Optimal Design of Stormwater Basins with Bio-sorption Activated Media (BAM) in Karst Environments – Phase I: Site Screening and Selection

FDOT Phase I Final Report

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DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation. Furthermore, the authors are not responsible for the actual effectiveness of these control options or for drainage problems that might occur due to their improper use. This report does not promote any specific use of any of these particular systems.

METRIC CONVERSION TABLE

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	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	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	Mg (or "t")

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

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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
Mg (or "t")	megagrams	1.103	short tons (2000 lb)	T

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

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per sq. inch	lbf/in^2

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16. Abstract

Anthropogenic activities within the Silver Springs springshed over recent decades may have contributed to elevated nutrient concentrations in stormwater runoff and groundwater, leading to the eutrophication of Silver Springs. To remove the nutrients from stormwater, Bio-sorption Activated Media (BAM) can be used. This is a report on Phase I research that includes examination of Highway runoff locations to determine which ones are appropriate for BAM-based filters before runoff waters enter karst regions. These highway locations typically are constructed in areas that have soils that do not remove dissolved nutrients. Fifteen stormwater basins within the Silver Springs springshed in Florida were screened based on cost and practical application criteria, with the end goal of selecting two test and two alternative stormwater basins for testing BAM-based Best Management Practices at the field scale in Phase II of this research.

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EXECUTIVE SUMMARY

The Florida Department of Transportation has been pro-active in developing and testing new, efficient, and environmentally friendly best management practices (BMPs) for the removal of nutrients. Bio-sorption Activated Media (BAM) is one of the BMPs by FDOT that assists in removing nutrients from stormwater runoff. BAM is made from recycled and natural mineral materials. The media are locally sourced and generally require less area to accomplish nutrient control in stormwater management relative to other options.

Nutrients are a growing concern in groundwater aquifers and springs throughout many areas in Florida. Over recent years, the nitrate-nitrogen concentration in many of Florida's aquifer springs has risen above 1 $mg \cdot L^{-1}$, which is considered higher than the 0.35 $mg \cdot L^{-1}$ threshold concentration in springs of the central Florida area. The study site for this project was the Silver Springs springshed, located in Central Florida. Silver Springs has one of Florida's largest spring flows and was one of Florida's earliest major tourist attractions, famous for its glass bottom boat tours. Tourism at Silver Springs has since been reduced because of dense algal blooms resulting from elevated nitrate concentrations.

The goal of this project identified as Phase I was to select two stormwater basins as test sites to utilize BAM treatment systems. The treatment systems will be constructed and tested in Phase II. In this project, two alternative stormwater basins were selected to be used as backup. Fifteen stormwater basins were initially selected for screening using a decision analysis support system based on multiple criteria. The criteria for selecting the stormwater basin sites included distance to Silver Springs, type of watershed, nitrogen concentration in stormwater runoff, watershed area, stormwater basin size, soil permeability, presence of karst features, and others. Extensive field campaigns including water quality sampling events, ground penetrating radar, standard penetration tests, and groundwater monitoring well construction were conducted to characterize the site, geophysical, and stormwater characteristics of each stormwater basin. Ultimately, SR 35 Basin 9b and SR 35 Basin 2 were selected as test sites for implementation of BAM treatment systems during Phase II. SR 35 Basin 3 and SR 35 Basin 5 were selected to be used as alternative sites during Phase II.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND OBJECTIVES

1.1 Background

State water management districts and the Florida Department of Environmental Protection (FDEP) have promulgated rules that require the Florida Department of Transportation (FDOT) to design stormwater management systems that address excess nutrients in stormwater runoff. One strategy for enhancing nutrient removal in stormwater basins is the incorporation of Bio-sorption Activated Media (BAM). BAM is defined as a solid media providing an environment for removal of water based nutrients by chemical, physical and biological means. A variety of BAM mixes were developed at the University of Central Florida (UCF) and under the support of DOT and FDEP. BAM assists in removing nutrients from stormwater runoff and generally requires less area to accomplish nutrient control in stormwater management relative to other options.

Nutrients, particularly nitrate, are a growing concern in groundwater aquifers and springs throughout many areas in Florida. The nitrate-nitrogen concentration in many of Florida's aquifer springs has risen above 1 $mg \cdot L^{-1}$ in recent years. This trend of increasing nutrient concentrations can be attributed to agricultural and urban land-use practices near groundwater recharge zones. A prime example of this is the Silver Springs area, located in Central Florida. Silver Springs is one of Florida's largest springs and is the source for the majority of flow in the Ocklawaha River and is the largest tributary of the St. Johns River (St. Johns Riverkeeper, 2014). Silver Springs was one of Florida's earliest major tourist attractions, famous for its glass bottom boat tours; however, these tours have since been abandoned due to eutrophication resulting from elevated nitrate concentrations, a decrease in flow rates resulting from excessive groundwater pumping, and a decline in the economy. Environmental degradation within the springshed over recent decades has resulted in nitrate-nitrogen concentrations more than 25 times higher than historic values. In addition, more than a 30% reduction in the spring flow from the long-term average (Silver Springs Restoration Plan, 2014) has been observed. These changes reveal that anthropogenic activities near the spring are having adverse effects on groundwater quality and in turn harming the quality and quantity of surface-water bodies. An aerial image of the eutrophication of Silver Springs is presented in Figure 1.

Figure 1: Eutrophication of Silver Springs State Park

In 2009, Silver Springs and the upper part of the Silver River were included in Florida's list of impaired water bodies submitted to the EPA. A total maximum daily limit (TMDL) was developed by 2012. FDEP proposed a formal target for achieving the water quality component of restoration by implementing a TMDL (Hicks and Holland, 2012). The TMDL was created through experimental research involving the relationship between nitrate concentrations and the growth of algae in Florida spring systems. Extensive data were collected from 1990-2007 and used to propose a target nitrate concentration for Silver River, which is now 0.35 $mg \cdot L^{-1}$. This concentration was chosen, such that it would precede the necessary concentration for extensive periphyton (a complex mixture of algae, cyanobacteria, microbes, and detritus) growth. The maximum monthly average nitrate concentration for 2000-2011 is 1.69 $mg \cdot L^{-1}$, meaning a reduction of 79% is required to meet the target nitrate concentration. One proposed explanation for the elevated nitrate concentrations is a decrease in spring discharge over recent years. A decrease in spring discharge means the nitrate will be more concentrated throughout the river due to a decrease in total water volume. Also, a decrease in the flow velocity may result in stagnant areas throughout the river, which, when combined with elevated nitrate concentrations, is the prime environment for harmful algal blooms. However, observations of spring discharge and nitrate concentrations show the relationship is not statistically significant and elevated concentrations are likely attributed to surrounding land use practices, which increase nitrogen loading to the landscape. These land use practices include, but are not limited to, citrus trees, pastures, golf courses, nurseries, residential areas, horse farms, domestic wastewater facilities, and on-site wastewater treatment (a.k.a. septic tanks).

Stormwater is a relatively untapped resource when it comes to meeting today's freshwater demand. Stormwater, if properly treated and managed, could provide an alternative source of freshwater for multiple uses. Proper management to reduce nitrogen concentrations within groundwater aquifers, lakes, and springs is essential to meet freshwater demands and can be accomplished in many ways, such as stormwater retention basins and/or injection wells with underground natural or constructed treatment systems. The addition of BAM to existing treatment strategies can provide effective treatment and storage of stormwater from a variety of roadway systems. This strategy can help reduce stormwater impacts, decrease transportation costs and water loss due to evaporation. If a stormwater basin is sized based on nutrient removal standards, incorporation of a BAM treatment system can decrease the required size of the stormwater basin, resulting in decreased construction and maintenance costs and a smaller environmental footprint. The goal of this research is to provide another flexible treatment option for nutrient reduction in impaired springshed areas, though applications of BAM. Developing nutrient control or removal plans via a BAM treatment system will contribute to restoring the Silver Springs watershed by reducing nitrogen concentrations, with the hope it may again one day be enjoyed by tourists and the people of Florida. An image of the approximate extent of the Silver Springs springshed is presented in Figure 2.

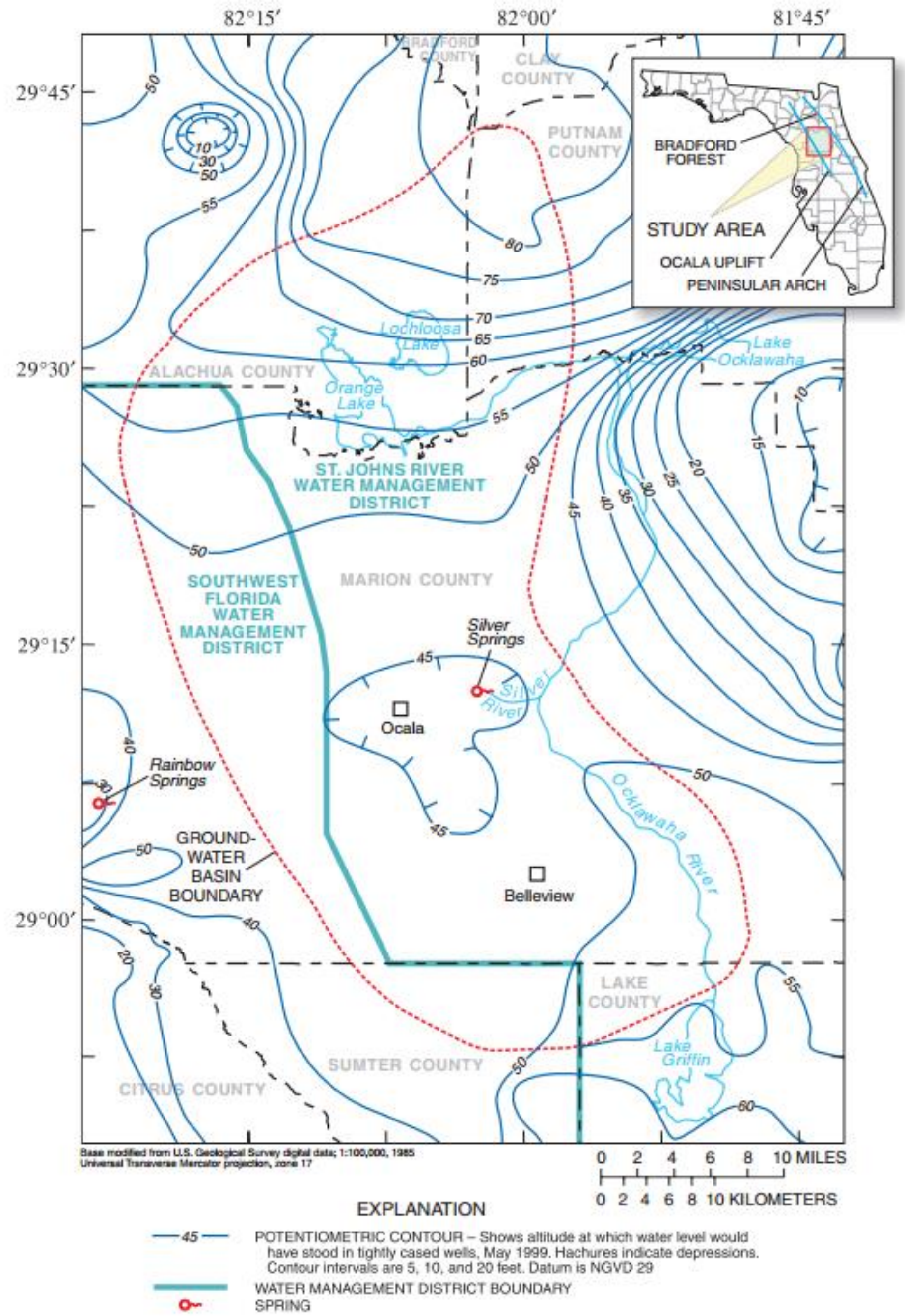


Figure 2: Silver Springs Springshed as delineated by Phelps (2004)

1.2 Objectives

In this Phase I study, the project objectives are to investigate 10 potential stormwater basins and select two of them within the Silver Springs springshed for future work in Phase II. This selection will aid in the future investigation of the optimal design, construction, and operation strategies at the BAM-retrofitted stormwater basins during Phase II. The site screening process in the scope of Phase I is robust enough to present two candidate stormwater basins that are ready to be retrofitted and tested in Phase II. In addition to recommending two stormwater basins, two additional basins will be selected as alternative sites, in case unforeseen circumstances render a primary site unusable. Field surveying of the selected final four stormwater basins will include testing of permeability using double-ring infiltrometer, geological borings in the neighborhood of the selected stormwater basins, and ground penetrating radar (GPR) scanning transects of the stormwater basins to document changes in soil types and confining layers to support possible BAM-based BMPs. Examples of BMPs using BAM for this area include curtain walls, and exfiltration pipes or French drains, in Phase II. A curtain wall, also referred to as a permeable reactive treatment zone, is a remediation technology that has been recognized as being cost-effective for *in situ* stormwater treatment.

