Final Report FDOT Project BD521-02

Performance Assessment of Portland Cement Pervious Pavement

Report 2 of 4: Construction and Maintenance Assessment of Pervious Concrete Pavements

A Joint Research Program of

Submitted by

Marty Wanielista
Manoj Chopra

Stormwater Management Academy
University of Central Florida
Orlando, FL 32816

Editorial Review by: Ryan Browne

June 2007

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.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		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
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

NOTE: Volumes greater than 1000 l shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

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
		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
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
Final		

4. Title and Subtitle	5. Report Date
Construction and Maintenance Assessment of Pervious Concrete Pavements	January, 2007
	6. Performing Organization Code
7. Author(s) Manoj Chopra, Marty Wanielista, Craig Ballock, and Josh Spence	8. Performing Organization Report No.
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.
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 (one of four on pervious concrete research) 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The information in this report focused on the construction and maintenance activities for Portland cement pervious concrete as used in selected sites in Florida, Georgia, and South Carolina. construction specifications were suggested for Portland cement pervious concrete pavement in regional conditions typical to the States of Florida, Georgia, and South Carolina based on current construction practices and updated as a result of this research. Contractor certification is necessary.

A total of 30 pervious concrete cores were extracted from actual operating pervious concrete sites and evaluated for infiltration rates before and after various rehabilitation techniques. The pervious concrete field sites investigated ranged in service life from 6 to 20 years and exhibited regionally similar structural integrity, infiltration rates, pavement cross sections and subsurface soils. The infiltration rates were performed at the same pressure head for comparative purposes. The techniques were pressure washing, vacuum sweeping and a combination of the two methods. For cores from pavements properly installed, it was found that the three methods of maintenance typically resulted in a 200% or greater increase over the original infiltration rates of the pervious concrete cores. However, it was noted that pressure washing may dislodge pollutants that can not be captured before entering receiving waters, thus in these situations, vacuum sweeping may be the preferred method.

17. Key Word	18. Distribution Statement
Pervious concrete, maintenance, construction, infiltration rates, pavements, rejuvenation	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	164	

Executive Summary

This report is one of three on the subject of Portland cement pervious pavements and reports on the construction practices and maintenance of the pervious concrete system to achieve a hydraulic effectiveness. Field sites for existing pervious concrete parking were located in Florida, Georgia, and South Carolina. It is hoped that by developing more standardized installation methods, and documentation of infiltration performance, wider acceptance of Portland cement pervious pavement can be achieved.

Objectives for selecting the sites were to evaluate the clogging potential of existing pervious concrete systems, to analyze rehabilitation techniques and develop installation specifications for the construction of Portland cement pervious concrete specific to the geographic site locations. Initially, infiltration rate data were collected for a pervious concrete system in a field laboratory with test cells containing typical Florida sandy soil conditions and groundwater elevations. Next, these field laboratory data were compared to actual data from multiple paving sites of long service life (6-20 years) in the three States.

Eight existing parking lots were evaluated to determine the infiltration rates of pervious concrete systems that received relatively no maintenance. Infiltration rates were measured using an embedded single-ring infiltrometer developed specifically for testing pervious concrete in an in-situ state. The average infiltration rates of the pervious concrete that was properly constructed at the investigated sites ranged from 0.4 to 227.2 inches per hour. A constant head was used for comparative purposes.

A total of 30 pervious concrete cores were extracted and evaluated for infiltration rates after various rehabilitation techniques were performed to improve the infiltration capability of the concrete. The techniques were pressure washing, vacuum sweeping and a combination of the

two methods. By evaluating the effectiveness of these rehabilitation techniques, recommendations have been developed for a maintenance schedule for pervious concrete installations. For properly installed sites, it was found that the three methods of maintenance investigated in this study typically resulted in a 200% or greater increase over the original infiltration rates of the pervious concrete cores. It is therefore recommended that as a general rule of thumb one or a combination of these rejuvenation techniques should be performed, however, with some sites pressure washing may result in the release of pollution to the receiving waters and thus vacuum sweeping is preferred or recommended choice.

Construction specifications were suggested for Portland cement pervious concrete pavement in regional conditions typical to the States of Florida, Georgia, and South Carolina based on current construction practices and updated as a result of this research.   It should be stressed that contractor qualifications by certification is one of the most important practices related to the installation of pervious concrete.

ACKNOWLEDGMENTS

First and foremost, the authors would like to thank the Ready Mixed Research Concrete Foundation, Rinker Materials and the Florida Department of Transportation for their monetary support and technical assistance. Without their support, this research would not be possible. In addition, the support of the Florida Department of Environmental Protection and the owners of the pervious parking areas noted in this report are appreciated. Lastly, the Stormwater Management Academy located at the University of Central Florida provided valuable assistance in the collection and analyses of laboratory and field derived data.

The authors also thank the reviewers of the draft document. They were Eric Livingston of the State Department of Environmental Protection, Scott Hagen of the University of Central Florida, Michael Davy and Matt Offenberg of Rinker Materials, and Karthik Obla of the National Ready Mixed Research Foundation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing of Materials
Cd	Cadmium
CNCPC	California-Nevada Cement Promotion Council
Cu	Copper
EPA	Environmental Protection Agency (United States)
FCPA	Florida Concrete Products Association
FDEP	Florida Department of Environmental Protection
GCPA	Georgia Concrete Products Association
HP	Horsepower
NRMCA	National Ready Mixed Concrete Association
Pb	Lead
PCA	Portland Cement Association
PSI	Pounds per Square Inch
RRC	Roller Compacted Concrete
SS	Suspended Solids
UCF	University of Central Florida
WMD	Water Management District

Zn	Zinc

LIST OF ASTM STANDARD TEST METHODS

ASTM C 29	Test Method for Bulk Density and Voids in Aggregate
ASTM C 33	Specification for Concrete Aggregates
ASTM C 136-06	Test Method for Sieve Analysis of Fine and Coarse Aggregates
ASTM C 150	Specification for Portland Cement
ASTM C 494	Specification for Chemical Admixtures for Concrete
ASTM C 595	Specification for Blended Hydraulic Cements
ASTM C 618	Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
ASTM C 989	Specification for Ground Granulated Blast-Furnance Slag for Use in Concrete and Mortars
ASTM C 1157	Performance Specification for Hydraulic Cement
ASTM C 1240	Specification for Silica Fume Used in Cementitious Mixtures
ASTM D 698	Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort
ASTM D 1556	Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method
ASTM D 1557	Test Methods for Laboratory Compaction Characteristics of Soil using Modified Effort
ASTM D 2434-68	Test Method for Permeability of Granular Soils (Constant Head)

ASTM D 3385-03 Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer

CHAPTER ONE: INTRODUCTION

1.1: Introduction

Porous concrete is a unique cement-based product whose porous structure permits free passage of water through the concrete and into the soil without compromising the concrete's durability or integrity. Also referred to as *enhanced porosity concrete, pervious concrete, Portland cement pervious pavement* and *pervious pavement,* porous concrete is a subset of a broader family of pervious pavements including porous asphalt, and various grids and paver systems. Portland cement pervious concrete is the primary interest within this report.

Portland cement pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures and water. The porosity of the pervious pavements is provided by emitting all or most of the fine aggregates. Typically, Portland cement pervious concrete has a void content in the 15 to 25 percent range, which imparts the necessary percolation characteristics to the concrete. In 2001 the American Concrete Institute (ACI) formed committee 522, "Pervious Concrete" to develop and maintain standards for the design, construction, maintenance, and rehabilitation of pervious concrete such as Portland cement pervious concrete. This recent interest in porous materials as a substitution for impervious surfaces can be attributed to desirable benefits of stormwater retention and structural features of conventional pavement which Portland cement pervious concrete offers.

Highly urbanized areas have a drastic impact on the ratio of impervious to pervious surface areas within a region and increase the volume of stormwater in surface discharge. By substituting impervious pavement with pervious paving surfaces water is given access to filter through the pavement and parent soil, allowing for potential filtration of pollutants in the stormwater. The U.S. EPA has published a Porous Pavement fact sheet (EPA, 1999) that lists the advantages of pervious pavements as follows:

- Water treatment by pollutant removal
- Less need for curbing and storm sewers
- Improved road safety because of better skid resistance
- Recharge to local aquifers

The disadvantages of pervious pavements include restricted use in cold regions, arid regions or regions with high wind erosion rates, and areas of sole-source aquifers (Pratt, 1997). In addition, the use of porous concrete is highly constrained, requiring deep permeable soils, restricted traffic, and adjacent land uses. Although Portland cement pervious concrete has seen increased use in recent years, there is still very limited practical documented experience with the material. Also, porous pavement sites have had a high failure rate, approximately 75 percent according to the EPA, which has been attributed to poor design, inadequate construction techniques, low permeability soil, heavy vehicular traffic and poor maintenance (EPA, 1999). Failure is determined when the pervious pavement can no longer function as a stormwater retention material due to clogging or as conventional pavement due to structural failure.

In response to the high failure rates and limited practical experience with porous concrete and with new regulations pending on “post equal pre” volume budgets for stormwater management, a current and updated assessment of the performance of pervious pavements has been conducted within this report. Specifically, an investigation has been undertaken which addresses the development of installation practices for the proper construction and maintenance of Portland cement pervious concrete. Addressed in this report is the field and laboratory investigations performed to analyze the effectiveness of current construction methodologies and the clogging potential of installed pervious concrete systems to analyze rehabilitation techniques.

1.2: Background

Extreme urban growth has been a problem in the United States for decades and environmental problems associated with urban land development have grown significantly serious. Specifically, the hydrology of a developing area is severely impacted by the increase in impervious surface areas from roofs, roads and parking areas. These structures and storm sewers increase the total volume of runoff and increase peak stream flows that lead to downstream flooding, stream instability and endanger water quality (Field & Singer, 1982).

With the realization of the effects of urbanization on the hydrological environment many communities and agencies, such as the EPA, passed laws encouraging land developers to practice stormwater management on their properties. Today, state and municipal governments as well as Water Management Districts (WMD) have a great interest in finding solutions for excess stormwater runoff and the associated water quality issues.

Common approaches to stormwater management focus primarily on detaining and retaining excess runoff on the site. Another alternative approach is to reduce the amount of impervious surfaces added to a site and, by doing so, reduce the generation of excess runoff. The installation of porous concrete in parking or low traffic roadways is one of the techniques utilizing this non-generation approach.

Today, probably the most extensive use of this type of stormwater management has been in Tokyo, where it is estimated that some 494,000 m^2 of porous pavement have been constructed since 1984 (Pratt, 1997). The main incentive for the use of porous pavements in Tokyo was the need to reduce the peak flows in the urban channelized rivers, where flooding in the densely populated areas was causing enormous damage and was a threat to life. In addition to providing significant decreases in river flows, other benefits such as the raising of groundwater levels, reduction of ground settlement, conservation of urban ecology (especially trees), and moderation of temperatures in the urban districts by local evaporative cooling has been generated by adopting this stormwater management technique (Pratt, 1997).

