearly removal is 14.7 pounds and the average yearly TP removal is 2.2 pounds. The cost per pound removed per year for TN is $95 and $636 for TP.

The other option when using swales is to collect water for reuse. For 1000 feet of 3 lane highway and continuing with the same design assumptions and location, the cost of a holding area and collection pipe installed is estimated as $23,800. This is based on a $1/gallon cost of a cistern (5179 gallons) plus the piping cost. The reuse provides 85% removal (Figure 44) or 16.2 pounds of TN removed per year and 2.1 pounds of TP removed per year. The average yearly cost based on 20 years of service life and a 3% interest rate is $1600/yr. Based on 85%, the average yearly cost for one pound of TN removal and one pound of TP removal is $100 and $760 respectively.

No data are available for removal on the use of sorption media (in particular Bold& Gold) when exfiltration pipe are used. When the data become available, it will be used to estimate per unit cost of removal.

CHAPTER 7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 INTRODUCTION

As the need to remove more nutrients from stormwater increases, innovative methods such as harvesting and filtration are introduced. Some will become part of a list of stormwater management methods in a "tool box". Some may not be cost effective. But all must be evaluated. Existing at the present time within regulations is the option to remove nutrients and other pollutants by using horizontal wells and sand filtration media. Other media may be available and this is a report on other filtration media called Biosorption Activated Media (BAM). Another constraint to using runoff water is that the natural groundwater adjacent to any source extraction, such as from a wet pond or from a horizontal well, must not be degraded or there must be a safe yield. To estimate the impact on the groundwater table, a computer model was developed and is labeled as the Stormwater Harvesting and Assessment for Reduction of Pollution (SHARP) model.

Most stormwater rules reference total nitrogen and total phosphorus. Typically, including in Florida, the rules require that "all stormwater treatment systems shall provide a minimum level of treatment sufficient to accomplish one of the following: (1) a percent reduction (typically 80%) of the post-development average annual loading of total nitrogen and total phosphorus from the project; or, (2) a reduction such that the post-development average annual loading of total nitrogen and total phosphorus does not exceed the nutrient loading from the project area's pre condition or the natural vegetative community types (10)."

The purpose of this work was to develop additional filtration options for the treatment of nitrogen and phosphorus found in stormwater and in particular those that would be helpful in pollution removal before harvesting. In addition, the options must address field operating conditions. The expectation is to provide these options consistent with current rules and regulations regarding stormwater treatment.

7.2 SUMMARY

If irrigation quality water is needed, which implies contact with humans, filtration is required. The water in storage (typically a stormwater wet pond) has to be treated by some form of filtration to provide a reliable level of water quality. Treatment considered within this report results from filtration media commonly called Biosorption Activated Media (BAM) and from disc filter technologies. When using BAM, the media was placed in a pipe (or suitable container) and wet detention water passed through the filter. The filter can be either a down-flow or up-flow configuration. Another option was to place the BAM in a pipe in a wet detention pond and draft the water through the pipe. The BAM pipe-in-pipe can then be moved from one location to another, and thus is considered to be a mobile treatment method. When using pipes, the options are called pipe-in-pipe treatment systems because of their practical configurations. A system for harvesting was also demonstrated for swales areas adjacent to roadways. The infiltrated water was improved when passed through BAM. The infiltrated water can also be collected by open compartments (exfiltration pipes) and the allowed to further percolate into the ground. The collection of excess water from a swale can also be done and that water reused.

Filtration media mixes were examined using laboratory columns. Ten mixes were examined for both removal and filtration rates. Others were tried but if the filtration rate was below about 5 inch per hour, they were not pursued for pollution removal. This rate was set based on economic considerations.

Three of the mixes were used in full scale treatment options. One mix was for a down-flow filter, another mix for an up-flow filter, and another for a mobile pipe-in-pipe filter. All demonstrated a successful operation but only after field corrections. For the down-flow filter, backwash systems had to be added. The up-flow filter needed only minor corrections for a lower flow rate. For the mobile pipe-in-pipe filter, the rate of filtration had to be reduced.