Water quality sampling was accomplished after a storm event at those stormwater basins having water in them. This was done to give some confidence that nitrogen levels will be high enough to measure nitrogen reduction in a BAM-based treatment assessment schedule in Phase II of this research. Specifically, the UCF team plans to answer the following questions within this Phase 1 effort:

1) Is the stormwater basin accessible for construction and is construction acceptable to the surrounding community?

2) Is the site in a Karst area in terms of geological conditions and infiltration rates?

3) Can the sites be configured to provide a BAM-retrofitted stormwater method, or even multiple BAM configurations consisting of curtain walls and pipe based treatment construction and testing in Phase II?

4) Does the site have sufficiently high nitrate concentrations to result in measurable reductions after BAM-based treatment?

2. TASK 1

The primary goal in Task 1 was to collect initial information to support the site screening and ranking in Task 2. Fifteen (15) candidate stormwater basins in potential karst areas of Marion County to include those along interstate highway 75, SR 35, SR 40, and SR 200 and two within residential areas were evaluated. All sites were within the groundwater boundary or springshed of Silver Springs. Five sites were eliminated because of construction work that may be implemented within the stormwater basins or adjacent to them.

2.1 Site Selection and Screening

The ranking of the remaining 10 potential stormwater basins was based on a multi-criteria decision making process. Two stages of the decision analysis were organized and used during the project. The first stage helped rank the 10 candidate stormwater basins, whereby the second stage was utilized to narrow down and select the two candidate stormwater basins and two alternative basins for Task 2. The first stage analysis was based on selected criteria that best addressed the future goals of the project. The selected criteria included basin size, contributing watershed area, water quality (TN concentration), type of watershed or land use, distance to Silver Springs, ease of access, groundwater table depth, and soil permeability. Ten site visits were made to evaluate the 10 remaining potential stormwater basins, with considerations made according to the criteria previously discussed. Visits to the FDOT Ocala Operations office were made to meet the FDOT employees and discuss the project, as well as to obtain engineering plans for some of the stormwater basins. Table 1 presents the 10 candidate stormwater basins screened in Task 1. Available plan-view drawings for eight of the stormwater basins are presented in Appendix A. The SR 40/41 and Lake Weir basins were not considered for further review because of potential conflicts with adjacent land owners.

Table 1: Candidate stormwater basins

Criteria	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 4	SR 35 Basin 5	SR 35 Basin 9a
Basin Type	Dry Bottom	Dry Bottom	Dry Bottom	Dry Bottom	Dry Bottom
Basin Size (acres)	2.88	1.51	3.34	0.99	0.30
Watershed Size (acres)	51.16	23.57	93.02	21.78	5.31
Criteria	**SR 35 Basin 9b**	**SR 35 Basin 1**	**SR 35 Basin 8**	**SR 40/41**	**Lake Weir**
Basin Type	Dry Bottom	Dry Bottom	Dry Bottom	Dry Bottom	Dry Bottom
Basin Size (acres)	0.73	1.84	4.04	2.0	0.15
Watershed Size (acres)	5.31	6.27	55.07	1.5	4.0

Preliminary ranking of the 10 candidate stormwater basins is based on eight (8) selection criteria and uses a set of weighting factors to account for the inherent importance of each criteria. The criteria and their weighted values are presented in Table 2. The weighting factor selection is considered to be more reflective of the relative value of each, however, the one with equal weight (i.e., 0.125 for each equally to derive non-weighted values) is used as basis to compare results against the counterpart of different weight. The following bullets provide the weighted value assigned to each criteria and justification for why that value was assigned.

- Ease of access and water quality data (TN concentration) were given the largest weighting factor (0.25). This weight (0.25) is considered to be twice as important as an equal weight ($2 \times 1/8$). Ease of access is important because if construction equipment cannot access the stormwater basin without future construction or permits then future work will be difficult if not possible. Also, if nitrogen concentrations are not high enough in the stormwater runoff then future work documenting BAM removal effectiveness will be more difficult to measure.

- The next highest weighting factor (0.125) was given to distance to Silver Springs and basin size. These criteria are important because Silver Springs is the impaired springshed of interest and the stormwater basin must be large enough to accommodate construction activities. Also the closer the basin is to Silver Springs, the more likely it is for nitrogen to reach the Silver Springs with minimal removal due to ground conditions. Also, stormwater basins that are closer to Silver Springs are considered more favorable for treatment as they have more influence on improving the quality in the Silver Springs River.

- The final weighting factor (0.0625) was given to contributing watershed area, type of watershed (land-use), groundwater table depth, and soil permeability. These criteria were considered to have less of an impact on ranking because the type of watershed and its area will have minimal effect on future construction at the stormwater basins but it is recognized that each affects the volume of runoff, which is an important parameter when measuring effectiveness of removal during the operation of the BAM. All of the watersheds for the candidate stormwater basins can be classified as roadways with some mixed residential/commercial land use and the contributing watershed size for each candidate stormwater basin is large. Depth to the groundwater table and soil permeability data were based on previous data obtained from consultant reports (PSI, 2009).

  When geological borings and GPR are performed at selected stormwater basins, the groundwater table depth and soil permeability data will become more valuable when selecting the two stormwater basins to be retrofitted with BAM.

Table 2: Criteria weighted and non-weighted values

Criteria	Weighted Values	Non-Weighted Values
Water Quality	0.2500	0.125
Ease of Access	0.2500	0.125
Distance to Silver Springs	0.1250	0.125
Basin Size	0.1250	0.125
Type of Watershed	0.0625	0.125
Watershed Area	0.0625	0.125
Groundwater Table Depth	0.0625	0.125
Soil Permeability	0.0625	0.125

The ranking system for each criteria uses a descriptor: poor, fair, good, and excellent and corresponding score value for each descriptor: 1, 2, 3, and 4 respectively. Stormwater basins with higher total scores are considered more suitable for the project, while stormwater basins with lower scores are not. A summary of the descriptors, score values, and the criteria ranking system are presented in Table 3. Stormwater basins that received a poor rating for total nitrogen (TN) concentration did not have any water present in the basin during site visits. No water does not necessarily imply now nitrogen concentrations but does imply low water volumes entering the basins which can limit the effectiveness of the analysis. The type of watershed correlates to the quantity of stormwater runoff that will be generated. Roadways will generate more runoff when compared to grassy areas, therefore watersheds containing primarily impervious surfaces were given more preference. Water samples collected from candidate stormwater basins with higher concentrations of TN (generally greater than 1 $mg \cdot L^{-1}$) were given preference to ensure there are sufficient nutrient levels that justify future BAM work. Larger watersheds and basin sizes were given preference as they will generate more stormwater runoff and be able to accommodate future construction activities respectively.

Table 3: Criteria ranking system

Descriptors	Score Awarded	Distance to Silver Springs	Type of Watershed	TN Conc.	Watershed Area
Poor	1	15-20 miles	Grassy Areas	No Data	<1 acre
Fair	2	10-15 miles	Residential	<0.5 mg/L	1-5 acres
Good	3	5-10 miles	Mix Type	0.5-1 mg/L	5-10 acres
Excellent	4	0-5 miles	Roadways	>1 mg/L	>10 acres

Descriptors	Score Awarded	Groundwater Table Depth	Basin Size	Soil Permeability	Ease of Access
Poor	1	>25 feet	0-0.25 acres	No Data	Not Accessible
Fair	2	20-25 feet	0.25-0.5 acres	0-5 ft/day	Minimal Access
Good	3	15-20 feet	0.5-1 acres	5-10 ft/day	Moderate Access
Excellent	4	0-15 feet	>1 acre	>10 ft/day	Easily Accessible

Utilizing the criteria weighting and descriptor score value systems each candidate stormwater basin is assigned a total score to be used in Task 2 and subsequent work. The descriptors for each candidate stormwater basin and total score awarded to that stormwater basin are presented in Table 4a (weighted criteria) and 4b (non-weighted criteria). The non-weighted scoring of each stormwater basin is included simply for comparative purposes if a weighting factor had not been utilized for each criteria. Non-weighted results represent the case of equal weight over all different criteria, in which no preference was emphasized cross those criteria. The highest score a stormwater basin may receive is 4, meaning it was awarded excellent for all criteria. The lowest score a stormwater basin may receive is 1 meaning it was awarded poor for all criteria.

Table 4a: Weighted candidate basin total scores

Criteria	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 4	SR 35 Basin 5	SR 35 Basin 9a
Basin Size	Excellent	Excellent	Excellent	Good	Fair
Watershed Area	Excellent	Excellent	Excellent	Excellent	Good
Water Quality	Excellent	Excellent	Poor	Excellent	Poor
Type of Watershed	Excellent	Excellent	Excellent	Excellent	Excellent
Distance to Silver Springs	Excellent	Excellent	Excellent	Excellent	Excellent
Ease of Access	Excellent	Excellent	Fair	Excellent	Excellent
Groundwater Table Depth	Poor	Poor	Good	Poor	Excellent
Soil Permeability	Fair	Fair	Good	Poor	Good
Total Weighted Score	3.69	3.69	2.63	3.50	2.88

Criteria	SR 35 Basin 9b	SR 35 Basin 1	SR 35 Basin 8	SR 40/41	Lake Weir
Basin Size	Good	Excellent	Excellent	Excellent	Poor
Watershed Area	Good	Good	Excellent	Fair	Fair
Water Quality	Poor	Poor	Poor	Poor	Poor
Type of Watershed	Excellent	Excellent	Excellent	Good	Good
Distance to Silver Springs	Excellent	Excellent	Excellent	Poor	Fair
Ease of Access	Excellent	Poor	Poor	Good	Poor
Groundwater Table Depth	Excellent	Poor	Poor	Poor	Poor
Soil Permeability	Good	Poor	Poor	Excellent	Excellent
Total Weighted Score	3.00	2.06	2.13	2.25	1.50

Table 4b: Non-weighted candidate basin total scores

Criteria	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 4	SR 35 Basin 5	SR 35 Basin 9a
Basin Size	Excellent	Excellent	Excellent	Good	Fair
Watershed Area	Excellent	Excellent	Excellent	Excellent	Good
Water Quality	Excellent	Excellent	Poor	Excellent	Poor
Type of Watershed	Excellent	Excellent	Excellent	Excellent	Excellent
Distance to Silver Springs	Excellent	Excellent	Excellent	Excellent	Excellent
Ease of Access	Excellent	Excellent	Fair	Excellent	Excellent
Groundwater Table Depth	Poor	Poor	Good	Poor	Excellent
Soil Permeability	Fair	Fair	Good	Poor	Good
Total Non-Weighted Score	3.38	3.38	3.13	3.13	3.13

Criteria	SR 35 Basin 9b	SR 35 Basin 1	SR 35 Basin 8	SR 40/41	Lake Weir
Basin Size	Good	Excellent	Excellent	Excellent	Poor
Watershed Area	Good	Good	Excellent	Fair	Fair
Water Quality	Poor	Poor	Poor	Poor	Poor
Type of Watershed	Excellent	Excellent	Excellent	Good	Good
Distance to Silver Springs	Excellent	Excellent	Excellent	Poor	Fair
Ease of Access	Excellent	Poor	Poor	Good	Poor
Groundwater Table Depth	Excellent	Poor	Poor	Poor	Poor
Soil Permeability	Good	Poor	Poor	Excellent	Excellent
Total Non-Weighted Score	3.25	2.38	2.50	2.38	1.88

After field verification and the multi-criteria decision analysis (see Table 4), it was decided that SR 35 Basin 2, SR 35 Basin 3, SR 35 Basin 5, and SR 35 Basin 9b be considered for additional investigation during Task 2. These stormwater basins represent candidate sites that scored highly in the decision analysis system, and more specifically, SR 35 Basin 9b offered a final treatment zone for groundwater before it is discharged to Silver Springs.

2.2 Number of Site Visits and Water Quality Data

Site visit dates and activities related to screening in the study area are presented in Table 5.

Table 5: Basin site visits

Visit Number	Date	Purpose
1	2/25/2015	Initial screening of sites along I-75, SR 40 west of I-75 and SR 200
2	2/27/2015	Remaining screening of sites along SR 40 east of I-75 and SR 35
3	3/3/2015	Confirmation visit to determine wet conditions and residential site visits
4	3/5/2015	Reduction of sites based on design data and confirmation of 15 sites
5	3/25/2015	Further screening to reduce sites to 10 based on design data
6	3/26/2015	Confirmation visits to determine logistics and access to sites
7	4/9/2015	Soil sampling to visual confirm data at 10 sites
8	4/15/2015	Site investigation and water/soil sampling
9	4/20/2015	Visit FDOT office and site visit/sampling
10	4/29/2015	Site Investigation and water sampling

Water quality samples were taken during site visits at candidate stormwater basins, if water was present. This was done to provide a better understanding of the stormwater infiltration characteristics in the Silver Springs springshed, as well as to be reasonable certain nitrogen concentrations were present in sufficiently high concentrations for future BAM related studies. Samples were analyzed at the University of Central Florida with a Hach machine, utilizing the Persulfate Digestion Method (method #10071) for TN and the USEPA PhosVer 3 with Acid Persulfate Digestion method (method #8190) for total phosphorus (TP) (EPA Compliant Methods, 2015). Results of water quality analyses are presented in Table 5. Two samples were taken for each location during site visits; the averaged concentration and corresponding standard deviation is presented in Table 6. SR 35 Basin 2 was completely dry during the April 20, 2015, site visit.