Another more recent study on porous pavements was conducted in Rezé, France where a comparison of the pollutant loading of runoff waters either collected at the outlet of a porous pavement with reservoir structure or coming from a nearby catchment drained by a conventional separate sewerage system was done to determine the impact of the reservoir structure on the quality of both runoff water and soil. Data were collected that included approximately forty rain events during a four-year water quality survey at the experimental site (Legret & Colandini, 1999). It was determined during this study that the quality of water is significantly improved by the passage through the porous pavement with a significant reduction in the pollution loads (SS, Pb, Cu, Cd, and Zn). (Legret & Colandini, 1999) Also, further samples taken from both the porous pavement and the soil underneath showed that metallic pollutants are mainly retained in the porous asphalt and that the soil under the structure did not present any significant contamination after the eight-year period during which the pavement was in operation (Legret & Colandini, 1999).

These examples of porous pavement use in Tokyo, and Rezé, demonstrate how porous pavements can be an effective means of reducing the runoff rates, volumes, and water quality degradation resulting from urbanization, or other land use changes. Although utilizing a pervious pavement material, neither of these cases made use of Portland cement pervious concrete, the porous material used in this study.

The earliest report of Portland cement pervious concrete installation in the United States was during the early 1970's in Clearwater, Ft. Myers, Naples and Sarasota, Florida (FCPA, 1990). The sandy soil conditions under the pervious pavement made these locations ideally suited for its application. Multiple concrete cores and field evaluations were conducted on these sites throughout Florida, Georgia, and South Carolina to evaluate the permeability, infiltration rate and durability of the Portland cement pervious concrete after years of service. The sites evaluated ranged from four to eight years of service life with very little maintenance. It was found that most of the sites evaluated experienced minor raveling in isolated areas and decreased permeability, approximately 40% reduction of original permeability, within the porous concrete. The subgrade conditions encountered did not appear to have changed significantly after years of service with very little decrease in permeability (FCPA, 1990). The test results of the pavement sections showed that under actual field service conditions Portland cement pervious concrete continued to demonstrate its ability to function as a stormwater system while also providing a structural pavement for traffic loadings. However, these data are limited and dated and there is a strong need for current and updated investigations of the long-term performance of Portland cement pervious concrete.

In addition to reducing runoff volume and rate and pollutant loads in stormwater, porous concrete is also an effective source for surface water storage and transmission. Conventional stormwater and environmental considerations include either wet or dry retention areas or an exfiltration installation. Although widely used, these systems require extensive land requirements, concentrate pollutants, require expensive maintenance, functionally deteriorate and are expensive. Generally, Portland cement pervious pavement is a viable option to satisfy the stormwater quality regulations in any area with favorable soil conditions. A designer can utilize the storage and filtration capacity above the water table of the natural soil or fill materials plus the pavement as stormwater retention storage (FCPA, 1990). This method of storage is considered a layered storage method, with each layer above the seasonal high water table elevation having a measurable storage capacity (FCPA, 1990). Similar to a conventional retention pond, the Portland cement pervious pavement must provide the reservoir capacity to store the first one-half inch of untreated runoff and recover that volume within a 72 hour time period following a storm (FCPA, 1990). Currently a consistent statewide policy has not been established in reference to credit for storage volume within the voids in the pavement and coarse aggregate base. However, in an attempt to provide an estimate of credit, Josh Spence with the University of Central Florida, created a mass balance model to be used for simulation of the hydrologic and hydraulic function of pervious concrete sections. The purpose of the model is to predict runoff and recharge volumes for different rainfall conditions and hydraulic properties of the concrete and the soil (Spence, 2006). Further analysis of the effect of ground water elevation and soil type on the storage capacity of Portland cement pervious concrete design sections is needed to develop a statewide policy for credit towards porous concrete storage volume.

The field derived hydraulic data were used to simulate infiltration volumes and rainfall excess given a year of rainfall as used in a mass balance operated from a spreadsheet. The results can be used for assessing stormwater management credit.

The typical cross-section of a porous concrete system depicted in the EPA Porous Pavement fact sheet involves four layers: porous concrete layer, filter layer, stone reservoir layer and filter fabric (EPA, 1999). The porous concrete layer consists of an open-graded concrete mixture usually ranging from a depth of 4 to 8 inches. To provide a smooth riding surface and to enhance handling and placement, a coarse aggregate of 3/8-inch maximum size is normally used. The filter layer consists of a crushed stone, which serves to stabilize the porous asphalt layer and can be combined with the reservoir layer using suitable stone. The reservoir layer is a gravel base, which provides temporary storage while runoff infiltrates into underlying permeable soils and is typically made up of washed, bank-run gravel or limestone fragments of 1.5 to 3 inches in diameter with a void space of about 30% (EPA, 1999). The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces. The layer should be designed to drain completely in a minimum of 12 hours or a maximum of 72 hours, while 24 hours is recommended. (EPA, 1999) The filter fabric lines the sides of the reservoir to inhibit soil migration into the reservoir that can cause a reduced storage capacity. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the soils' infiltration capability. In Figure 1, a typical porous pavement cross section is shown.

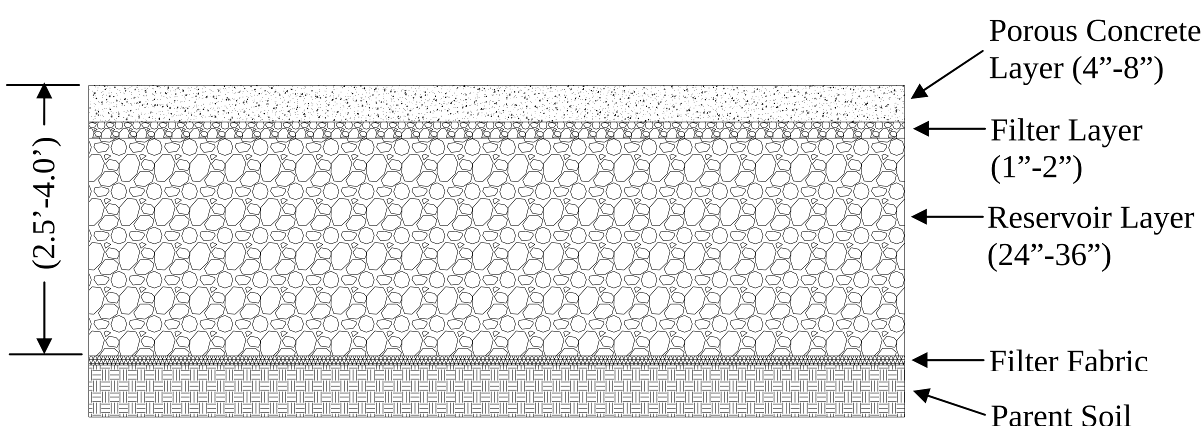


Figure 1: Typical Porous Pavement Cross Section (EPA, 1999)

Various modifications or additions to the standard design have been implemented to pass flows and volumes in excess of the storage capacity or to increase the storage capacity of porous concrete sections. The placement of a perforated pipe near the top of the reservoir layer allows the passage of excess flows after the reservoir is filled. Also, the addition of a sand layer and perforated pipe beneath the stone layer can allow for filtration of the infiltrated water. Native sandy soils can have naturally high permeability, and pervious concrete may be placed directly on top of the native soil once the site has been stripped and leveled without the need for a reservoir layer (Offenberg, 2005).

Porous concrete systems are typically used in low-traffic areas, such as, parking pads in parking lots, residential street parking lanes, recreational trails, golf cart and pedestrian paths and emergency vehicle and fire access lanes. Heavy vehicle traffic use must be limited to ensure raveling or structural failure does not occur in the porous pavement surface, which may fail under constant exposure to heavy vehicle traffic. The slopes of these installations should be flat or gentle to facilitate infiltration versus runoff and the EPA recommends a four-foot minimum clearance from the bottom of the system to the water table if infiltration is to be relied on to remove the stored water volume (EPA, 1999). Figure 2 shows a typical porous concrete installation.

Given suitable site conditions, Portland cement pervious concrete can reduce the need for stormwater drainage systems and retention ponds required for impermeable pavements by stormwater regulations. This has the advantage of generally lowering installation costs and allows for increased utilization of commercial properties. Also, a further benefit of substitution of pervious surfaces for impervious ones is the acquisition of credit based on the volume of the stormwater that can be stored and allowed to replenish the aquifer. Currently in the St. Johns

River WMD, credit is not given for Portland cement pervious concrete without current and updated investigations of the material that address the design cross-section profile including materials and dimensions for use in sandy type soils and the location of the groundwater table (Register, 2004).

Figure 2: Typical Porous Concrete Installation

1.3: Current State of the Art

The most recent design procedures and specifications for Portland cement pervious concrete can be found in the Portland Cement Pervious Pavement Manual (FCPA, 1990) or the EPA Storm Water Technology Fact Sheet for Porous Pavement (EPA, 1999). These documents contain general guidelines for the use of porous pavements that are based on limited performance data gathered from various test locations. Both documents express a need for further investigation to better understand the long-term performance of pervious concrete.

The Portland Cement Pervious Pavement Manual, produced by the Florida Concrete and Products Association, provides guidance on the use of Portland cement pervious concrete and attempts to make the benefits of pervious pavement available for wider use through explaining what it is, how best to put it together and how to obtain a satisfactory end product. Details of subgrade preparation are discussed therein as well as recommended design procedures. Suggestions on determination of infiltration rates of stormwater are given, as are recommendations on making effective use of Portland cement pervious pavement if unfavorable site conditions are encountered.

Due to the physical characteristics of pervious concrete, the Portland Cement Pervious Pavement Manual recommends the use of modified apparatus and procedures when evaluating site locations. When determining permeability of the subgrade rather than using the standard percolation testing in accordance to septic drain field evaluation, it is advised to use a surface permeability test, such as a double ring infiltrometer, after the subgrade has been compacted to specifications. In regards to evaluating the permeability of the pervious pavement the manual suggests that until such time that the various methods of making and testing of the Portland cement mixture have been defined and these results are reproducible at a reasonable standard deviation, it is recommended that the specification be based on a proportional mix design. Non-standardized testing, such as that presented in this report, is one of the primary reasons why further investigations, such as follows at the end of this report, are needed to produce a standard method of evaluating porous pavements. Eventually, the goal is to allow a credit to be provided for this type of installation.

The Portland Cement Pervious Pavement Manual also provides design procedures for pervious pavement installations. In relation to the geometric design it is noted that due to the void structure of a pervious concrete mixture it not only allows vertical transmission of water, but will also permit horizontal flow. Since the vertical rate of flow is directly related to the permeability of the subgrade and the thickness and void ratio of the pavement, it is advised to maintain a level profile grade, which will allow as much time as possible for the subgrade to absorb and transmit water to the lower strata and reduce the horizontal flow rate. Additionally, after compaction subgrade soils have much less vertical water transmission than lateral transmission by a ratio of as much as 1:10. This is why a reservoir layer can be necessary to increase the rate of absorption of water into the subgrade (FCPA, 1990). The manual states that, to date, most research and testing data for pervious concrete relates to building construction applications and limited research is specifically related to pavements. Also, there is limited research relative to subgrade reactions and the recommendations stated in the manual are based on a limited number of projects in Florida that have shown good performance. This limited research is why further study is needed to evaluate the drainage capabilities of pervious concrete in relation to water table elevation, parent soil type and pavement thickness.