To predict the ground water levels, a computer model called SHARP was used and it was found to be easily calibrated and verified in the field. The model is spreadsheet based and is limited only by the ability to adequately define the input parameters.

A major concern of harvesting from a wet detention pond is the potential effect on the surrounding vegetation when the water in a wet detention pond is lowered. Thus, a computer model was developed and tested to determine the safe yield of a wet detention pond, as controlled by the harvesting schedule and the minimum ground water level at select points in the study area. This integrated surface and ground water model was used for Stormwater Harvesting and Assessment for Reduction of Pollution, and is thus called the SHARP model.

BAM filtration media mixes were laboratory tested for pollution removal and filtration rates. The laboratory work was conducted in columns and the media mix depth was equal to what was expected in a full scale operating filter. The medium mixes are then demonstrated in pipes placed in operation at existing wet detention ponds.

A wet detention pond in Tampa receiving runoff from an urban watershed composed of highways, parking lots, and buildings was the site of the down-flow filter. This down-flow media filter for water from the wet detention pond was successful in removing nutrients. It was installed with provisions for removing debris and with mechanisms to backwash the filter media. A reliable and redundant operation was possible because of the filter design and the provision for backwashing the filter. The discharges from the filter meet water quality standards.

A mobile pipe-in-pipe system was also demonstrated and application at a high rate of filtration showed to have marginal improvement in water quality. Therefore, a lower filtration rate was recommended.

The effectiveness of disc filtration using water from a wet detention pond in Miramar, Florida, was also reported. A disc filter was an alternative to BAM filtration and it did provide reliability and redundancy.

A swale filter system using BAM was also demonstrated and it removed more pollutants relative to Type A-3 soils. The water quality of the groundwater can be improved with the use of a BAM filter. The removal was especially significant with new sod. Also, a pipe or other storage area can be used to collect the filtrate from the swale, and then reuse the water before surface discharge. Example calculations for a swale were presented.

7.3 RECOMMENDATIONS

1) The water quality from harvesting (reusing) stormwater in wet detention ponds can be improved with BAM media filtration mixes.

2) BAM mixes should be considered for removing nutrients from stormwater runoff and nutrients remaining in wet detention pond water.

3) Phosphorus can be removed by sorption and in the presence or absence of oxygen. Nitrogen removal needs special conditions of enhanced moisture content and low dissolved oxygen as well as the proper form of nitrogen.

4) Media mix specifications must be based on the filtration rate and the target level of pollutant removal. Laboratory column tests can assist in determining the mix. Three different mixes were used in this report, one for a down-flow filter, one for an up-flow filter and the pipe-in-pipe, and one for swales.

5) A down-flow filter with a BAM mix achieved about 41 % reduction in total nitrogen and 76% reduction in total phosphorus. Clogging of the filter must be minimized and backwashing is recommended.

6) An up-flow filter also has to backwashed, but not as frequently as a down-flow one. The expected total nitrogen and total phosphorus removals are over 25% when the influent waters are high in dissolved organic nitrogen and low in phosphorus.

7) Mobile pipe-in-pipe filter flow rate must be adjusted in the field to meet the residence time conditions.

8) Disc filters are useful for polishing operations. For a high quality pond water in Miramar Florida, the filter was operated over a one year period and an additional removal of 33% Total Phosphorus was recorded.

9) The SHARP model can be used to predict the portion of reuse from runoff and groundwater. It can also be used to predict annual yields and safe yields based on draw down elevations adjacent to the pond.

10) Any of the filters can be used for inter-event treatment.

11) The use of BAM mixtures in swales will enhance the removal of nutrients. Total Nitrogen and Total Phosphorus removals are expected to be at least 50% and 71%. The cost of removing one pound of TN and one pound of TP using BAM in a swale is $95 per year and $636 per year respectively.

12) The cost for removing one pound of TN and TP using BAM in an upflow or in a down-flow filter is about $115 per year and $690 per year respectively.

13) When reusing 85% of rainfall excess from a storage area after a swale the cost for removing one pound per year of TN and TP is $100 and $760 respectively.

14) Additional testing for sorption mixes in ultra urban environments when BAM is used in exfiltration, tree wells, and baffle boxes is necessary.

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