Table 6: Water quality sampling results

	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 5
Date	4/15/2015	4/15/2015	4/15/2015
TN ($mg \cdot L^{-1}$)	2.6 ± 0.5	1.2 ± 0.8	1.3 ± 0.7
TP ($mg \cdot L^{-1}$)	2.59 ± 1.29	1.20 ± 0.21	1.11 ± 0.21
Date	-	4/20/2015	4/20/2015
TN ($mg \cdot L^{-1}$)	-	1.4 ± 0.4	1.4 ± 0.1
TP ($mg \cdot L^{-1}$)	-	2.18 ± 1.87	1.18 ± 0.13

Initial sampling showed promising results and revealed the average concentration of TN in basin water at SR 35 Basin 2, SR 35 Basin 3, and SR 35 Basin 5 was above 1 $mg \cdot L^{-1}$. This result was also considered in the multi-criteria decision support system. A comparison of SR 35 Basin 3 from the April 15 to April 20, 2015, site visits is presented in Figure 3. Figure 3 shows the infiltration capacity of SR 35 Basin 3 over a time period of five days.

Figure 3: SR 35 Basin 3 on April 15 (left) and April 20 (right)

Images of SR 35 Basin 5 are presented in Figure 4. The watershed as well as the basin conditions during the April 15, 2015, site visit can be seen in Figure 4. SR 35 Basin 2 is presented in Figure 5. On the April 15 site visit there was a small quantity of water present in the inlet pipes of SR 35 Basin 2, however, on the April 20 site visit there was no water present in the stormwater basin. Lastly, SR 35 Basin 9a/9b can be seen in Figure 6. There was no water present in SR 35 Basin 9a/9b during either the April 15 or April 20, 2015, site visits. It is interesting to note that SR 35 Basin 9a/9b is located directly across the street from the Silver Springs State Park and recreational water park slides could be seen from the roadway during the site visits.

Figure 4: SR 35 Basin 5 watershed April 15 (left) and April 20 (right)

Figure 5: SR 35 Basin 2 (same dry condition all visits)

Figure 6: SR 35 Basin 9a (left) and SR 35 Basin 9b (right) (same dry condition all visits)

3. TASK 2

The primary objective of Task 2 was to further investigate four stormwater basins selected in Task 1. The four stormwater basins chosen for additional investigation include SR 35 Basin 2, SR 35 Basin 3, SR 35 Basin 5, and SR 35 Basin 9b. The selection of these four stormwater basins was based on multiple criteria and their attractiveness for potential BAM application during Phase II. Work performed at these four stormwater basins during Task 2 included collection of surface layer soil samples via hand auger drilling, double ring infiltrometer readings, GPR analysis, and mechanical soil borings/groundwater monitoring well construction at two of the four stormwater basins. The following sections provide a discussion of the pertinent findings.

3.1 Preliminary Soil Sampling

Soil samples were collected from the four stormwater basins on April 15, 2015, using a hand auger. These samples were tested using a sieve analysis to document the soil characteristics near the ground surface. The soil samples collected contained a distribution of soil from the ground surface to a depth of roughly four feet. The soil characteristics near the ground surface are important because they disclose essential soil characteristic for determining water retention and infiltration rates through the top soil layer. Understanding these characteristics is vital to the process of selecting the two stormwater basins for BAM application during Phase II and reveal why some stormwater basins held water (ponded environments) and others were dry during the site visits. The results of the sieve analysis on soil collected from each of the four stormwater basins is presented in Figure 7. Soil characteristics obtained from the sieve analysis are presented in Table 7.

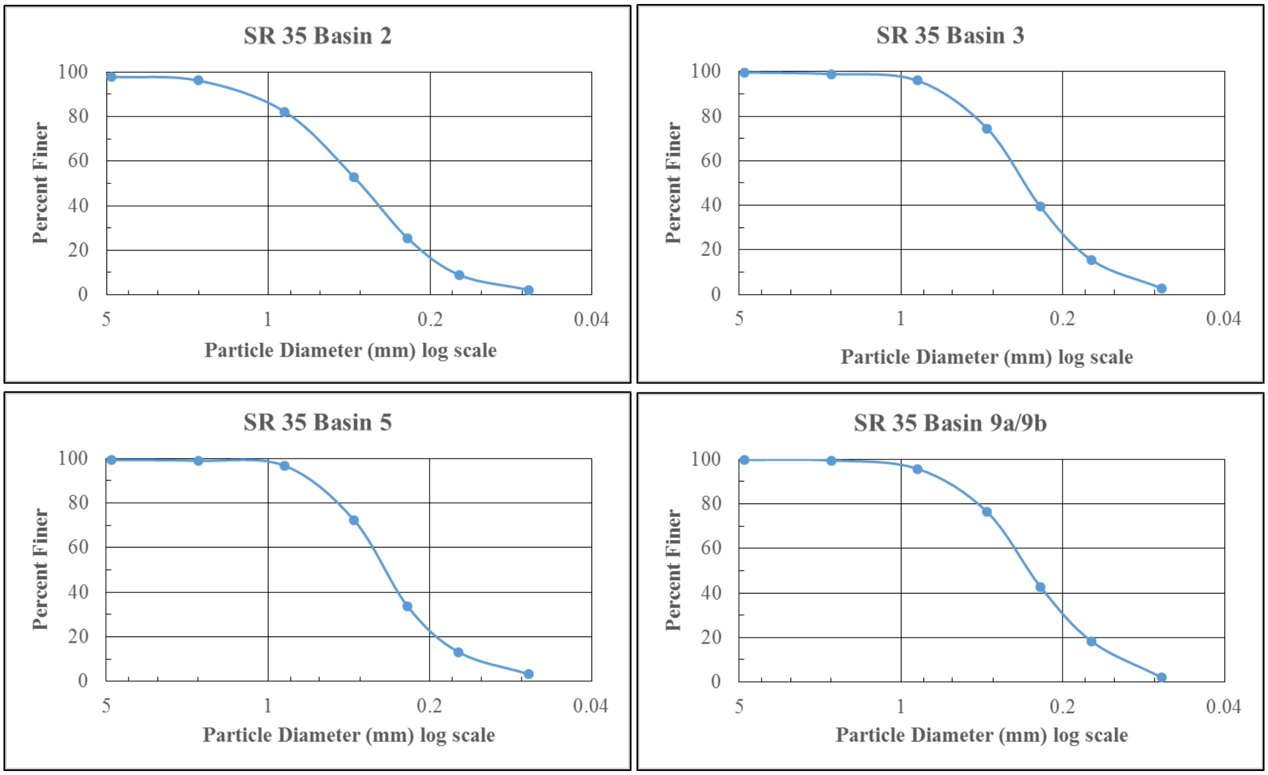


Figure 7: Sieve analysis results

Table 5: Upper soil characteristics

	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 5	SR 35 Basin 9a/9b
d_{60} (mm)	0.52	0.37	0.38	0.35
d_{30} (mm)	0.30	0.22	0.24	0.20
d_{10} (mm)	0.16	0.12	0.13	0.11
Uniformity Coefficient (C_u)	3.25	3.08	2.92	3.18
Coefficient of Gradation (C_c)	1.08	1.09	1.17	1.04
Soil Classification	SP	SP	SP	SP

Based on interpretation of sieve analyses, the soil found between the ground surface and a depth of four feet can be classified as poorly graded sand with little or no fines (SP) for each of the four stormwater basins. The similarity of the soil types to a depth of four feet suggests the soil causing water to be retained or infiltrated is likely found at depths greater than four feet, or other soil properties exist to reduce infiltration rates. These other properties were investigated using GPR and mechanical soil borings. The uniformity coefficient (C_u) for these soil samples ranges from 2.92 to 3.25. The coefficient of gradation (C_c) of the soil samples ranges from 1.04 to 1.17. In order for a sand to be classified as well graded, the following criteria must be met, $C_u \geq 6$ and 1

$< C_c < 3$; thus, these samples are classified as poorly graded. Poorly graded soils will typically have better drainage rates than a well graded soil because there are more available void spaces for water to infiltrate in a poorly graded soil. Images of the soil samples collected from each of the stormwater basins are presented in Figure 8. It should be noted that because samples were only collected from one location within the stormwater basins and to a depth of four feet, these results may not accurately depict the soil characteristics of the whole stormwater basin and are only a preliminary source of data.

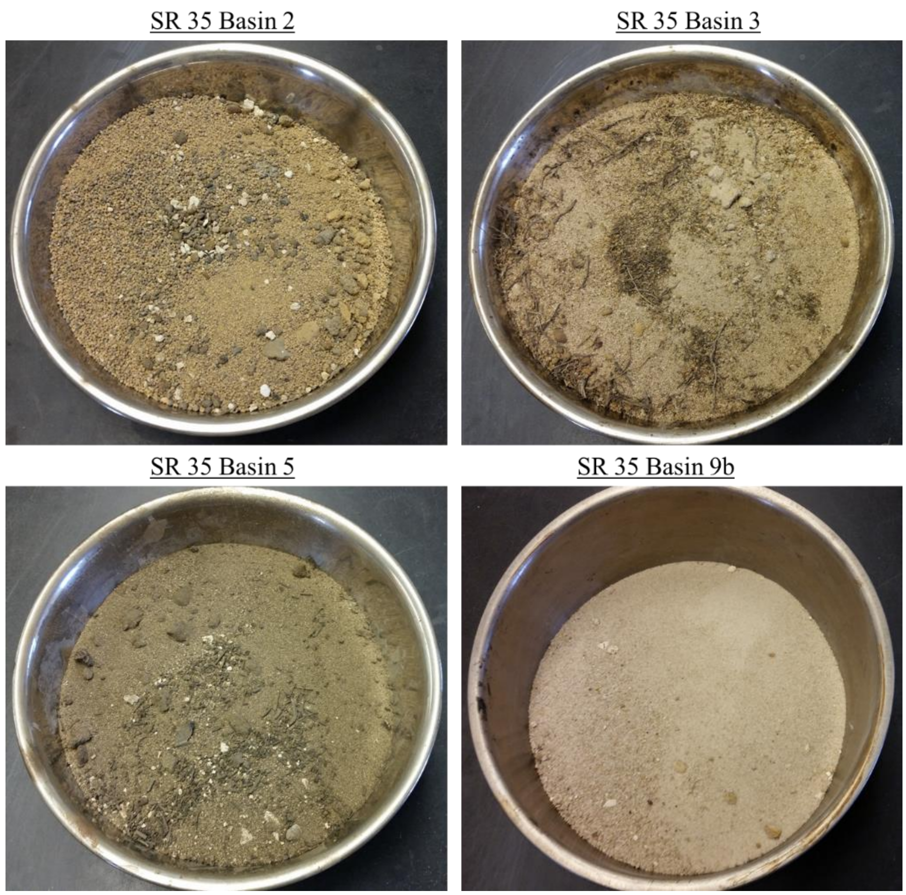


Figure 8: Collected soil samples

3.2 Ground Penetrating Radar

On June 17, 2015, the UCF team met with a GeoView employee to perform the GPR investigation of subsurface geophysical characteristics at the four stormwater basins. GPR consists of a set of integrated electronic components that transmits high frequency (270 megahertz) electromagnetic waves into the ground and records the energy reflected back to the ground surface.

A GPR survey provides a graphic cross-sectional view of subsurface conditions. This cross-sectional view is created from the reflections of repetitive short-duration electromagnetic waves that are generated as the antenna is pulled across the ground surface. The reflections occur at the subsurface contacts between materials with differing electrical properties. The GPR method is commonly used to identify such targets as underground storage tanks, buried debris, and voids or geological features, such as sink holes or other anomalies. .

SR 35 Basin 9b and SR 35 Basin 2 were both dry during the GPR investigation and the GPR survey was conducted along a series of perpendicularly oriented transects spaced 25 ft. apart (see figures in Appendix B). SR 35 Basin 3 and SR 35 Basin 5 were both holding water during the time of the investigation so the GPR survey was conducted along the four sides of the basin berm. The GPR data were collected from all four stormwater basins using a GSSI radar system with a 270-Megahertz antenna. The time range setting used for the GPR data collection was 100 nanoseconds, which provided a maximum depth of investigation of between 16 and 17 feet below the ground surface. Images of the stormwater basin conditions during the GPR investigation are presented in Figure 9.

SR 35 Basin 2

SR 35 Basin 3

SR 35 Basin 5

SR 35 Basin 9b

Figure 9: Basin conditions during GPR investigation

Three types of anomalies were observed during the GPR investigation that are pertinent to this project. The anomaly type as well as a brief description is presented in Table 8. Type A anomalies are considered to be the most severe and most likely to be associated with potentially active karst features (sink holes), while Type C anomalies are considered to be least severe. The greater the severity of these features or a combination of these features the greater the likelihood that the identified feature is a sinkhole. It is not possible based on the GPR data alone to determine if an identified feature is a sinkhole, or more importantly, whether that feature is an active sinkhole.