Some field studies on Portland cement pervious concrete are also presented in the Portland Cement Pervious Pavement Manual, which, along with laboratory studies of pervious concrete, are the basis of the design recommendations presented in that manual. The investigations and studies included in the FCPA manual encompassed the following:

- Development of field test procedures
- Pavement’s long-term durability, significant signs of distress, and effect of materials or placing methods on performance

- Subgrade conditions relative to permeability and density after years of water intrusion
- Degree of infiltration (clogging) of the pavement
- Field permeability relationships of pavement, subgrade or subbase, and grass sod
- Unit weight determinations of pavement samples
- Cylinder molding and testing relationships

Since permeability and durability were the prime factors in the evaluation of the Portland cement pervious concrete, the field investigations were conducted at pavements installed with many years of service. Five locations within Florida, two in Georgia, and one in South Carolina were selected to study Portland cement pervious pavement's ability to perform under field conditions. It was found from these locations that there was no significant reduction in the subgrade's permeability and that there was a very small amount of clogging in the porous concrete after many years of service. Although the projects studied in this investigation presented favorable results, the locations were limited and the effect of the subgrades and subbases on the Portland cement pervious concrete was not fully investigated.

The EPA Storm Water Technology Fact Sheet for Porous Pavement presents the general applicability, advantages, disadvantages, and design criteria for porous pavements. The design criteria presented in this report are the basic guidelines most pervious pavement systems are based on, but are general for all types of pervious pavements and are not specific for any one type. These guidelines are based on very few field locations and may not pertain to any specific location. For these reasons, material and geographical specific guidelines are needed to accurately develop design section specifications. The EPA Fact Sheet also states that more information is needed on whether porous pavement can maintain its porosity over a long period of time, particularly with resurfacing needs and snow removal.

In 2001, the American Concrete Institute formed committee 522, “Pervious Concrete” to develop and maintain standards for the design, construction, maintenance, and rehabilitation of pervious concrete. This committee is currently drafting a document entitled, “Report on Pervious Concrete” but has yet to release this material. Interest like this has increased the demand for more accurate and conclusive data on Portland cement pervious concrete.

The Southwest Florida Water Management District recently conducted an investigation on infiltration opportunities in parking lot designs that will reduce runoff and pollution. The experimental design was for a parking lot that allowed for the testing of three paving surfaces as well as basins with and without swales, creating four treatment types with two replicates. The three treatment types included asphalt paving with no swale, asphalt paving with a swale and porous paving. Water quality and sediment samples were collected and runoff measurements taken and compared. It was concluded from this analysis that basins with porous pavement had the greatest runoff reduction and also showed the best percent removal of pollutant loads. This study, like the investigation in Rezé, focused primarily on the runoff reduction and water quality improvement capabilities of pervious pavement and not on the design criteria for the design section.

Due to state and municipal governments, as well as water management interests in finding solutions for excess stormwater runoff and the associated water quality issues, a current evaluation of the performance of pervious pavements is greatly needed. In this report, issues such as materials and dimensions for use in sandy type soils and the rehabilitation of clogged pavements will be evaluated and the necessary information to produce a design section for pervious pavements.

1.4: Chapter Summary

In summary, presented in this chapter are the composition and applications of Portland cement pervious concrete and how the installation of this material can decrease stormwater runoff rates and volumes. Some benefits for the use of Portland cement pervious concrete are: sediment removal, less need for curbing and storm sewers, improved road safety because of better skid resistance, and recharge to local aquifers. A typical pervious pavement design section, based on EPA design recommendations, is described along with the corresponding layers and their functions within this typical design section.

Within the current state of the art section of this chapter, the latest studies and documents pertaining to porous concrete were evaluated and reviewed. Specifically, the Portland Cement Pervious Pavement Manual by the Florida Concrete & Products Association, which presents the latest design and testing procedures for Portland cement pervious concrete, and the EPA Storm Water Technology Fact Sheet for porous pavements were presented. These documents present field data and design criteria for pervious pavement sections but do not fully cover the effects of the soil type or water table elevation on the infiltration rates through the permeable pavement. These studies have limited field sites and further study is needed to determine whether porous pavement can maintain its porosity over a long period of time. Also found in this section are the results of field studies that evaluated porous pavements efficiency in pollutant removal and stormwater runoff reduction. In both studies, namely the one in Southwest Florida and in

France, it was found that pervious pavements are very efficient in the removal of pollutants, especially suspended solids, and is also able to significantly reduce stormwater runoff volumes and rates. This chapter depicts the strong need for a current and updated investigation of Portland cement pervious concrete that addresses the construction specifications and maintenance of pervious concrete.

1.5: Roadmap

This report is comprised of six chapters. In the first chapter an introduction to the topic and background information on Portland cement pervious concrete is presented. Also, reviews are presented for current research efforts to study the application and affects of pervious concrete systems. In Chapter 2 the purpose and expected contributions of this research are defined. Proposed in Chapter 3 are the field exploration methodology and the laboratory modeling approach. It also includes the design outline of the in-situ testing apparatus. Chapter 4 presents the results of the field tests and a description of each of the investigated field sites. The results of the associated laboratory testing and infiltration remediation testing are also presented and discussed in this chapter. Included in Chapter 5 are the recommended pervious concrete construction specifications and recommended maintenance and inspection program. The conclusions and recommendations for future research are presented in Chapter 6.

CHAPTER TWO: PROBLEM DEFINITION

2.1: Problem Statement

Currently, a consistent statewide policy has not been established in reference to credit for storage volume within the voids in Portland cement pervious concrete and the coarse aggregate base. To gain widespread acceptance for use, answers and information are needed pertaining to the design cross-section profile and whether porous pavement can maintain its porosity over a long period of time. By modeling a pervious concrete system in the laboratory with tanks that simulate soil conditions and groundwater elevations typical of sandy soils and combining these data with field data from multiple sites of long service life, a specific construction methodology can be developed. These results can then be evaluated to develop current construction specifications for pervious concrete use in specific soil conditions, including, contractor qualifications, details on materials and mix design, construction guidelines, post construction guidelines, and testing and inspection guidelines.

In addition, an in-situ testing method for measuring infiltration rates of pervious concrete parking lots was also developed to measure hydraulic operational efficiency and to gather data for utilization in comparing the effectiveness of various infiltration rehabilitation techniques on clogged pervious concrete. The field data will also be utilized to compare the effectiveness of vacuum sweeping and pressure washing on clogged pervious concrete cores. This information is to be used in developing general maintenance schedule recommendations.

2.2: Research Contributions

By investigating existing pervious concrete pavement systems in Florida, Georgia, and South Carolina and reviewing previous construction specifications, a more accurate construction methodology can be developed for specific soil characteristics. With more accurate design cross-sections, the reservoir layer can be more accurately evaluated and reduced to eliminate unnecessary soil excavation. Credit can be given for storage volume within the voids in Portland cement pervious concrete and the coarse aggregate base once statewide-accepted standards for the design cross-section have been determined.

The various sandy type soils encountered during the field investigation will be analyzed to better understand the infiltration capabilities of the parent soils. By observing the infiltration and flow of stormwater into the parent soil, conclusions can be drawn on the soil types' affect on the depth of the reservoir layer necessary for a given type of soil. This will allow for more accurate design sections for less permeable soils, which will reduce the chance of flooding during high volume and intensity rain events.

Cores obtained from the field investigation performed at eight sites within Florida, Georgia and South Carolina are initially tested for infiltration capability in the laboratory and then rehabilitated using various testing methods including, vacuum sweeping and pressure washing. By comparing infiltration rates of the pervious concrete cores prior to rehabilitation and after, conclusions can be drawn on the effectiveness of these techniques. Once the effectiveness of these techniques has been established a more accurate maintenance schedule can be developed for pervious concrete sites.

The most important contribution made by this research will be the widespread acceptance of Portland cement pervious concrete as an answer to the stormwater runoff problem associated with urban development. With the increased use of pervious pavement land developers will be able to reduce the size of retention areas and in doing so increase the amount of developable land on their property. Finally, this research will greatly contribute to the reduction of costs associated with porous pavement use by making it possible to more accurately predict a maintenance schedule for the porous pavement and by making it possible to gain credit for porous pavement use. If proven effective in performance, this is a much less costly water storage device than the conventional retention pond.

2.3: Research Limitations

The research presented in this paper is limited to information originated from sites with the southeastern United States. Soil information was limited to the sandy type parent soils due to the inability of the embedded single-ring test to function with highly impermeable soils and systems with a gravel reservoirs. The effects of snow and freezing are not considered in this research since they are rare cases in the geographic area covered by this study. Also, the research conducted in this report considered only Portland cement pervious concrete and no other type of pervious pavement.

CHAPTER THREE: METHODOLOGY

3.1: Laboratory Investigation

In preparation of the field investigation, it was necessary to develop a testing method to assess the conditions of in-situ pervious concrete at the selected field sites. Data collected from field testing was applied in the development of the construction specifications for pervious concrete and was also used to assess the infiltration capability of pervious concrete after it had been in operation for several years. This information was also used in comparison to infiltration rates of the pervious concrete after various rehabilitation techniques had been applied.

A field test site for experimentation on the University of Central Florida campus was constructed at the Stormwater Management Academy Field Laboratory. Two test cells were designed as self-contained systems that were impermeable on all sides except for the surface. Each test cell was built six feet square and four-and-one-half feet deep from the surface of the pavement and was constructed side-by-side into the face of an existing berm. The design included an underdrain system for the removal of water and monitoring the water level in the test cells.

The test cells were constructed with plywood and lined with an impermeable rubber liner. The fill soil used in the cells was a Type A hydrologic soil classified as a fine sand or A-3 soil using the AASHTO soil classification system. The soil was compacted in 8 inch lifts to a minimum of 92% of the Standard Proctor maximum unit weight of 104 lb/ft^3. The soil had a hydraulic conductivity of approximately 12 inches per hour as determined by permeability testing prior to compaction. After compaction, the infiltration rate was approximately two inches per hour as determined by application of a double-ring infiltrometers test (ASTM D 3385-94). One cell contains a five-inch deep reservoir of $^3/_8$ to ½ inch coarse aggregate, and both cells have a five- inch thick pervious concrete slab. Depicted in Figure 3 is the installation of the pervious concrete in the test cells as well as a double-ring infiltrometer test being performed on the compacted subsoil.

Figure 3: Stormwater Academy Porous Concrete Test Cell Installation

Test cells were used to conduct the initial evaluation of various in-situ testing methods which included the use of double-ring and single-ring infiltration tests that were potential methods of evaluating the flow rates into pervious concrete in the field investigation portion of this study. The test cells could not be used for the additional purpose as a system to evaluate mass balance in a pervious concrete system due to leakage.

A double-ring infiltrometer (ASTM D3385-03) was the first method evaluated to calculate the in-situ infiltration rate of the porous concrete, a procedure used in similar pervious concrete field investigations (Bean, 2005). The double-ring infiltrometer is a cylindrical or square metal frame with no bottom so that the water is directed downward as shown in Figure 4. The walls of the infiltrometer reduce the effect of lateral infiltration. There is no standard dimensions for infiltrometers but studies have found that the larger the diameter, the lower the error (Minton, 2002).