Table 6: GPR anomalies

Classification of GPR Anomaly	Description
Type A	A downwarping of GPR reflector sets, that are associated with suspected lithological contacts, toward a common center. Such features typically have a bowl or funnel shaped configuration and can be associated with a deflection of overlying sediment horizons caused by the migration of sediments into voids in the underlying limestone.
Type B	A localized significant increase in the depth of the penetration and/or amplitude of the GPR signal response. The increase in GPR signal penetration depth or amplitude is often associated with either a localized increase in sand content at depth or a decrease in soil density.
Type C	An apparent discontinuity in the GPR reflector sets that are associated with suspected lithological contacts. The apparent discontinuities and/or disruptions of the GPR reflector sets is often associated with erosional, rather than sink-hole related activity. However, this type of anomaly can be associated with an area of enhanced permeability.

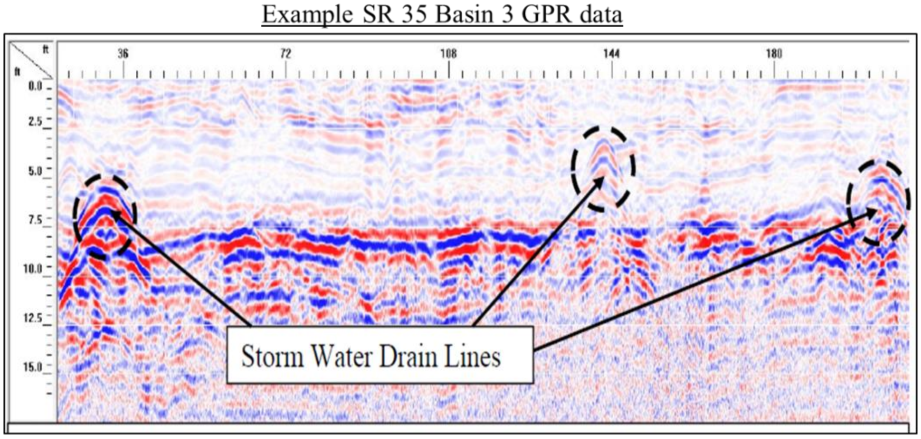
The findings of the GPR investigation are summarized in Table 9. For each of the four stormwater basins the well-defined, relatively continuous set of GPR reflectors likely represents either the transition from a surficial sand stratum to sandy clay to clayey sand or a water table at that depth. After conducting the soil borings at Basin 9b, the GPR reflectors likely represent the groundwater table. The large number of GPR anomalies identified in SR 35 Basin 2 and SR 35 Basin 9b may help explain the ability of the stormwater basins to infiltrate water, due to karst environments of high permeability found beneath the ground surface. By contrast, few anomalies were identified in SR 35 Basin 3 and SR 35 Basin 5, which suggests the existence of a uniform sandy clay to clayey sand layer at the bottom of the basins (roughly six feet below the bermed ground surface) is inhibiting water infiltration and causing the basins to retain water. Two and three stormwater drainage lines were identified under the ground surface at SR 35 Basin 5 and SR 35 Basin 3 respectively. Images of the four stormwater basins showing transects of the GPR analysis and locations of the observed anomalies are presented in Appendix B. It is important to note that although there were no anomalies observed around the berm of SR 35 Basin 3 and SR 35 Basin 5, it cannot be concluded that these anomalies do not exist within the center of the basin. Due to the presence of water at these two stormwater basins at the time of GPR testing, the exact geological characteristics are still unknown at this time.

Table 7: GPR investigation results

Basin	Number of Anomalies Observed	Description
SR 35 Basin 2	Type A: 13 Type B: 11 Type C: 2	• Results of the GPR survey indicated the presence of a well-defined, relatively continuous set of GPR reflectors at an approximate depth range of 3 to 9 ft. • The thirteen Type A anomalies ranged in diameter from 20 to 40 ft. and extended to a depth range of 5 to 17 ft. This type of feature is commonly associated with karst, or sinkhole activity. • The eleven Type B anomalies ranged in diameter from 3 to 30 ft. and extended to maximum depths of 5 to 15 ft. This type of feature is commonly associated with raveling zones, soil pipes, and/or areas of lower density soils. • The two Type C anomalies ranged in diameter from 15 to 40 ft. across and extended to a maximum depth of 5 to 10 ft.
SR 35 Basin 3	Type A: 0 Type B: 0 Type C: 0	• Results of the GPR survey indicated the presence of a well-defined, relatively continuous set of GPR reflectors at an approximate depth range of 6 to 8 ft.
SR 35 Basin 5	Type A: 0 Type B: 0 Type C: 0	• Results of the GPR survey indicated the presence of a well-defined, relatively continuous set of GPR reflectors at an approximate depth range of 6 to 8 ft.
SR 35 Basin 9b	Type A: 9 Type B: 47 Type C: 0	• Results of the GPR survey indicated the presence of a well-defined, relatively continuous set of GPR reflectors at an approximate depth range of 5 to 7 ft. • The nine Type A anomalies ranged in diameter from 10 to 22 ft. and extended to a depth range of 9 to 17 ft.. This type of feature is commonly associated with karst, or sinkhole activity. • The 47 Type B anomalies ranged in diameter from 3 to 35 ft. and extended to maximum depths of 3 to 17 ft. This type of feature is commonly associated with raveling zones, soil pipes, and/or areas of lower density soils.

Examples of the GPR data obtained from the analysis of all four stormwater basins are presented in Figures 10 and 11. These data validated that the uniform and consistent sandy clay to clayey sand layer found within SR 35 Basin 3 and SR 35 Basin 5 is inhibiting water infiltration and causing the stormwater basins to retain water. As seen in Figures 10 and 11, the presence of karst features (denoted as Type A and Type B anomalies) is providing areas of enhanced permeability within SR 35 Basin 9b and SR 35 Basin 2, allowing the stormwater runoff to concentrate in these areas and easily infiltrate to deeper soil layers. This phenomenon explains why SR 35 Basins 9b and SR 35 Basin 2 have been predominantly dry during all site visits. Due to SR 35 Basin 3 and SR 35 Basin 5 having a uniform layer of soil consisting of sandy clay to clayey sand that is causing the stormwater basins to retain water, it is likely that these stormwater basins will not be suitable candidates for additional BAM-related studies.

Example SR 35 Basin 3 GPR data



Example SR 35 Basin 9b GPR data

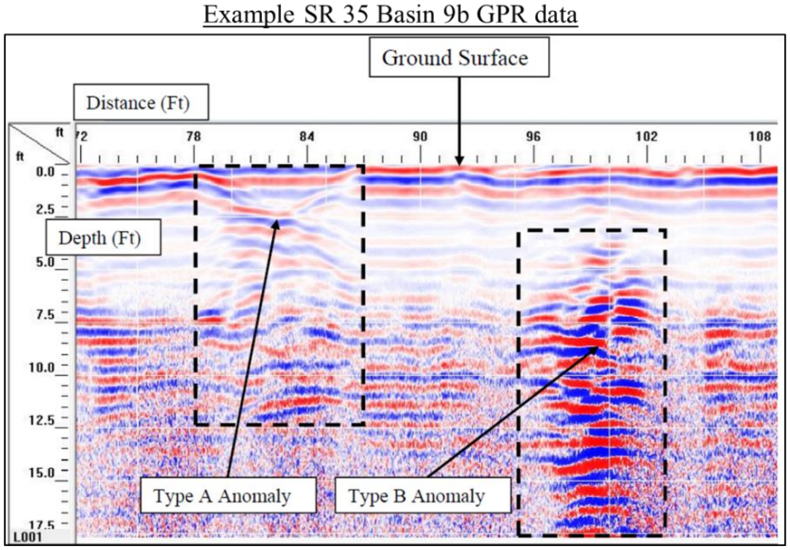


Figure 10: GPR data comparison of SR 35 Basin 3 (top) and SR 35 Basin 9b (bottom)

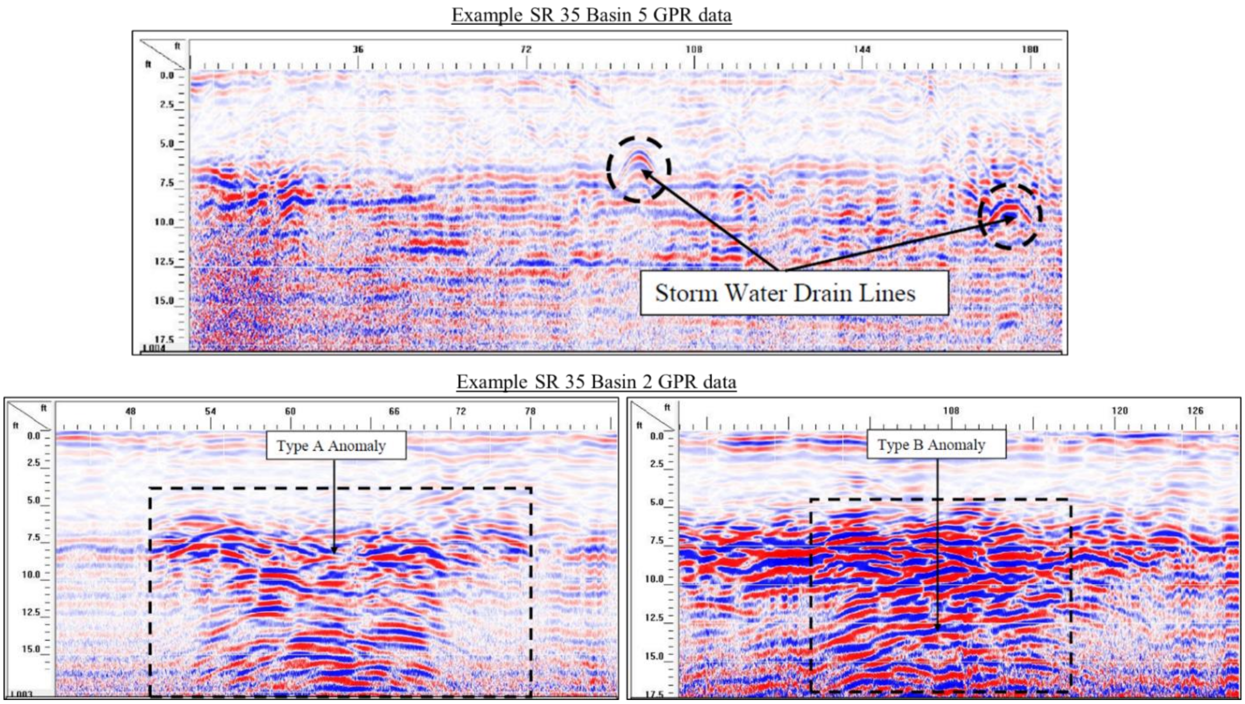


Figure 11: GPR data comparison of SR 35 Basin 5 (top) and SR 35 Basin 2 (bottom)

3.3 Soil Borings and Groundwater Monitoring Wells

On June 24, 2015, the UCF team met with Terracon employees to perform the standard penetration test (SPT) and construct groundwater monitoring wells at SR 35 Basin 9b and SR 35 Basin 2. Four PVC groundwater monitoring wells were installed and one SPT was performed at each stormwater basin. The SPT borings were sampled using split spoon sampling devices consistent with ASTM D1586. Five samples were obtained in the upper ten feet of each boring and at intervals of five feet thereafter.

The auger borings were advanced with a solid stem auger and a one-inch diameter PVC observation casing with a removable cap was placed into the borehole after the auger was extracted. Clean sand was backfilled around the PVC riser to secure it in the borehole.

The field exploration also included observations for the groundwater table. Depth to the groundwater table was found using a water table indicator produced by Heron Instruments. This instrument was lowered into the PVC observation wells and a sensor would beep, notifying the user when the presence of water was detected. This occurred during the exploration program while the boreholes were being advanced. The following paragraphs detail the results of the subsurface exploration at SR 35 Basin 9b and SR 35 Basin 2.

One SPT boring (SPT-1) was performed to a depth of ten feet and four PVC observation wells were installed at SR 35 Basin 9b. An image of the boring locations for SR 35 Basin 9b is presented in Figure 12. Details of the observation well construction and depth to groundwater table for each well is detailed in Table 10.

Figure 12: Well locations at SR 35 Basin 9b

Table 8: Well data for SR 35 Basin 9b

Identification	Screen Length (feet)	Riser Length (feet)	Stick-up (inches)	Depth to Groundwater (feet-inches)
SPT-1	10	5	4	5-5
W-1	10	5	4	11-0
W-2	10	5	17	7-2
W-3	10	5	7	10-4

One SPT boring (SPT-2) was performed to a depth of 26 feet and four PVC observation wells were installed at SR 35 Basin 2. An image of the boring locations for SR 35 Basin 2 is presented in Figure 13. Details of the observation well construction and depth to groundwater table for each well is detailed in Table 11.