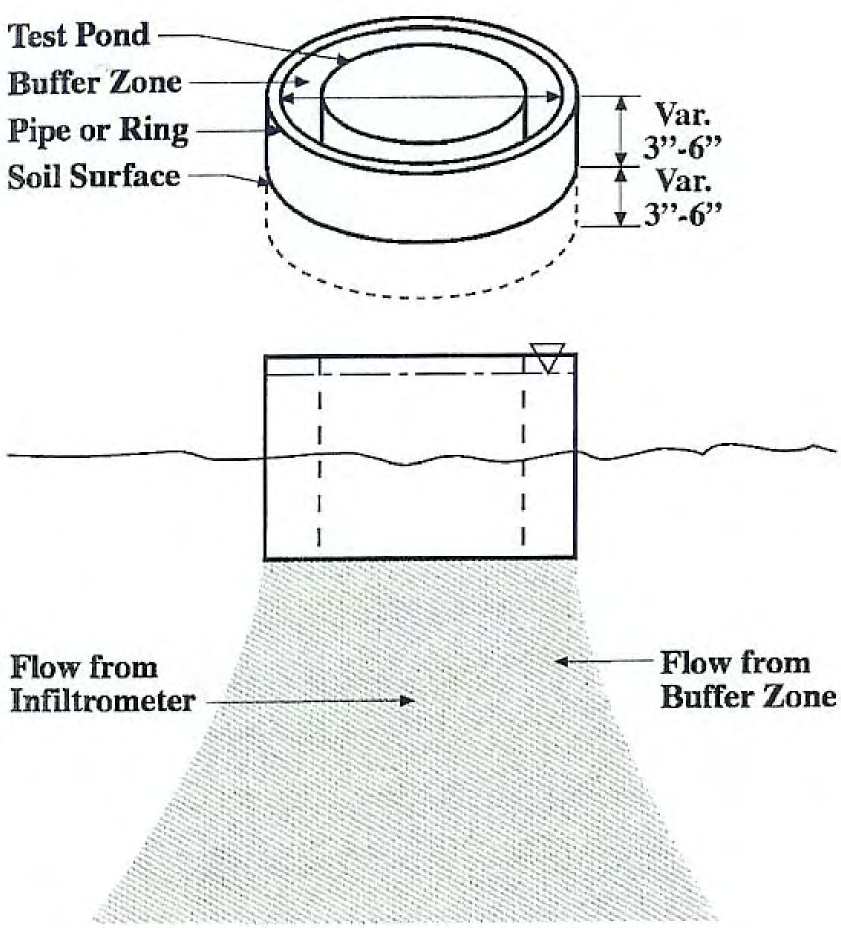


Figure 4: Double-Ring Infiltrometer (Minton, 2002)

Water is placed in both the inner and outer rings, but the measurement is made only of the water flow to the inner ring. The rate at which water must be added to maintain the water level at the height of the infiltrometer is measured. This rate defines the infiltration rate at the water depth of the test. The standard test method for the infiltration rate of soils in the field using double-ring infiltrometer, ASTM D3385-03(ASTM, 2003), states that this test method is difficult to use or the resultant data may be unreliable, or both, in very pervious soils. Since Portland cement pervious concrete is both very pervious and does not allow the double-ring infiltrometer to be inserted into the material, it allows preferential lateral flow as shown in Figure 5.

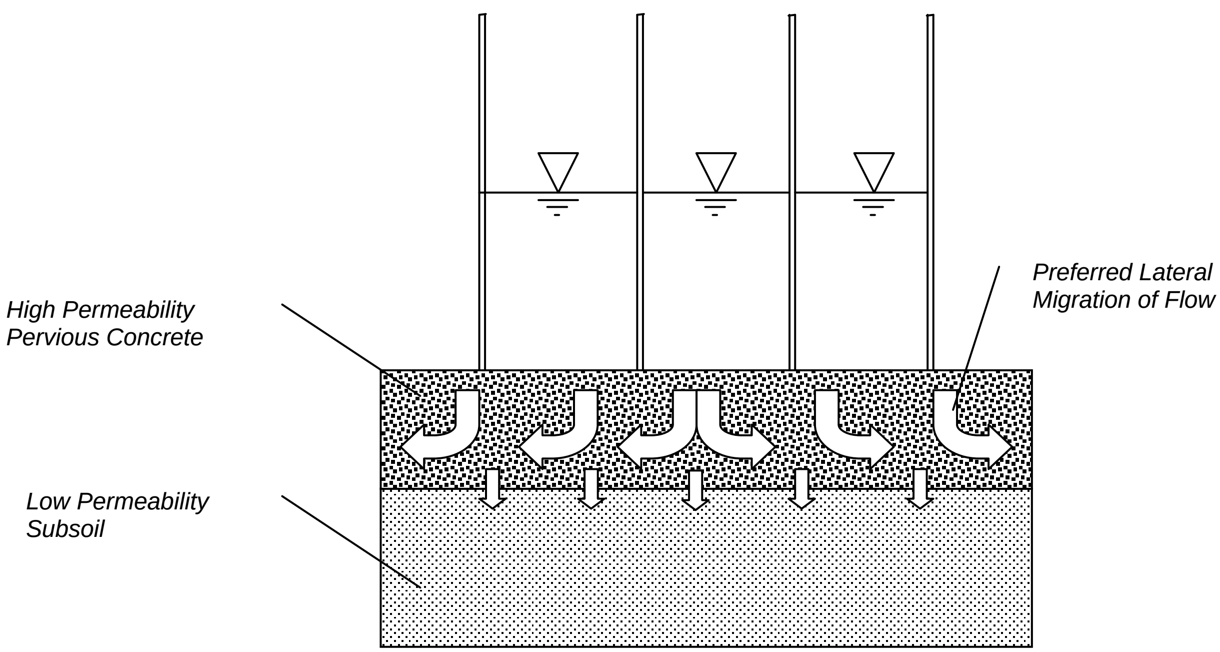


Figure 5: Double Ring Test on Pervious Concrete

Infiltration tests performed on the surface of the concrete using the double-ring infiltrometer produced highly unrealistic results due to the lateral flow in the pervious concrete, which limited the ability of the water to infiltrate into the subsoil. It was determined a modified method of the double-ring infiltrometer, which would isolate the pervious concrete and subsoil causing one-dimensional flow, would be required to realistically measure the in-situ performance of pervious concrete.

To allow infiltration of the subsoil, and thus one dimensional flow, would require the embedment of a device similar to the double-ring infiltrometer into the subsoil of the pervious concrete system. As testing in the field was to be performed in an in-situ state it would be necessary to develop a more destructive method of testing to reach the subsoil. By cutting a circular section of concrete using a concrete coring machine, a ring similar to those used in a standard double-ring infiltrometer test could be driven into the parent soil material. It was necessary to test a large enough portion of a pervious concrete site to be considered a "representative area" while limiting the area of destructive testing, a 12-inch diameter core bit was chosen. A 12-inch bit creates an 11 5/8-inch diameter concrete core with a 3/16-inch circular cut.

The ring crafted to embed through the pervious concrete and into the subsoil was a 20-inch long rolled steel tube with an inner diameter of 11 5/8 inches and 11-gauge thickness as shown in Figure 6. The tube was designed to be inserted around the concrete core and embedded into the underlying soil. This single-ring infiltrometer encourages one-dimensional flow through the interface of the pervious concrete and the soil by limiting the ability of water to travel laterally through the pervious concrete and the soil. Thus the concrete and subsoil are considered as one integrated 'system'.

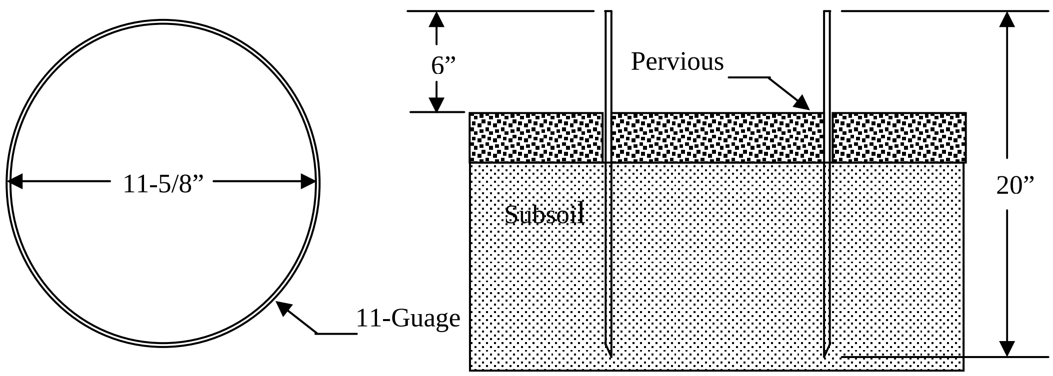


Figure 6: Single-Ring Infiltrometer

The single-ring infiltrometer utilizes the same testing procedure as the double-ring, as outlined in ASTM D3385-03 “Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer” with the modification of its embedment and the use of a single ring. A specific head (three inches) was maintained, water was added at specified time intervals, and the amount of water added at each time interval was recorded. The tests were stopped after at least two consecutive time periods recorded approximately equal additions of water.

The embedment depth was determined by finding the necessary depth to maintain one-dimensional flow at the interface and the need for a sufficient length of the tube to remain above the surface of the pavement to allow for a specific head to be maintained and also to allow for removal of the tube after embedment. After several evaluations of different embedment depths by comparing infiltration rates measured by the single-ring infiltrometer to those measured by the double-ring infiltrometer at the standard embedment depth, it was determined that the 14 inches beneath the surface of the concrete (typically 8 inches of embedment into the subsoil) produced equivalent infiltration rates to the double-ring infiltrometer. This allowed 6 inches of tube above the surface to be utilized for maintaining a specified head during the test.

Single-ring infiltrometer trial tests were conducted on the test cells at durations between 20 and 45 minutes to reach a constant infiltration rate. It was determined from these trials that during a test of equivalent duration approximately two inches of water infiltrated the subsoil. Assuming a porosity of 0.35, typical of the regional soils, the wetting front from of the infiltrated water would not have passed the depth of the embedded tube during the course of the test. This assures that approximately one dimensional flow was occurring at the soil-concrete interface. It was assumed that the soils local to the test areas would be typical of the proposed field sites.

Finally, during testing at the Stormwater Management Academy Field Lab, a method for the extraction of the embedded single-ring infiltrometer was developed. Since the ring was embedded using compaction force it became lodged securely and could not be removed easily. In order to extract the embedded apparatus ½-inch holes were drilled in the steel tube, approximately one inch from the top of the tube. The holes were threaded with a U-bolt attached to a chain and the chain was wrapped around a two foot long, two-inch by two-inch hollow-body steel section. The steel section was propped across two hydraulic jacks, which were then used to hydraulically lift the infiltrometer out of the ground.

3.2: Field Investigation Methodology

Several pervious concrete sites in the Central Florida area and surrounding states were tested to measure infiltration rates using the embedded Single-Ring Infiltrometer Test. These sites ranged from 6 to 20 service years and are located in and around the cities of Orlando and Tallahassee, Florida; in Atlanta and Guyton, Georgia; and in Greenville, South Carolina. The sites are functional parking lots, and one landfill, that are currently in operation and are in various conditions in terms of maintenance, clogging and raveling. The location and year of construction for each field site is listed below:

- Site 1: Sun Ray Store-Away Storage Facility: Lake Mary, Florida [1991].
- Site 2: Strang Communication Office: Lake Mary, Florida [1992].
- Site 3: Murphy Veterinarian Clinic: Sanford, Florida [1987].
- Site 4: FDEP Office: Tallahassee, Florida [1985].
- Site 5: Florida Concrete & Products Association Office: Orlando, Florida [1999].
- Site 6: Southface Institute: Atlanta, Georgia [1996].
- Site 7: Cleveland Park: Greenville, South Carolina [1995]
- Site 8: Effingham County Landfill: Guyton Georgia [1999].

A standardized procedure was developed and followed in the field to determine the infiltration rates of the pervious concrete. The step-by-step procedure is outlined below:

1. The pervious concrete surface is cored in three evenly spaced locations utilizing a 12 inch outside diameter, diamond tipped concrete core bit. The drilling process takes between 10 and 30 minutes per concrete core depending on the type of aggregate used in the concrete mix and depth of the concrete slab. The coring rig and the core bit are shown in Figure 7.

Figure 7: Coring Rig, Core Bit, Single-Ring Infiltrometer, and Generator

The core samples are left in place after drilling for in-situ infiltration testing. When necessary, the cores were extracted and grinded along the sides to remove irregularities formed during the coring process to allow the single-ring infiltrometer to fit around the core. A four-inch angle grinder with a masonry disk was utilized for this task. Figure 8 shows the 12 inch core placed next to the location it was removed from in the pavement. It is clear that the pavement system at this site does not have a drainage layer of gravel. This configuration is typical for pavements on soils with high permeability values.

Figure 8: Pervious Concrete Pavement Core

2. Once the single-ring infiltrometer can pass into the cut made by the coring rig, the infiltrometer is embedded into the subsoil by applying a downward force. The infiltrometer is typically installed using a hand-tamper making sure to mark the infiltrometer before embedment to ensure the infiltrometer is installed to the proper depth.
3. After the single-ring infiltrometer is embedded to the proper depth, a bead of plumber’s putty is placed around the inside circumference of the infiltrometer to prevent side-wall leakage.
4. Infiltration rates of the three cored locations are measured using the embedded Single-ring Infiltrometer Test as discussed in the previous section. Figure 9 shows a test in progress with the infiltrometer in the embedded state.

Figure 9: Pervious Concrete Pavement Core Test

5. Pervious concrete cores are then extracted using the two hydraulic jacks to be returned to the Stormwater Management Academy (SMA) laboratory to be tested individually, for the infiltration rate of the pervious concrete and the effectiveness of various rehabilitation techniques.
6. An additional infiltration test is performed on the bare soil beneath on of the core locations to determine a soil infiltration rate using the same method for the concrete and subsoil system.

7. The field unit weight of the subsoil is then determined using the Sand Cone Method as outlined in ASTM D 1556 "Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method". Figure 10 shows a sand cone test in progress.

Figure 10: Performing Sand Cone Test

8. A soil profile beneath the pervious concrete surface is generated utilizing a hand-operated bucket auger. Soil samples are obtained at locations of soil-type change down to the depth of the water table. These soil samples are later analyzed for permeability, void ratio, and grain sizes using the methods outlined in ASTM D 2434-68 and ASTM C 136-04.

9. Water table depths are recorded for use in modeling studies planned for the pervious concrete system.
10. The subsoil shall be replaced and the pervious concrete is repaired using the original specifications at the locations where it was cored. An example of this patching is depicted in Figure 11.

Figure 11: Repair of Concrete Core Area

Soil samples gathered in the field were sieved and categorized and selectively tested for permeability. Also, the cores obtained in the field were individually tested for permeability and unit weight. Permeability tests on cores were conducted by wrapping the cores tightly in six millimeter plastic and securing the plastic along the entire length of the core with duct tape. The wrapped core is elevated on wooden blocks and the infiltrometer is fitted over it. The gaps between the core and the infiltrometer are filled with plumber's putty to limit flow to the pores in the concrete. The infiltrometer is filled to a specific head of water and the setup is checked for leaks prior to the beginning of the test. The infiltration of the cores is then tested utilizing the same techniques as described above for the embedded test. See Figure 12 for laboratory test setup. The concrete cores average thickness and weight are measured in order to approximate the individual cores unit weights.

3.3: Infiltration Rehabilitation Methodology

A major concern and limiting factor in pervious concrete systems is the potential for the pervious concrete to clog during operation. Several clogging rehabilitation techniques have been recommended, including, pressure washing and vacuum sweeping. Current literature from the Mississippi Concrete Industries Association predicts recovery of 80 to 90 percent infiltration capability of pervious concrete specimens after rehabilitation techniques have been performed. In order to verify these predictions the effectiveness of these two techniques was analyzed using the cores obtained in the field test investigation portion of this research. Techniques investigated in this study include:

- Vacuum Sweeping
- Pressure Cleaning
- Combination of both Vacuum Sweeping and Pressure Cleaning

The ultimate objective of this study is to develop a standardized inspection and maintenance schedule. The standardized laboratory testing process for investigating the improvement in pavement infiltration performance due to these rehabilitation techniques is described below.

1. The 12 inch pervious concrete cores were first wrapped in a 6 mil impermeable poly film and this material was then secured to the core by wrapping it in a layer of duct tape. This was done to limit flow through the concrete core to one-dimensional vertical flow.
2. Initial infiltration rates of each of the cores were determined by the following steps:
    a. Elevate the core to allow water to freely flow from the bottom of the core
    b. Attach the Single-Ring Infiltrometer to the core
    c. Apply plumbers putty to the inside and outside edge of the Single-Ring Infiltrometer where it meets the pervious concrete to eliminate flow down the side of the cores as shown in Figure 12.

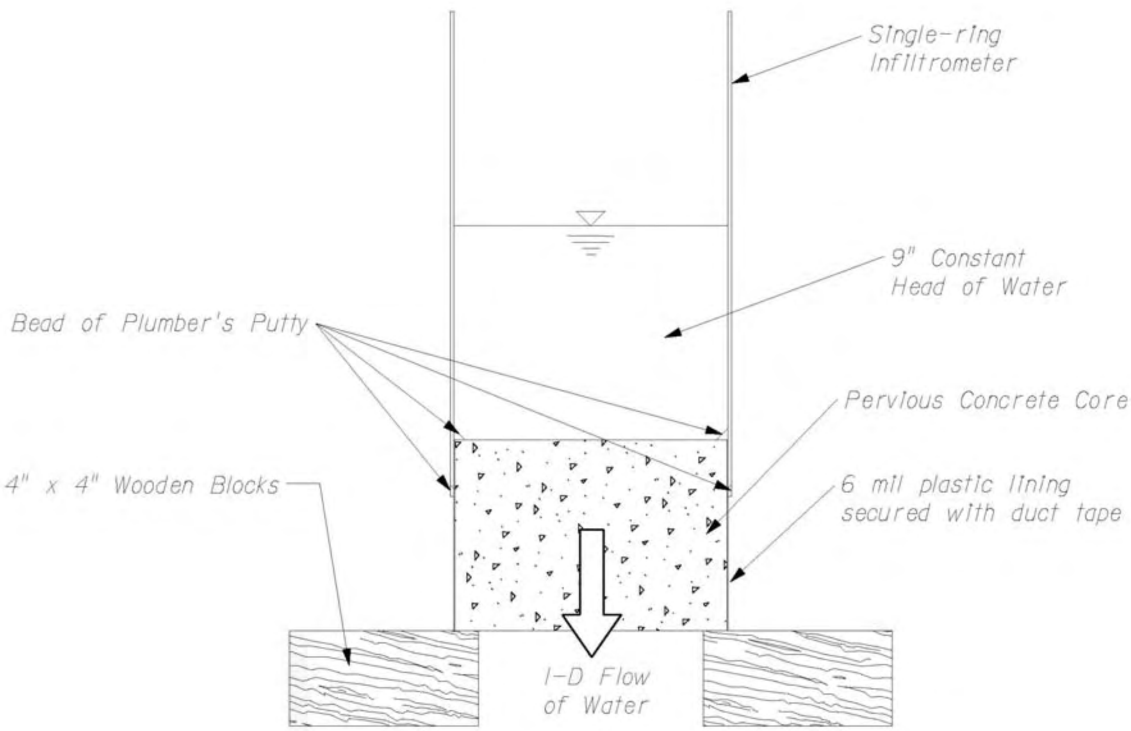


Figure 12: Laboratory Core Infiltration Schematic (Spence, 2006)

    d. Apply water to the core to achieve an approximately eight-inch head.

3. Infiltration rate of the water through the core was monitored by maintaining a constant head on the core when flow rates were low enough. If flow rates were too high the infiltration rate was determined by monitoring the falling head.
4. Each of the cores obtained at each field site (typically three at each site) had one of the following rehabilitation techniques performed:
    a. Pressure washed using a 3000 psi gas pressure washer
    b. Vacuum sweep using a 6.5 hp wet/dry vacuum and sweeper
    c. Pressure washing then followed by vacuum sweeping
5. Sediment removed during the rehabilitation was collected for further analysis including determining the grain-size distribution.
6. Rehabilitated infiltration rates of each of the cores were determined by the steps outlined above for determination of the initial infiltration rates.

In addition to the outlined procedure for the analysis of the effectiveness of various infiltration rehabilitation techniques, it was also necessary to determine the limit of pressure and distance applied in the use of a pressure washer. By testing typical pressures and distances used in pressure cleaning, a limit was found to limit raveling of the pervious concrete. By validating the use of these rehabilitation methods and determining the effectiveness in recovering infiltration capability in pervious concrete, maintenance recommendations and scheduling can be developed. This is discussed further in Chapters 4 and 5.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1: UCF Stormwater Management Academy Field Laboratory Results

Preliminary evaluation of in-situ, infiltration measurement techniques were performed at the UCF Stormwater Academy Field Laboratory. Typical methodology for testing in-situ infiltration rates of surficial soils includes the use of a double-ring infiltrometer. As this study calls for the measure of the infiltration rate of both the pervious concrete and the subsoil as a system, an apparatus was developed that limited the destruction of the in-situ pervious concrete. The embedded single-ring infiltrometer developed required analysis to ensure that infiltration rates produced using this in-situ test were comparable to those obtained with the standard double-ring infiltrometer. Several soil infiltration rates were measured at the UCF Stormwater Academy Field Laboratory using both the double-ring and single-ring infiltrometers in relatively identical soil conditions and for about 5 inches of rainfall. The results of these tests are presented in Table 1.

Table 1: Comparison of Single-Ring and Double-Ring measured infiltration rates

Measured Infiltration Rate (in/hr)	
Single-Ring Infiltrometer	**Double-Ring Infiltrometer**
20.41	21.15
23.51	23.34
20.52	21.40

The measured infiltration rates from the comparison of the single-ring and double-ring infiltrometer tests were found to be comparable. Two additional parameters needed to be specified to confirm the accuracy of the single-ring infiltrometer results. The hydraulic head applied during the test was determined by performing a single-ring infiltrometer test, allowing the flow rate to reach equilibrium, and then adjusting the hydraulic head in a range of 4 to 8 inches above the pervious concrete surface. A head of 1 inch was also used and the rate decreased by about 50% but there was still no significant differences between the double and single ring infiltration rate measurements. Finally, the test duration was evaluated by allowing a single test to run for an extended duration. A graph of the results of this test is depicted in Figure 13.