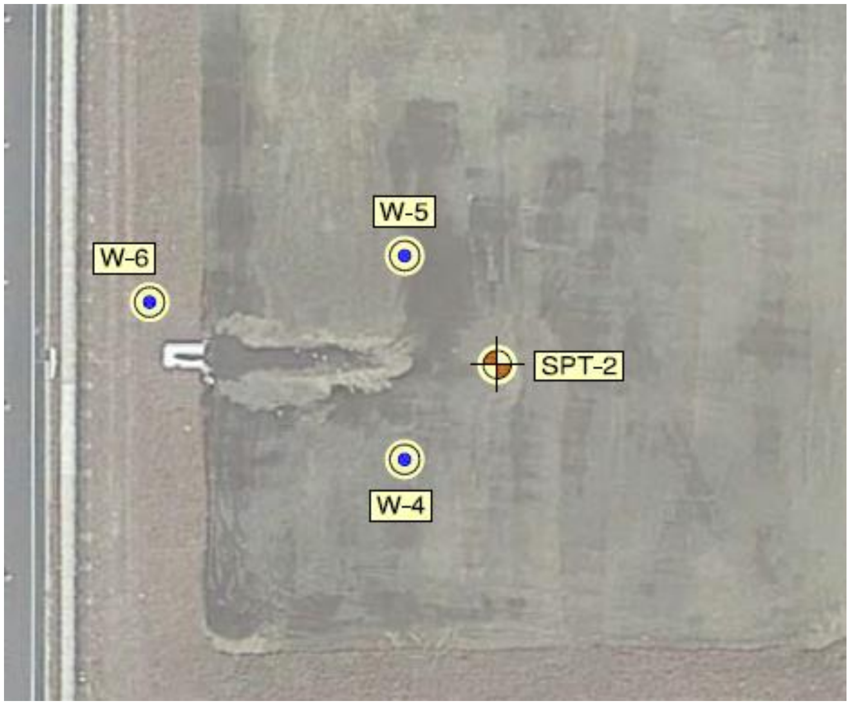


Figure 13: Well locations at SR 35 Basin 2

Table 9: Well data for SR 35 Basin 2

Identification	Screen Length (feet)	Riser Length (feet)	Stick-up (inches)	Depth to Groundwater (feet-inches)
SPT-2	10	25	60	24-0
W-4	10	10	4	NA
W-5	10	10	4	NA
W-6	10	5	4	NA

Soil samples obtained from SPT-1 and SPT-2 were reviewed by a geotechnical engineer to identify soil descriptions. The well logs of the SPT at each stormwater basin are presented in Appendix C. The results of SPT-1 at SR 35 Basin 9b show sand (SP) in the first 3.5 feet of soil. The soil then transitions to clayey sand (SC) from a depth of 3.5 to 5.5 feet. After a depth of 5.5 feet the soil transitions to limerock to a depth of 10 feet, were the boring was terminated. The groundwater table was observed at a depth of 5.8 feet. The soil classification matched the results of the sieve analysis discussed earlier in the report for roughly the first four feet of soil. The comparison of the GPR anomalies found and the results of the SPT performed at SR 35 Basin 9b were consistent and directly over a large Type B anomaly. Type B anomalies represent a localized increase in sand content or a decrease in soil density, which could be explained by the limerock soil layer found between 5.5 and 10 feet.

The results of SPT-2 at SR 35 Basin 2 show sand (SP) from the ground surface to a depth of 26 feet. The groundwater table was observed at a depth of 24.2 feet. The SPT was the only boring to discover the groundwater table at SR 35 Basin 2, the other three auger borings were drilled to a depth of 20 feet (not deep enough to reach the groundwater table). The location selected for SPT-2 revealed the soil is much more uniform and the groundwater table is located far deeper when compared to SR 35 Basin 9b. The location selected for SPT-2 was located near two Type A anomalies discovered during the GPR, however, there were no variations in soil characteristics observed in the SPT.

Photographs taken during the field work conducted on June 24, 2015, are presented in Figures 14 and 15 for SR 35 Basin 9b and SR 35 Basin 2 respectively.

Figure 14: SPT and well installation at SR 35 Basin 9b

Figure 15: SPT and well installation at SR 35 Basin 2

3.4 Double Ring Infiltrometer

On June 24, 2015, a double ring infiltrometer test was conducted at SR 35 Basin 9b and SR 35 Basin 2. Infiltrometers are devices used to measure the rate of water infiltration into soil or other porous media. The most commonly used infiltrometers are a single ring or double ring infiltrometer. The double ring infiltrometer test was conducted in the center of SR 35 Basin 9b and at two locations within SR 35 Basin 2 (near the inlet along SR 35 and in the center of the stormwater basin). Two locations were selected for SR 35 Basin 2 because water was observed to be pooling around the inlet (see Figure 15), while the rest of the stormwater basin was dry. The interest was in characterizing changes in soil permeability from the inlet to the center of the stormwater basin. The test was performed by first driving a four-inch diameter PVC pipe eight inches into the ground. Next, a twelve-inch diameter aluminum pipe was driven eight inches into the ground, so that it surrounded the smaller four-inch pipe. Next, water was poured into the pipes until the water level in each pipe reached a height of five inches. As water within the pipes infiltrates into the soil, the water level within the pipes begins to drop. The objective of the test is to keep the water level constant within the pipes by adding additional water when the height drops below the five-inch mark. Every 15 minutes, the volume of water added to both the inner and outer pipes to keep the water level constant at five inches was recorded. Each test was conducted for a time period of one-hour. Images of the double ring infiltrometer tests are presented in Figure 16.

Figure 16: Double ring infiltrometer test at SR 35 Basin 9b (left), SR 35 Basin 2 near inlet (middle), SR 35 Basin 2 center of stormwater basin (right)

The results of the double ring infiltrometer tests are presented in Table 12. SR 35 Basin 2 – Test 1 was performed near the inlet and SR 35 Basin 2 – Test 2 was performed in the center of the stormwater basin. As would be expected from the observation of pooling water near the inlet of SR 35 Basin 2, the infiltration rate of the soil near the inlet was much lower when compared to the soil in the center of the stormwater basin. The infiltration rate of the soil in the center of SR 35 Basin 9b was higher when compared to SR 35 Basin 2. This finding explains why SR 35 Basin 9b has been dry during all site visits, while SR 35 Basin 2 has had some minor pooling near the inlet and sporadically throughout the basin. The presence of very permeable soil, the anomalies found during GPR, and the higher water table leads to the conclusion that stormwater in the basin infiltrates faster through the vadose zone at SR 35 Basin 9b and may not be receiving sufficient residence time for nutrient removal before entering the groundwater table. Conversely, the soil type at SR 35 Basin 2 and large vadose zone is most likely not providing nitrate removal before the water enters the groundwater.

Table 10: Double ring infiltrometer test results

Basin	Infiltration Rate (in·hr^{-1})
SR 35 Basin 2 - Test 1	0.45
SR 35 Basin 2 - Test 2	3.85
SR 35 Basin 9b	>10

3.5 Multi-Criteria Decision Making System

In order to document the selection process to be presented in Task 3 a second multi-criteria decision support system was created based on results from GPR analysis, SPTs, double ring infiltrometer rates, and groundwater monitoring well construction. The criteria and descriptors (similar to Task 1) used in this multi-criteria decision support system are presented in Table 13. The scores each stormwater basin received based on these criteria are presented in Table 14. Each criteria was equally weighted for this decision support system.

This project must be done in a Karst region, thus the presence of Karst features is important to the site selection process. There are many drainage retention basins in Marion County, but not all have Karst features. The greater the number of Karst features, the more desirable the stormwater basin location. However if there were a distinct sink hole feature, the site was not considered further. There were no such feature detected at the four sites. Since the basin must infiltrate water, the higher the soil permeability the more desirable the stormwater basin location. Ponded water over the study period means that it would be more expensive to retrofit the stormwater basin to infiltrate runoff water. These ranking descriptions are shown in Table 13.

Table 11: Criteria ranking system

Descriptors	Score Awarded	Presence of Karst Features	Soil Permeability (in·hr^{-1})	Water Retention
Poor	1	0-10 Anomalies	0-1	Ponded
Fair	2	10-20 Anomalies	1-2	Moderate Ponding
Good	3	20-30 Anomalies	2-3	Minimal Ponding
Excellent	4	>30 Anomalies	>3	Dry

Table 12: Candidate stormwater basin scores

Criteria	SR 35 Basin 2	SR 35 Basin 3	SR 35 Basin 5	SR 35 Basin 9b
Presence of Karst Features	Good	Poor	Poor	Excellent
Soil Permeability	Good	Fair	Fair	Excellent
Water Retention	Good	Poor	Poor	Excellent
Total Score	3.00	1.33	1.33	4.00

Due to the uniform layer of sandy clay to clayey sand found at SR 35 Basin 3 and SR 35 Basin 5 that is inhibiting water infiltration and resulting in consistently ponded conditions, these stormwater basins are considered as alternative sites for Phase II. These stormwater basins would cost more to adopt additional treatment methods using a BAM based removal mechanism. The higher water table and high infiltration rates found at SR 35 Basin 9b make this stormwater basin attractive for a curtain wall design in Phase II. The large basin size and observations of high flow rates (due to accumulation of water around the inlet) make SR 35 Basin 2 an attractive option for a horizontal exfiltration pipe (a.k.a. a French drain) type design.

4. TASK 3

The goal of Task 3 is to finalize the decision of which two stormwater basins are recommended as test sites and which two stormwater basins are recommended as alternative sites during Phase II construction and testing. Example BAM design illustrations are also suggested during Task 3 to facilitate the execution of Phase II proposal and work. Groundwater samples are collected from SR 35 Basin 9b and used to establish baseline TN concentrations in the groundwater, which is essential in order to assess the effectiveness of future BAM treatment systems during Phase II.

4.1 Groundwater Sampling

On July 26, 2015, groundwater samples were collected from the groundwater monitoring wells constructed during Task 2 at SR 35 Basin 9b. A portable generator and peristaltic pump were utilized to pump groundwater out of the monitoring wells (shown in Figure 17). One sample was collected from each monitoring well at SR 35 Basin 9b. The resulting TN concentration of each groundwater sample is presented in Table 15. The location of each groundwater monitoring well can be found in Figure 12. These results show the TN concentration in groundwater at SR 35 Basin 9b is consistently equal to or greater than 1.0 $mg \cdot L^{-1}$.

Table 13: Groundwater sampling results

SR 35 Basin 9b	
Well Identification	TN ($mg \cdot L^{-1}$)
W-1	1.2
SPT-1	1.5
W-2	1.3
W-3	1.0

Figure 17: Groundwater sampling at SR 35 Basin 9b

4.2 Overview of BAM-Based BMPs

Potential BAM designs are included to solicit review comments on future design possibilities at the two stormwater basins. The exact locations of the treatment systems within the stormwater basins are to be determined during Phase II. Dimensions shown in the figures are for illustrative purposes and exact dimensions are to be determined in Phase II. Potential BAM-based treatment systems include curtain walls, pipe based exfiltration systems, such as French drains or barrel treatment systems. Other alternative designs may be proposed for screening and selection in Phase II. The following sections provide a description of each treatment technology as well as preliminary recommendations for which stormwater basin they may be suitable at.

4.2.1 Curtain Walls

A curtain wall is a groundwater remediation technology that may also be recognized as being a cost-efficient technology for in situ stormwater treatment. Curtain walls can be composed of a wide variety of materials, depending on the project goals and species targeted for removal. In this study, the curtain wall is composed of a BAM mixture and would be installed directly into the soil profile of the stormwater basin. This technology is focused around amending the soil to achieve a desired outcome. For example, stormwater basins with consistent flooding issues may be amended with more permeable soils that allow for greater infiltration rates, thereby reducing the risk of flooding, while reducing nitrate concentrations.

For application to Basin 9b, the goal is to remove nitrates from stormwater and groundwater by amending the stormwater basin with Bold & Gold (B&G), a type of BAM, which is a proven technology for removing nutrients and other pollutants through a combination of physical, chemical, and biological processes. Installation of a horizontally oriented curtain wall (i.e., parallel to the ground surface) may be best suited for SR 35 Basin 9b, due to the high infiltration rate and relatively shallow groundwater table in the stormwater basin. Example diagrams of a horizontal curtain wall is presented in Figure 18 and Figure 19. In this example, the 2-foot thick, 15-foot wide horizontal curtain wall would be located four feet beneath the ground surface and would intercept and treat stormwater as it percolates through the soil profile. Also, groundwater that rises above the bottom of the curtain wall will also be directed into the BAM. At Basin 9b, the water table was identified as about six feet below the ground on one occasion. The depth of the bottom of the BAM must be identified before construction.