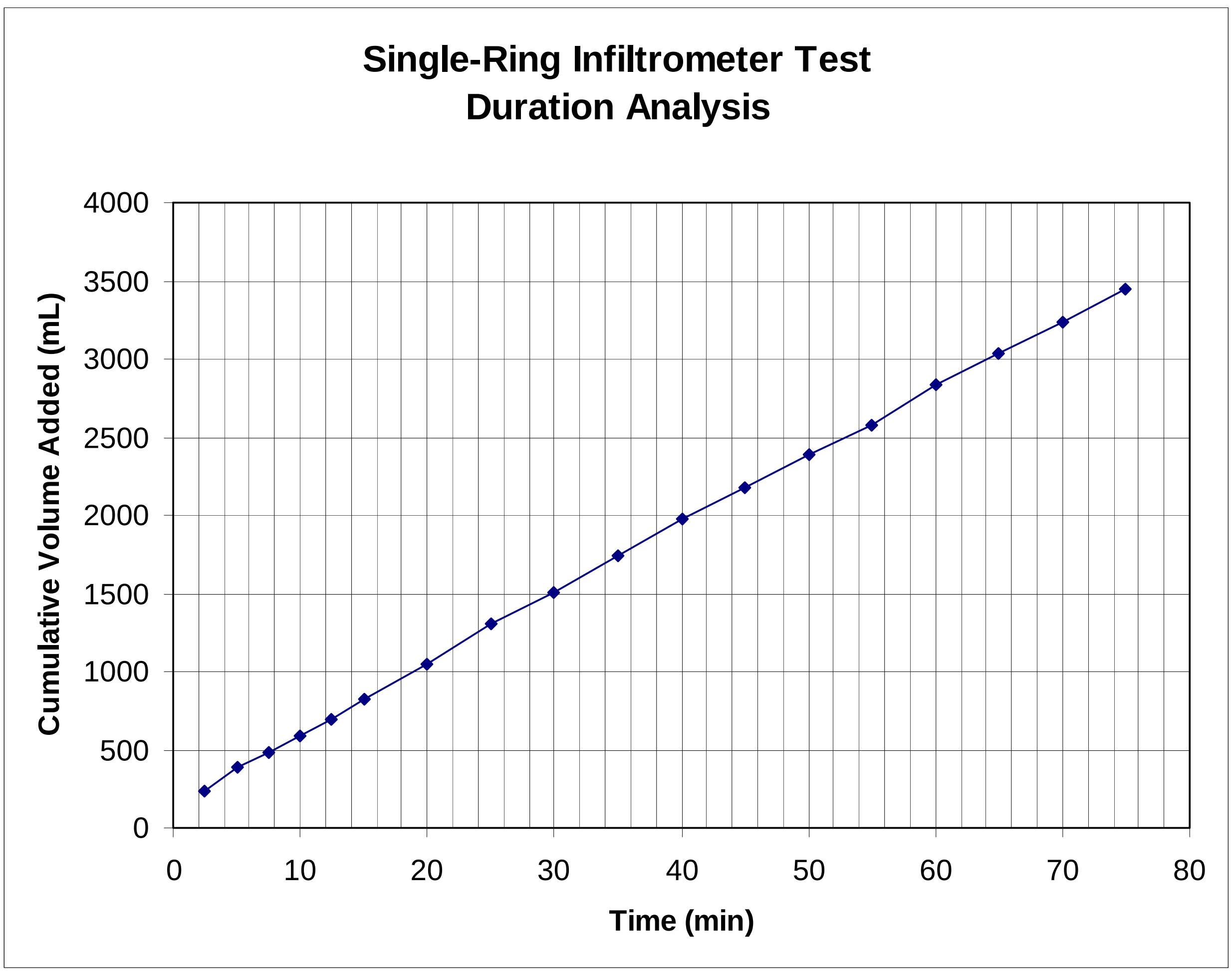


Figure 13: Single-Ring Infiltrometer Duration Analysis

It can be concluded from the single-ring infiltrometer duration analysis that little variance was recorded in the measured infiltration rate after two consecutive infiltration rates were measured. A termination criterion of a minimum test duration of fifteen minutes that can be stopped after two consecutive infiltration rates are recorded is therefore specified for future tests.

With the validation of the single-ring infiltrometer testing method several infiltration tests were performed using the test cells constructed at the UCF Stormwater Academy Field Laboratory. The properties of the soil used in the test cells were measured prior to testing and are summarized in Table 2.

Table 2: Summary of Test Cell Soil Properties

Soil Property	**Value**
% Passing No. 200 Sieve:	1.3 %
AASHTO Soil Classification:	A-3
Hydrologic Soil Classification	A
Void Ratio, e	0.74
Porosity, n	0.43
Maximum Dry Unit Weight	104.7 lb/ft^3
Optimum Moisture Content	14.3%
Measured Dry Unit Weight	98.28 lb/ft^3
Infiltration Rate	2.61 in/hr

The pervious concrete section in the test cell was cored in two locations to allow testing of the pavement system. Each of these core locations were tested using the embedded single-ring infiltrometer on four separate occasions. Various recharge times were permitted between tests to evaluate the impact of soil saturation on the measured infiltration rates. Each of the tests was performed with a head of 8 inches and duration of 45 minutes. These tests are summarized in Table 3 and depicted in Figure 14.

Table 3: Summary of Pervious Concrete System Infiltration Rates

Core	Test Date	Infiltration Rate (in/hr)
A	1/19/05	2.40
B	1/19/05	2.41
A	1/20/05	1.16
B	1/20/05	1.21
A	1/21/05	1.03
B	1/21/05	1.45
A	1/25/05	1.48
B	1/25/05	1.45

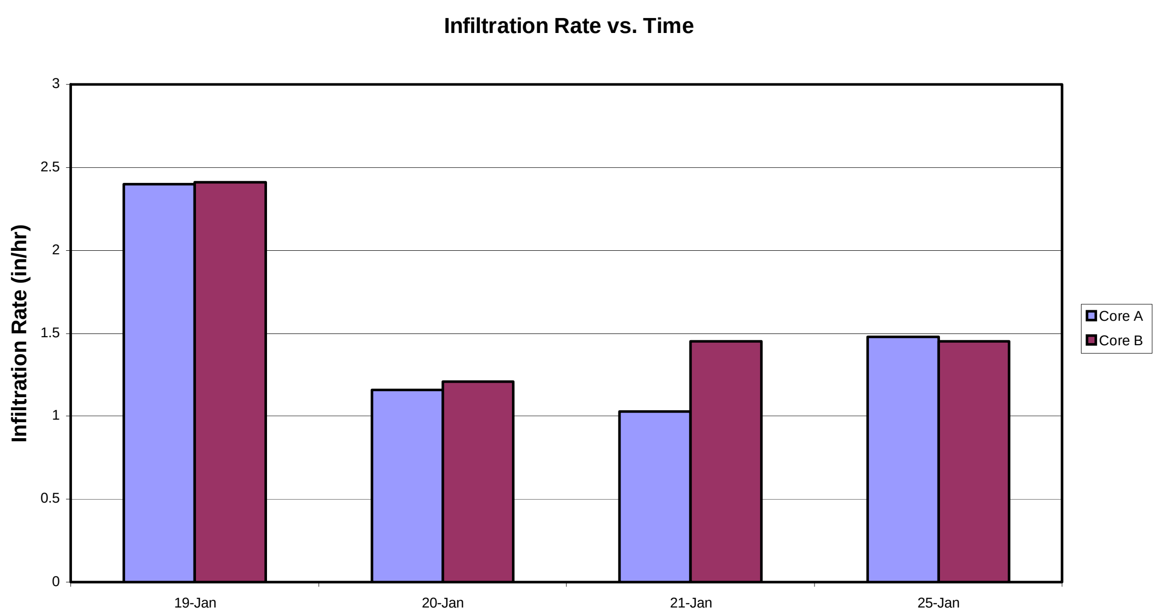


Figure 14: Visual Summary of Pervious Concrete System Infiltration Rates

Several trends are depicted in the results of the preliminary single-ring infiltrometer tests. The pervious concrete and subsoil system displays infiltration rates of nearly the same magnitude as the subsoil prior to the pervious concrete placement (2.61 in/hr). Also, infiltration rates from the single-ring infiltrometer tests performed on the pervious concrete and subsoil system decrease when the subsoil is still saturated from previous testing due to reduced storage capacity and ease of migration. With these conclusions and validation of the single-ring infiltrometer measurements various field sites were visited to evaluate pervious concrete systems with long service life.

4.2: Field Site Investigations

Pervious concrete sites in Florida, Georgia, and South Carolina area were tested to measure infiltration rates using the embedded single-ring infiltrometer test. A total of eight field sites were investigated, four of which were located in the Central Florida area: Sunray Store-Away, Strang Communication, Murphy Veterinarian Clinic, and the Florida Concrete and Products Association (FCPA) Office. The four other sites included locations in Tallahassee, Florida (Florida Department of Environmental Protection (FDEP) Office), Atlanta, Georgia (Southface Institute), Guyton, Georgia (Effingham County Landfill); and Greenville, South Carolina (Cleveland Park). These sites ranged from 6 to 20 years of service.

Sites are typically functional parking lots, with the exception of the landfill site, and are currently in operation and in various conditions in terms of maintenance, clogging and raveling. Each field site was investigated for infiltration rates of the existing pervious concrete and the soil properties of the subsoil. In addition the cores obtained in the field are utilized in evaluating the effectiveness of various rehabilitation techniques in a lab environment.

4.2.1: Sun Ray Store-Away Storage Facility

Located in Lake Mary, Florida and constructed in 1999, the Sun Ray Store-Away Storage Facility is 0.7 acre storage facility subjected to a variety of loads. Pervious concrete is utilized in the roadway system around the 823 storage units and in the 62 parking spaces available for large vehicle storage. Pervious concrete thickness across this site ranged from 5.1 to 6.9 inches. Damage to this pervious concrete system is limited to the area in the vicinity of the front gate and in the area of the garbage dumpster. The cracking encountered at the front gate can be attributed to the fact that all traffic entering into the facility passes over the area causing additional loading. The cracking encountered in the dumpster area can be attributed to the extreme impact-type loads caused by the garbage truck when emptying the dumpster. Figure 15 is an approximate schematic drawing for this site.

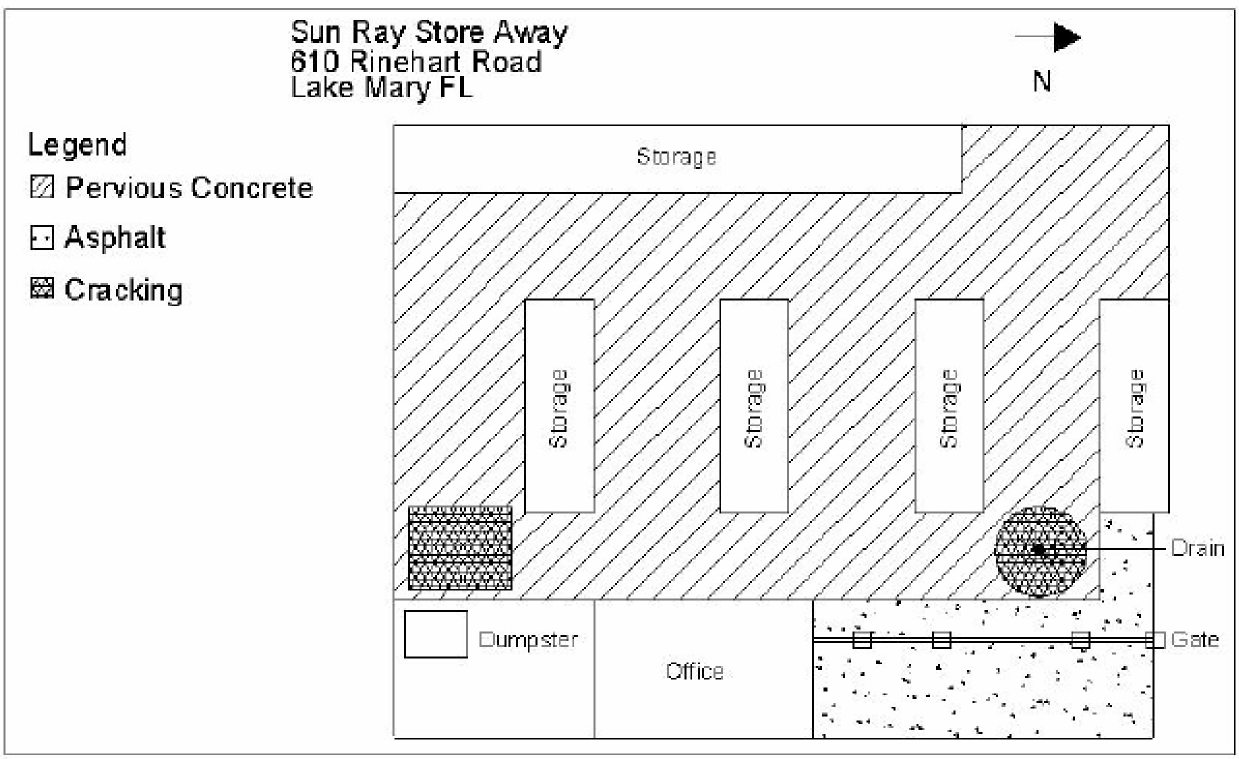


Figure 15: Sun Ray Store-Away Storage Parking Lot Schematic (Not to scale) (Mulligan, 2005)