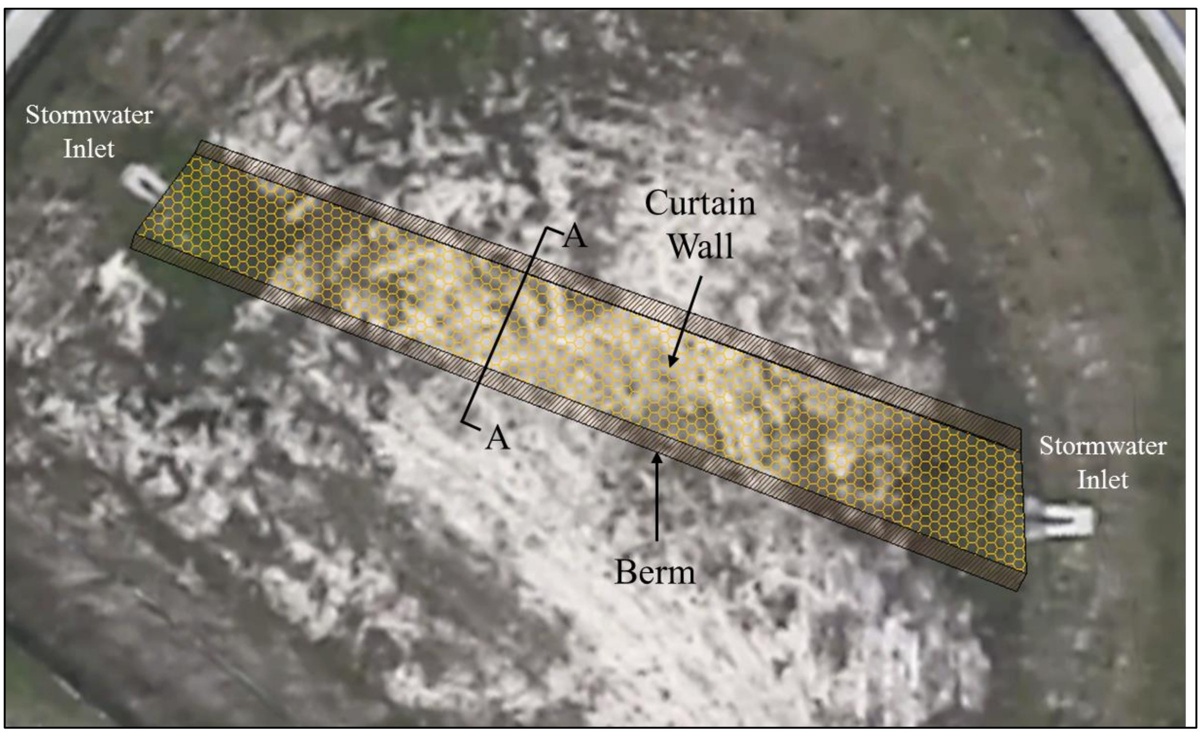


Figure 18: Plan view of a horizontal curtain wall in Basin 9b (dimensions in feet)

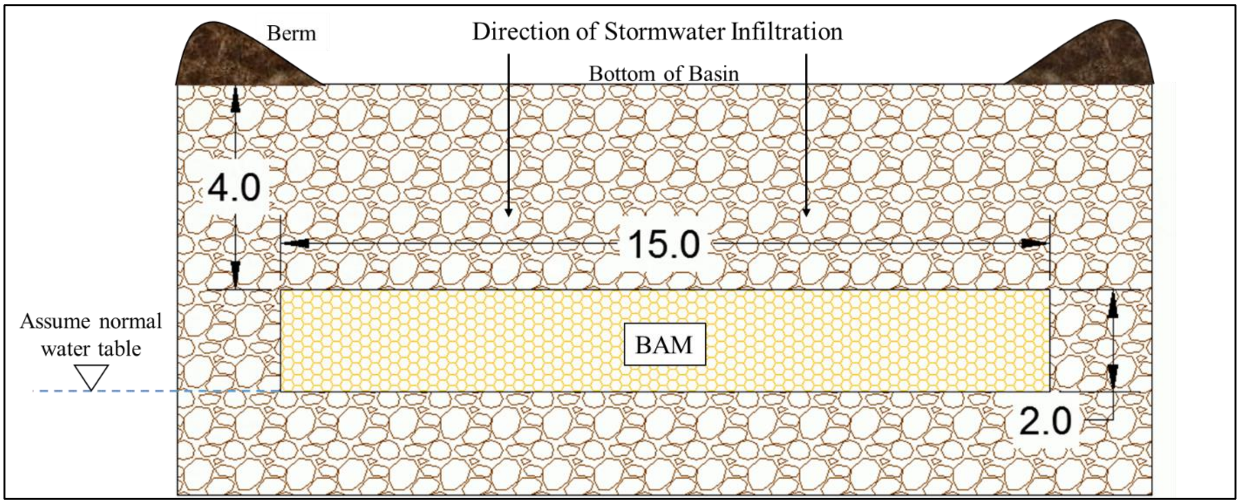


Figure 19: Section (A-A) view of a horizontal curtain wall in Basin 9b (dimensions in feet)

4.2.2 French Drain

French drains are a type of horizontal trench filled with gravel, rock, or other media that contain a perforated pipe that redirects surface water and groundwater away from an area. In stormwater management, the traditional French drain can be retrofitted with BAM to not only control stormwater quantity, but also provide stormwater treatment. By directing collected stormwater through a pipe filled with BAM, nutrients and other pollutants can be removed.

Installation of a French drain would be best suited for SR 35 Basin 2, due to the large size of the stormwater basin, deeper groundwater table, and slower infiltration rates. An example diagram of a French drain is presented in Figure 20. In this example, stormwater flowing into the stormwater basin is first collected in a concrete holding tank. As the tank begins to fill, the stormwater eventually reaches a height where the inlet to the French drain is located. As the water level continues to rise within the holding tank, stormwater begins to flow out of the concrete holding tank and is transported through a French drain filled with B&G. A 30 foot section is shown in Figure 19, but that is only for illustrative purposes. Three different lengths of French drain are recommended to test the idea of longer residence times with effectiveness. Nutrients and other pollutants are removed within the French drain through a combination of physical, chemical, and biological processes that occur within the B&G.

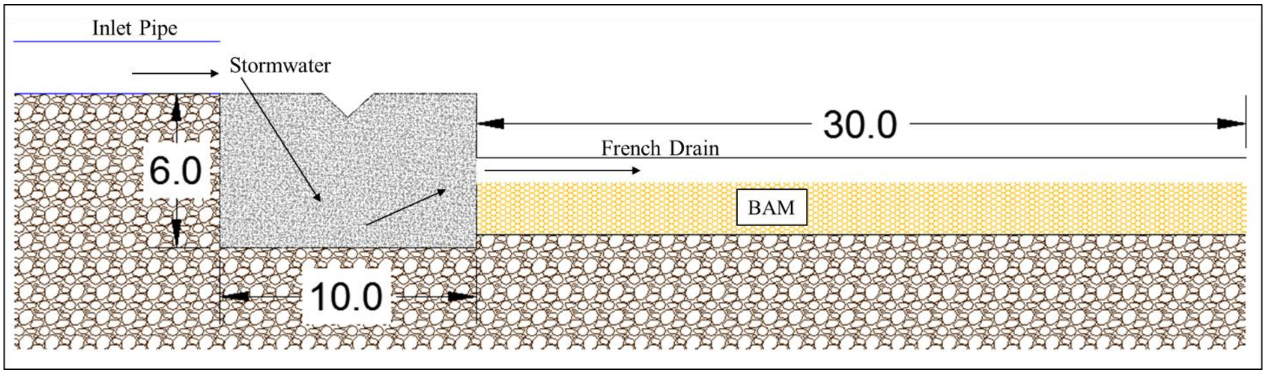


Figure 20: Section view of a potential French drain system (dimensions in feet)

4.2.3 Barrel Treatment Network

A barrel treatment network is an innovative, simple, and cost-efficient strategy for removing excess nutrients from stormwater runoff. A barrel treatment network functions by directing the stormwater runoff into a set of infiltration barrels, which would be filled with B&G. As the stormwater percolates downward through the barrels, nitrates and other pollutants are removed by the B&G before the stormwater is discharged from the bottom of the barrel. A barrel treatment network is also a flexible technology in that different lengths of barrels can be tested for comparative removal purposes and barrels can easily be accessed for maintenance. An example diagram of a barrel treatment network is presented in Figure 20. In this example, stormwater flowing into the stormwater basin is initially collected in a concrete holding tank. As the holding tank begins to fill, stormwater is transported to a second, smaller holding tank where the inlets to the treatment barrels are located. When stormwater within the second holding tank reaches a certain height, it begins flowing into the inlet pipes attached to the treatment barrels. In this example, there would be six total treatment barrels, two on each side of the second holding tank (excluding the inlet side of the tank). The treatment barrels in Figure 20 are 6-foot long, 3-foot diameter pipes that would be placed within the stormwater basin and filled with the B&G mixture.

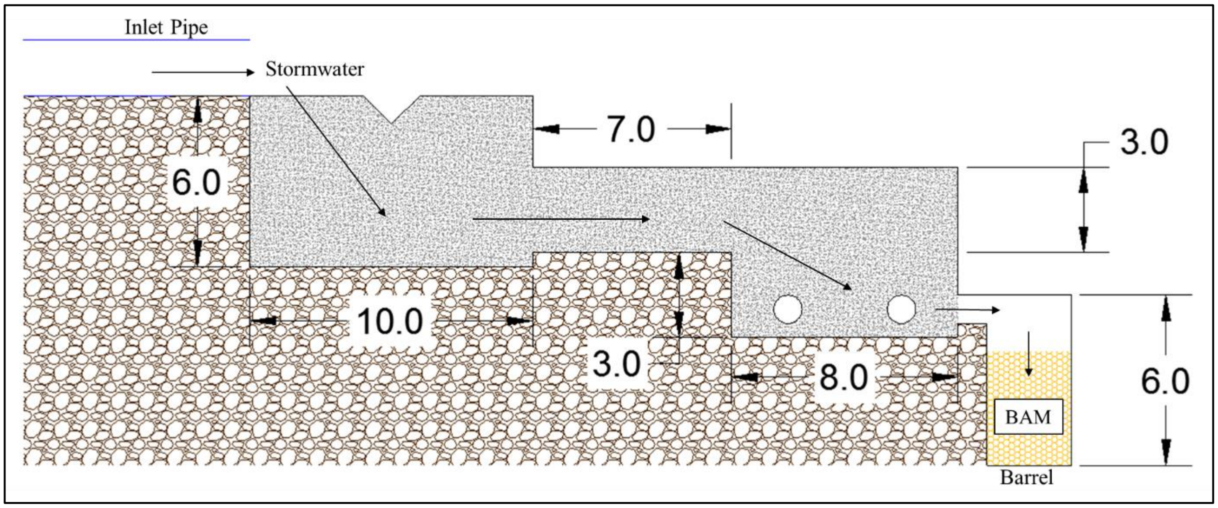


Figure 21: Section view of a potential barrel treatment network (dimensions in feet)

4.2.4 Combination of BAM-Based BMPs

BAM based treatment technologies may be combined in series or parallel to provide enhanced nutrient removal and co-treatment of stormwater runoff. For example, the French drain and barrel treatment network may both be installed at the same initial holding tank and the flow could be split into two equivalent treatment trains. For comparative purposes, the total volume of B&G within the French drains should be equivalent to the total volume of B&G within the treatment barrels. This would allow for comparisons to be made between the two treatment technologies with regards to removal efficiency, mass of pollutants removed per mass of BAM, and operability. An example of the dual stream treatment train, combining French drains and a barrel treatment network, is presented in Figure 20. This combination of treatment technologies would be best suited for SR 35 Basin 2, due to the large stormwater basin area and high volume of stormwater runoff required to be treated. The diagram in Figure 21 shows a potential location of the B&G treatment system at the southern inlet at SR 35 Basin 2. All dimensions are approximated and will be determined in Phase II and before construction to retrieve data on removal effectiveness as a function of size and residence time.

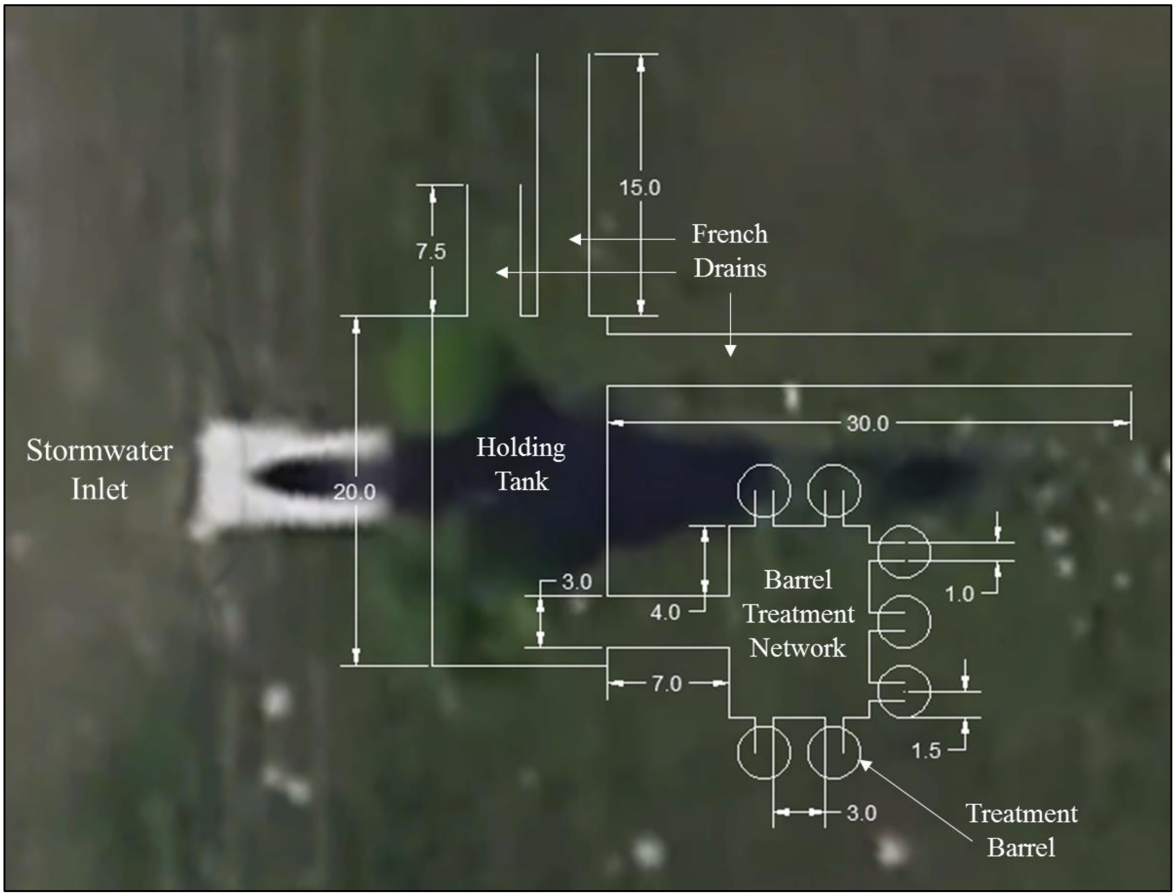


Figure 22: Plan view of potential French drains and barrel treatment network in parallel at SR 35 Basin 2. All dimensions are in feet and only for preliminary sizing.

4.3 Water Quality Monitoring Plan

Collection of water quality samples at SR 35 Basin 2 and SR 35 Basin 9b during Phase II is essential in order to characterize the efficiency of the BAM treatment systems. Water quality samples collected prior to the construction of the treatment systems is also important in order to establish a baseline nitrate-nitrogen concentration in stormwater runoff and groundwater. All treatment systems, with the exception of the horizontal curtain wall at SR 35 Basin 9b, require storm events in order for a water quality sample to be obtained. Therefore, prior to the construction of BAM treatment systems, sufficient storm event water quality samples should be collected in order to establish the baseline water quality characteristics. Following the construction of the treatment systems, sufficient storm event water quality samples must be collected in order to assess the efficiency of the BAM treatment systems in removing nitrate-nitrogen from stormwater runoff and groundwater. Since the horizontal curtain wall at SR 35 Basin 9b will be constructed near and slightly within the groundwater table, dependency on storm events for collection of water quality samples will not be an important factor. The exact number of water quality samples to be collected will be determined in Phase II.

5. CONCLUSION

An important step to restoring the Silver Springs springshed is development of effective, environmentally sustainable treatment systems that remove nutrients from stormwater runoff and groundwater. Anthropogenic activities near the springshed over recent decades may have resulted in nitrogen concentrations more than 25 times higher than historic values, presumably resulting in the eutrophication of Silver Springs and a deterioration of the ecosystem. Two candidate stormwater basins have been chosen as test sites to be retrofitted with BAM treatment systems during Phase II. These test sites are SR 35 Basin 2 and SR 35 Basin 9b. The selection of these two stormwater basins was based on geophysical, stormwater, soil, and site data collected during Phase I. Implementation of BAM treatment systems to remove excess nutrients from stormwater runoff and groundwater at SR 35 Basin 2 and SR 35 Basin 9b will be a step forward for restoring the Silver Springs springshed.

The information in this report is used to support the selection of two sites for the construction and testing of BAM optional treatment methods with a high probability of successful operation and testing. An additional two sites were also identified as alternative sites.

REFERENCES

"EPA Compliant Methods." HACH, 2015. Web. 28 Oct. 2015. http://www.hach.com/epa.

Hicks, R., and Holland, K. (2012). *Nutrient TMDL for Silver Springs, Silver Springs Group, and Upper Silver River (WBIDs 2772A, 2772C, and 2772E)*. Tallahassee, FL: Florida Department of Environmental Protection. 112 pp. http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp1/silver-springs-2772ace-nutr-tmdl.pdf, accessed October 27, 2015.

Phelps, G.G. (2004). *Chemistry of Ground Water in the Silver Springs Basin, Florida, with an Emphasis on Nitrate* (USGS Scientific Investigations Report 2004-5144). Reston, VA: U.S. Department of Interior, U.S. Geological Survey. 60 pp. http://pubs.usgs.gov/sir/2004/5144/pdf/sir20045144.pdf, accessed October 27, 2015.

Professional Service Industries, Inc. "S.R. 35 Widening from South of S.R. 464 to S.R. 40 Marion County, Florida," 2009.

"Silver Springs Restoration Plan." (2014): 50. The Howard T. Odum Florida Springs Institute. Web. 28 Oct. 2015. http://floridaspringsinstitute.org/Resources/Documents/Silver_Springs_Restoration_Plan.pdf.

St. Johns Riverkeeper (2015). "Springs of the St. Johns: (blog post). http://www.stjohnsriverkeeper.org/blog/the-springs-of-the-st-johns/, accessed October 27, 2015.