The field investigation at this site included the collection of six cores and soil samples at two of the core locations. The single-ring infiltrometer was used to determine in-situ infiltration rates of the pervious concrete and subsoil system and the subsoil and pervious concrete cores separately. Table 4 summarizes the results of the soil analyses and Table 5 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 4: Summary of Sun Ray Store-Away soil parameters

Soil Parameter	**Soil Sample Location**					
	Core A-1			**Core A-6**		
Sample Depth (ft)	0-2.1	2.1-2.5	5-6	0.5-1.7	3.5-4.3	4.3-4.7
Moisture Content (%)	12	15	4	13	13	27
Percent Passing -200 Sieve (%)	1	3	1	1	3	15
Soil Classification (AASHTO)	A-3	A-3	A-3	A-3	A-3	A-3
Permeability Test	Sample Depth: 0-2.1'			Sample Depth: 5.7-6.5'		
Dry Density (lb/ft^3)	98.41			96.01		
Void Ratio, e	0.68			0.72		
Porosity, n	0.40			0.42		
Infiltration rate, (in/hr)	21.34			17.76		

Table 5: Summary of Sun Ray Store-Away infiltration rates and unit weights

Core No.	**Field System Infiltration Rate (in/hr)**	**Field Soil Infiltration Rate (in/hr)**	**Laboratory Core Infiltration Rate (in/hr)**	**Core Thickness (in)**	**Core Weight (lb)**	**Core Unit Weight (lb/ft^3)**
A-1	--	34.50	627	5.1	34	102
A-2	17.77	--	34.5	5.1	38	114
A-3	17.72	--	20.2	5.5	41	114
A-4	10.50	--	3.7	6.9	52	115
A-5	--	14.76	4.8	5.8	45	119
A-6	10.41	--	3	6.0	47	120

The subsoil characteristic to the pervious concrete internal roadway system at the Sun Ray Store-Away Facility exhibited infiltration rates typical of type A hydrologic soils. Infiltration rates of the subsoil ranged from 14.76 to 34.5 in/hr in the field and laboratory permeability tests confirmed these rates. Core infiltration rates exhibited a wide range of infiltration rates measured in the laboratory that ranged from a high of 627 to a low of 3 in/hr. Instances where the system infiltration rates are higher than the individual core infiltration rates measured in the lab is due to infiltration along the sidewall of the cores that occurred in the field but was restricted in the lab producing false high infiltration rates in the field. The cores performed in the area of cores 1, 2 and 3 exhibited higher infiltration rates than other areas. This result was anticipated as the pervious concrete surface in that area was after visual determination in better condition; this area is shown in Figure 16.

Figure 16: Sun Ray Store-Away Pervious Pavement at Core Locations 1, 2 & 3

4.2.2: Strang Communication Office

Located in Lake Mary, Florida the Strang Communication Office is a 0.3 acre parking lot for a 200 employee office building that was constructed in 1992. There are 71 parking stalls in three rows in this lot that are made using pervious concrete the remaining stalls consist of asphalt. The pervious concrete is limited to the stalls themselves and the areas directly behind each stall. Pervious concrete thickness across this site ranged from 7.0 to 7.1 inches.

This pervious parking lot exhibited minimal damage to the surface, although, significant raveling has taken place in one location on the site. Raveling is the deterioration of the concrete due to repeated loads over time on an area. The nine spaces located in the northwest area of the pervious concrete are raveling at the entrance to each stall. Also, a small amount of raveling at the entrance to the parking row on the west was also noted. Algae and leaf debris staining are also present over a majority of the pervious concrete parking lot. Figure 17 shows the location of the raveling and algae in this parking area. Depicted in Figure 18 is a picture of this site.

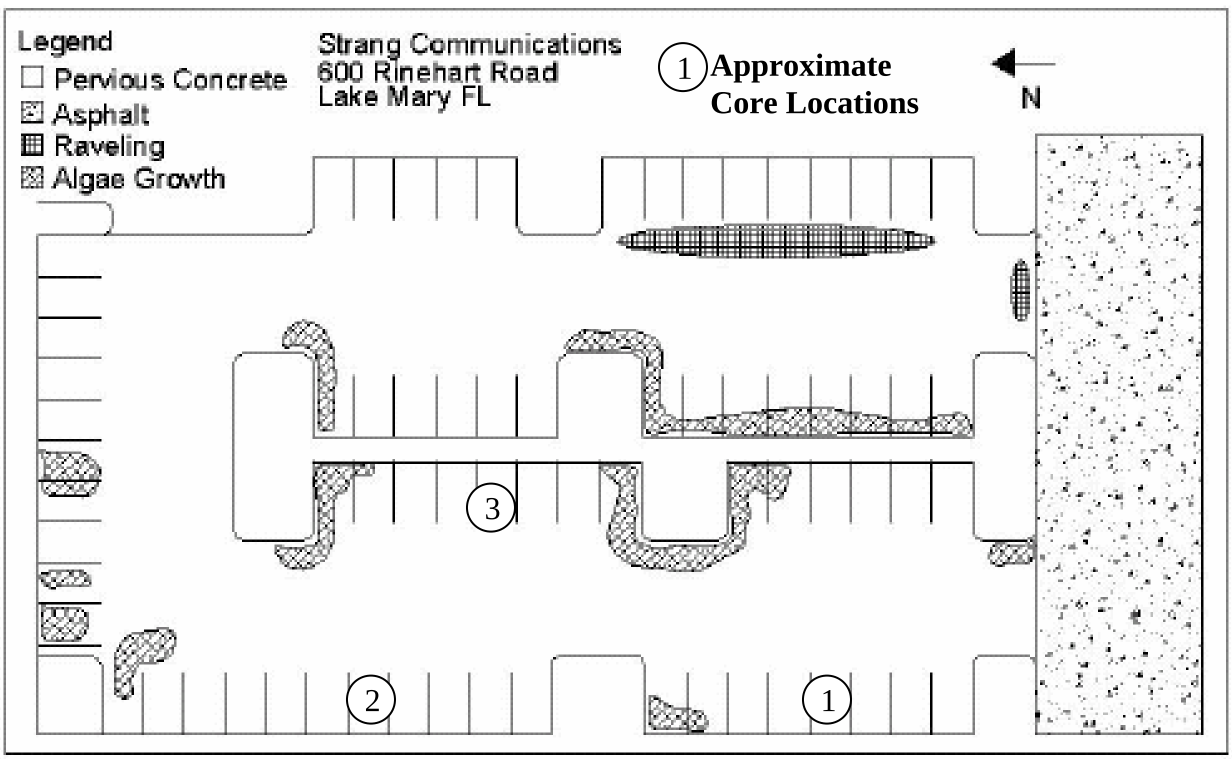


Figure 17: Strang Communication Office (Not to scale) (Mulligan, 2005)

Figure 18: Strang Communication Office Parking Lot

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. The single-ring infiltrometer was used to determine in-situ infiltration rates of the pervious concrete and subsoil system and the subsoil and pervious concrete cores separately. Table 6 summarizes the results of the soil analyses and Table 7 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 6: Summary of Strang Communication Office soil parameters

Soil Parameter	Soil Sample Location			
	Core B-1		Core B-2	
Sample Depth (ft)	3-4	5.5-6	0-2.5	6.3-6.5
Moisture Content (%)	3	5	13	16
Percent Passing -200 Sieve (%)	1	1	1	19
Soil Classification (AASHTO)	A-3	A-3	A-3	A-2-4
Permeability Test	Sample Depth: 0-3’		Sample Depth: 2.5-4’	
Dry Density (lb/ft^3)	100.66		97.29	
Void Ratio, e	0.64		0.70	
Porosity, n	0.39		0.41	
Infiltration rate, (in/hr)	11.27		23.99	
Atteberg Limit Test	Sample Depth: 4.7-5.5’		Sample Depth: 6.3-6.5’	
Liquid Limit (%)	24.2		22.2	
Plastic Limit (%)	23.2		21.1	
Plastic Index	1		1	
Soil Classification (AASHTO)	A-2-4		A-2-4	

Table 7: Summary of Strang Communication Office infiltration rates and unit weights

Core No.	Field System Infiltration Rate (in/hr)	Field Soil Infiltration Rate (in/hr)	Laboratory Core Infiltration Rate (in/hr)	Core Thickness (in)	Core Weight (lb)	Core Unit Weight (lb/ft^3)
B-1	--	5.41	1.4	7.1	57	123
B-2	17.29	--	5.6	7.0	51	111
B-3	10.60	--	7.1	7.1	49	105

The subsoil characteristic to the pervious concrete parking lot at the Strang Communication Office exhibited infiltration rates typical of type A hydrologic soils. However, silty sands were encountered at depths ranging from 4.7 to 6.5 feet below ground surface. These soil types are anticipated to exhibit reduced infiltration rates due to the high fines content. Infiltration rates of the subsoil ranged from 5.41 to 23.99 in/hr. in the field and laboratory permeability tests. Instances where the system infiltration rates are higher than the individual core infiltration rates measured in the lab is due to infiltration along the sidewall of the cores that occurred in the field but was restricted in the lab producing false high infiltration rates in the field. Core infiltration rates exhibited infiltration rates measured in the laboratory that ranged from 1.4 to 7.1 in/hr. This result indicates that the pervious concrete surface is acting as the limiting factor at this pervious concrete installation.

4.2.3: Murphy Veterinarian Clinic

Located in Sanford, Florida the Murphy Veterinarian Clinic is a 13 stall pervious concrete parking lot that was constructed in 1987. Located on the west end of the parking lot is a dumpster that is connected to the roadway by an asphalt drive to limit the heavy loads caused by garbage trucks. In addition a 15-foot strip of conventional concrete has been placed along the east edge of the pervious pavement that connects to the roadway to limit the impact of entering and exiting traffic. Pervious concrete thickness across this site ranged from 5.9 to 6.1 inches. The pervious concrete is in good condition with minimal structural damage to the surface of the pavement. Figure 19 depicts a general schematic layout of the site.