APPENDIX

Appendix A: Plan View of Basins

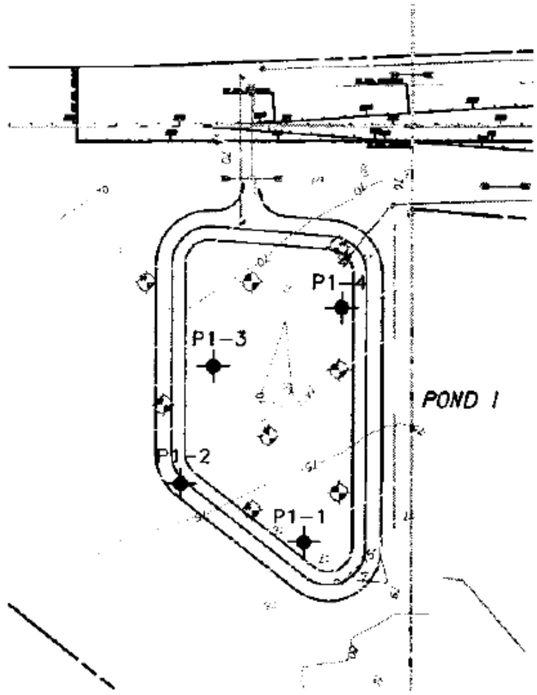


Figure 23: SR 35 Basin 1

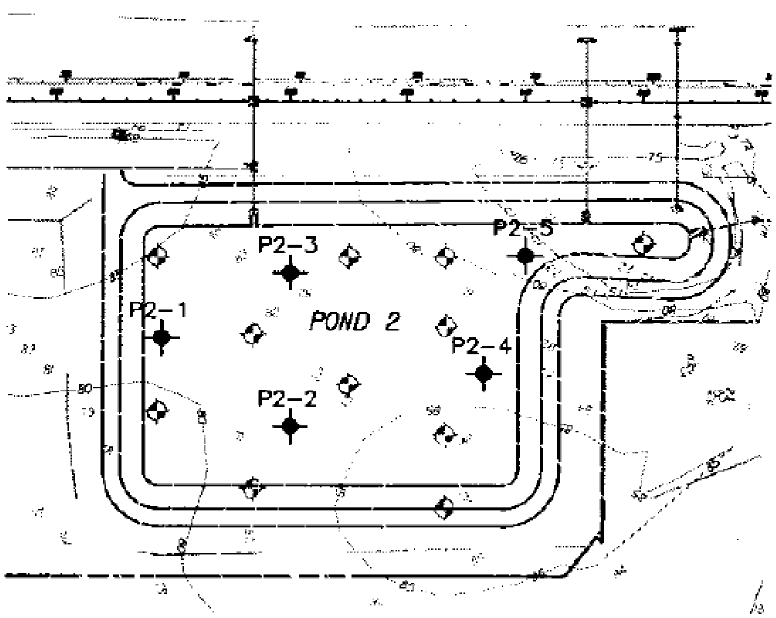


Figure 24: SR 35 Basin 2

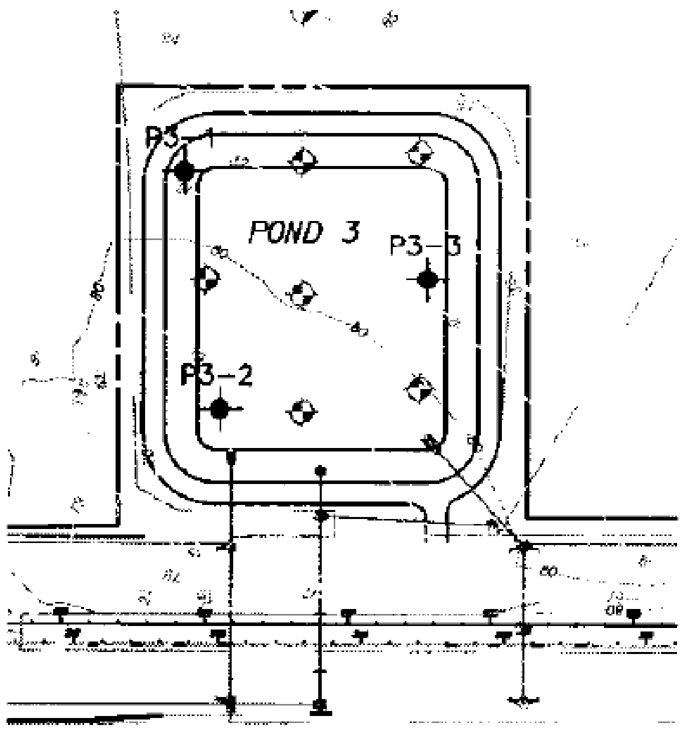


Figure 25: SR 35 Basin 3

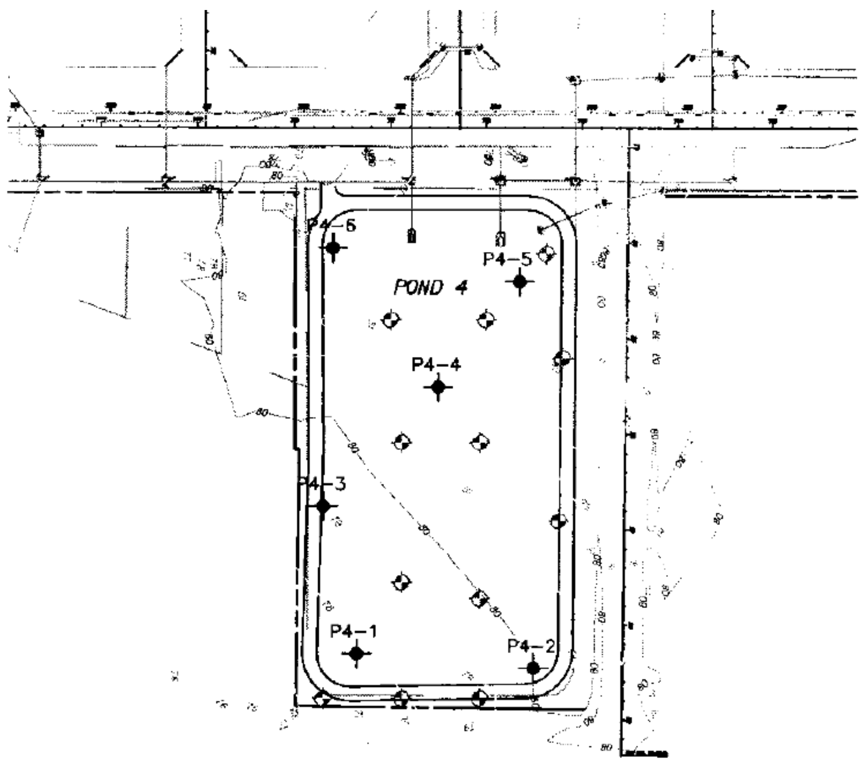


Figure 26: SR 35 Basin 4

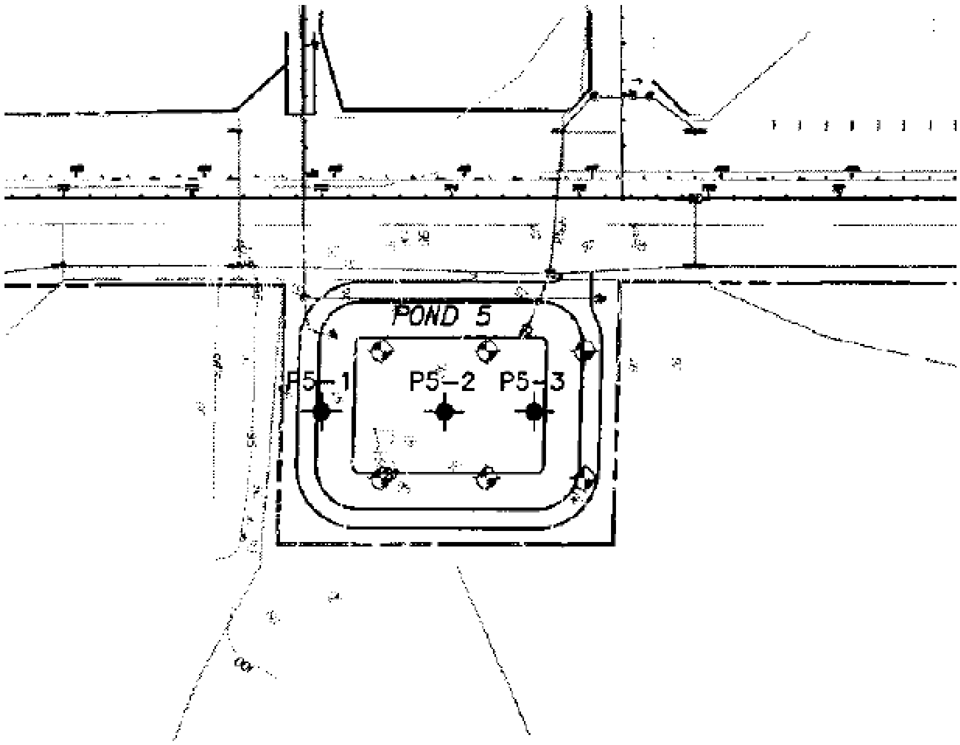


Figure 27: SR 35 Basin 5

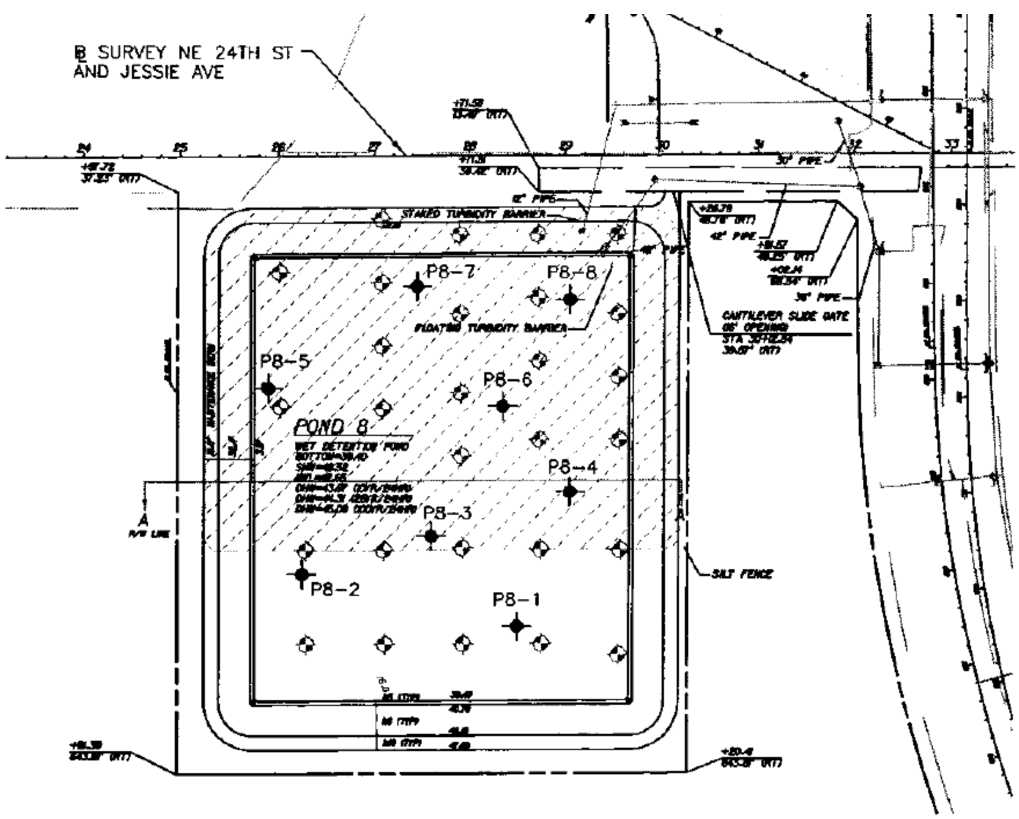


Figure 28: SR 35 Basin 8

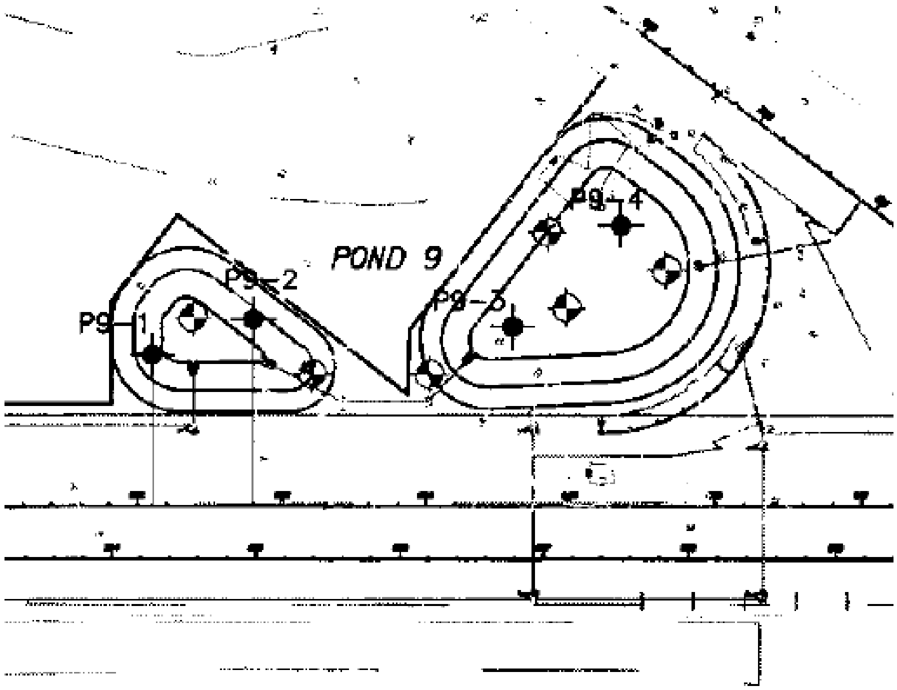


Figure 29: SR 35 Basin 9a (left) and 9b (right)

Appendix B: GPR Anomaly Locations

Figure 30: GPR anomalies of SR 35 Basin 2

Figure 31: GPR anomalies of SR 35 Basin 3

Figure 32: GPR anomalies of SR 35 Basin 5

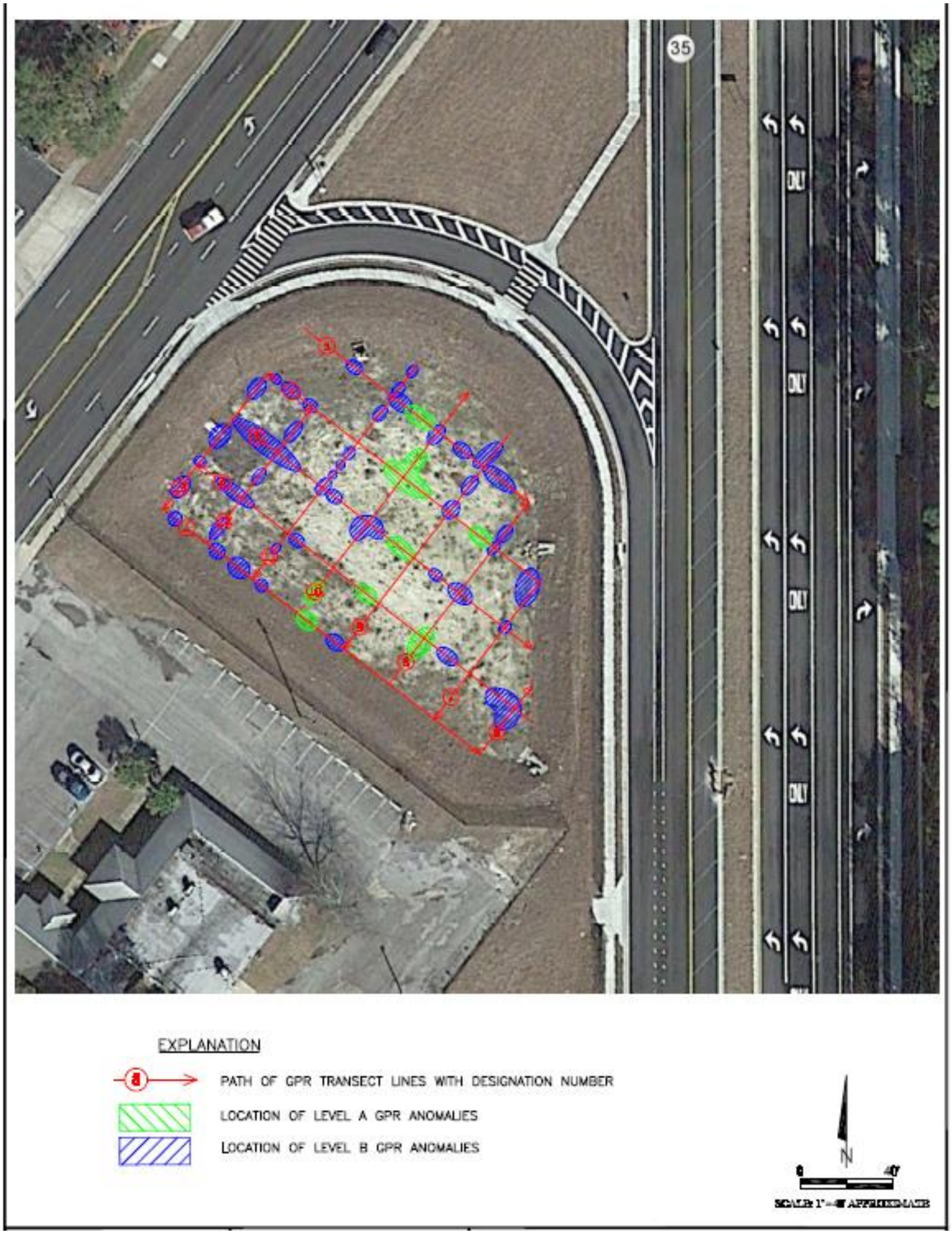


Figure 33: GPR anomalies of SR 35 Basin 9b

Appendix C: Results of the Standard Penetration Tests

WELL LOG NO. SPT-1

Page 1 of 1

PROJECT: UCF Stormwater Research	**CLIENT: Stormwater Management Academy Orlando, Florida 32816**
SITE: Silver Springs, Marion County, Florida	

LOCATION See Exhibit A-2

DEPTH	Description	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS
0.5	SAND (SP), fine grained, light gray, loose				
1.0	SAND (SP), with limerock base, light brown, loose				2-2-4-4 N=6
3.5	SAND (SP), fine grained, gray, loose				2-2-2-2 N=4
5.5	CLEYEY SAND (SC), gray, loose	5	▽		4-3-3-3 N=6
10.0	LIMEROCK, loose to medium dense	10			6-6-4-4 N=10; 4-4-3-3 N=7
	Boring Terminated at 10 Feet				

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method: Mud Rotary	See Exhibit A-3 for description of field procedures. See Appendix B for description of laboratory procedures and additional data (if any). See Appendix C for explanation of symbols and abbreviations.	Notes:
Abandonment Method:		

WATER LEVEL OBSERVATIONS	Terracon 1675 Lee Road Winter Park, Florida	Well Started: 6/24/2015	Well Completed: 6/24/2015
▽ *Observed Groundwater Level at 5.8' Depth*		Drill Rig: DR898	Driller: Terracon
		Project No.: H1155098	Exhibit: A-6

Figure 34: SPT results of SR 35 Basin 9b

BORING LOG NO. SPT-2

Page 1 of 1

PROJECT: UCF Stormwater Research

CLIENT: Stormwater Management Academy Orlando, Florida 32816

SITE:

Silver Springs, Marion County, Florida

GRAPHIC LOG | LOCATION See Exhibit A-2

DEPTH

SAND (SP), fine grained, light brown to orangish-brown, loose to medium dense

DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS
			3-4-4-4 N=8
			7-6-7-6 N=13
5			7-7-7-5 N=14
			6-6-5-6 N=11
			5-4-4-4 N=8
10			5-6-5-5 N=11
			6-5-7-7 N=12
15			7-7-7-7 N=14
			9-8-7-6 N=15
			7-9-9-9 N=18
20			6-8-8-10 N=16
			10-9-10-10 N=19
25	▽		9-9-9-9 N=18

26.0

Boring Terminated at 26 Feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud Rotary

Abandonment Method:

See Exhibit A-3 for description of field procedures.
See Appendix B for description of laboratory procedures and additional data (if any).
See Appendix C for explanation of symbols and abbreviations.

Notes:

WATER LEVEL OBSERVATIONS

▽ *Observed Groundwater Level at 24.2' Depth*

Terracon
1675 Lee Road
Winter Park, Florida

Boring Started: 6/24/2015	Boring Completed: 6/24/2015
Drill Rig: DR898	Driller: Terracon
Project No.: H1155098	Exhibit: A-7

Figure 35: SPT results of SR 35 Basin 2