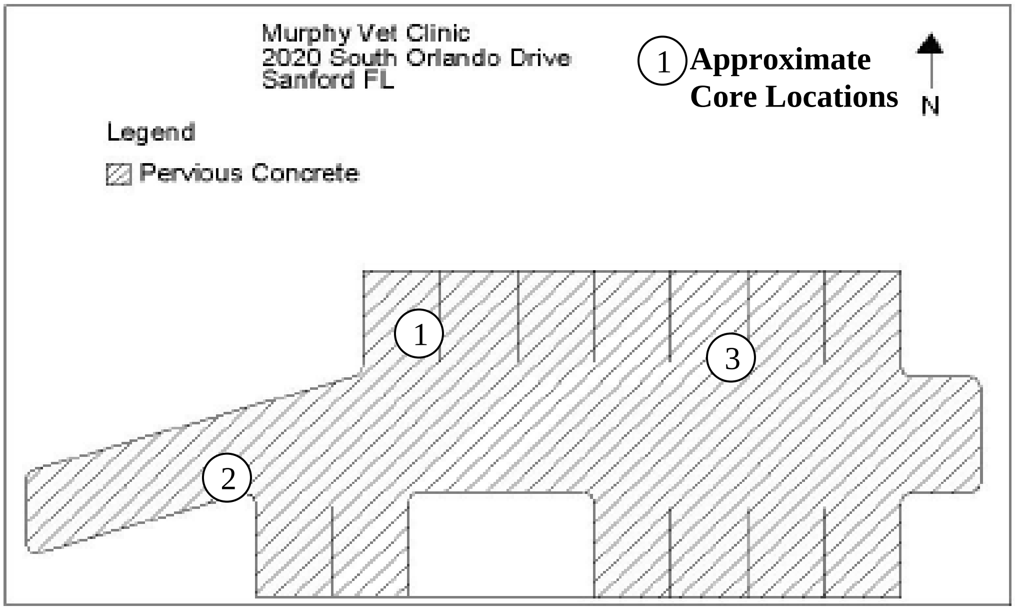


Figure 19: Murphy Veterinarian Clinic Parking Lot Schematic (Not to scale) (Mulligan, 2005)

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. The single-ring infiltrometer was used to determine in-situ infiltration rates of the pervious concrete and subsoil system and the subsoil and pervious concrete cores separately. The results of the soil analyses and the pervious concrete infiltration rates measured in the field and laboratory are presented in Tables 8 and 9 respectively.

Table 8: Summary of Murphy Vet Clinic soil parameters

Soil Parameter	**Soil Sample Location**					
	Core C-1				**Core C-3**	
Sample Depth (ft)	0-0.5	1-1.5	1.5-2.7	4.7-5	3.1-3.5	4-4.3
Moisture Content (%)	7	22	18	32	23	24
Percent Passing -200 Sieve (%)	2	2	2	6	3	4
Soil Classification (AASHTO)	A-3	A-3	A-3	A-3	A-3	A-3
Permeability Test	C-1: 0-2.1’		C-3: 0-3.1’		C-3: 4.5-5’	
Dry Density (lb/ft^3)	94.52		94.01		92.99	
Void Ratio, e	0.75		0.76		0.78	
Porosity, n	0.43		0.43		0.44	
Infiltration rate, (in/hr)	6.25		7.91		3.41	

Table 9: Summary of Murphy Vet Clinic Infiltration Rates and Unit Weights

Core No.	Field System Infiltration Rate (in/hr)	Field Soil Infiltration Rate (in/hr)	Laboratory Core Infiltration Rate (in/hr)	Core Thickness (in)	Core Weight (lb)	Core Unit Weight (lb/ft^3)
C-1	--	--	2.3	6.0	45	115
C-2	--	15.78	19.7	6.1	42	105
C-3	--	27.21	24.0	5.9	42	109

The subsoil characteristic to the pervious concrete parking lot at the Murphy Veterinarian Clinic exhibited infiltration rates typical of type A hydrologic soils. Infiltration rates of the subsoil ranged from 15.78 to 27.21 in/hr. in the field and 3.41 to 7.91 in/hr. in the laboratory permeability tests. The difference in infiltration rate is believed to be due to the higher level of compaction of the laboratory soil samples. Field system infiltration rates were not measured due to the lack of access to a power source at the field site, which limited the ability to grind the sides of the pervious concrete cores to allow the single-ring infiltrometer to fit around the core. Core infiltration rates exhibited infiltration rates measured in the laboratory that ranged from 2.3 to 24 in/hr. This result indicates that the pervious concrete surface is acting as the limiting factor at this pervious concrete installation. Figure 20 depicts a subsoil infiltration test being performed at the field site.

Figure 20: Murphy Veterinarian Clinic Core Test

4.2.4: FDEP Office

Located in Tallahassee, Florida the Florida Department of Environmental Protection building has two pervious concrete loading areas that were constructed in 1985. At one of these loading areas a portion of the original pervious concrete was replaced in 1995, as indicated on Figure 21. Pervious concrete thickness across this site ranged from 5 to 8.9 inches. The pervious concrete exhibits little structural damage, however, a portion of the concrete is visibly sealed allowing no water to infiltrate the surface. A sample of these visibly sealed areas was taken to document the density of the concrete to further verify that the installation resulted in a sealed concrete. Site infiltration tests were also done on these suspected concrete areas to further document the impervious nature of the concrete. These areas of concrete have no pores, possibly due to an excess of water used in the initial construction. This sealed state is primarily found in the area of pervious concrete that was replaced.

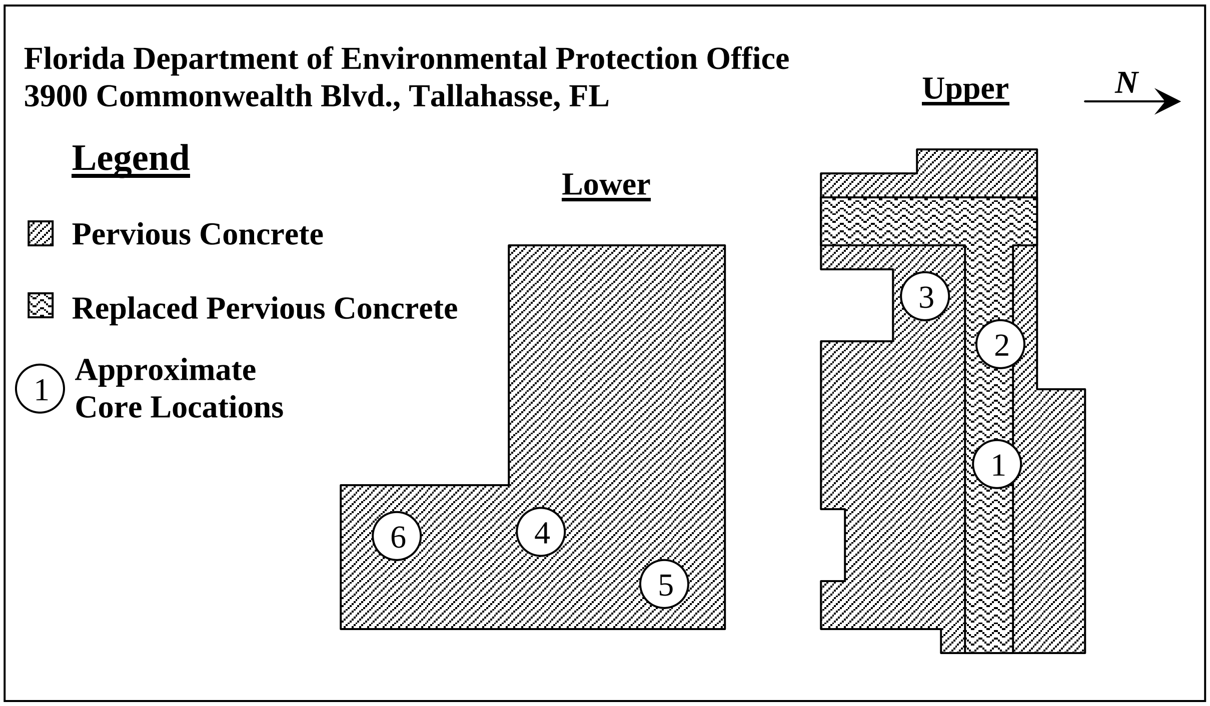


Figure 21: Florida Department of Environmental Protection Parking Lot Schematic (Not to Scale)

The field investigation at this site included the collection of six cores and soil samples at three of the core locations. The single-ring infiltrometer was used to determine in-situ infiltration rates of the pervious concrete and subsoil system and the subsoil and pervious concrete cores separately. Table 10 summarizes the results of the soil analyses and Table 11 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 10: Summary of FDEP Office Soil Parameters

<table>
<tr><th rowspan="2">Soil Parameter</th><th colspan="5">Soil Sample Location</th></tr>
<tr><th>Core D-2</th><th colspan="2">Core D-4</th><th colspan="2">Core D-6</th></tr>
<tr><td>Sample Depth (ft)</td><td>0-1</td><td>1-1.8</td><td>3.5</td><td>0-0.5</td><td>1</td></tr>
<tr><td>Moisture Content (%)</td><td>14</td><td>9</td><td>21</td><td>15</td><td>17</td></tr>
<tr><td>Percent Passing -200 Sieve (%)</td><td>2</td><td>26</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td>Soil Classification (AASHTO)</td><td>A-3</td><td>A-2-6</td><td>A-2-6</td><td>A-2-4</td><td>A-2-6</td></tr>
<tr><td>Permeability Test</td><td colspan="3">D-6: 0-0.5’</td><td colspan="2">D-4: 3.5’</td></tr>
<tr><td>Dry Density (lb/ft^3)</td><td colspan="3">104.64</td><td colspan="2">88.22</td></tr>
<tr><td>Void Ratio, e</td><td colspan="3">0.58</td><td colspan="2">0.87</td></tr>
<tr><td>Porosity, n</td><td colspan="3">0.37</td><td colspan="2">0.47</td></tr>
<tr><td>Infiltration rate, (in/hr)</td><td colspan="3">10.85</td><td colspan="2">0.09</td></tr>
<tr><td>Atteberg Limit Test</td><td colspan="3">D-4: 1-1.8’</td><td colspan="2">D-6: 1’</td></tr>
<tr><td>Liquid Limit (%)</td><td colspan="3">30</td><td colspan="2">26</td></tr>
<tr><td>Plastic Limit (%)</td><td colspan="3">12</td><td colspan="2">13</td></tr>
<tr><td>Plastic Index</td><td colspan="3">17</td><td colspan="2">13</td></tr>
</table>

Table 11: Summary of FDEP Office infiltration rates and unit weights

Core No.	Field System Infiltration Rate (in/hr)	Field Soil Infiltration Rate (in/hr)	Laboratory Core Infiltration Rate (in/hr)	Core Thickness (in)	Core Weight (lb)	Core Unit Weight (lb/ft^3)
D-1	--	20.1	0	5.6	51	139
D-2	--	11.23	0	5.0	48	147
D-3	0.17	--	1.3	6.1	49	123
D-4	0.29	--	4.8	8.9	71	122
D-5	--	0	1	5.9	52	135
D-6	1.78	--	5.2	8.1	65	123

The subsoil characteristic to the pervious concrete loading areas at the FDEP Building exhibited infiltration rates typical of type A hydrologic soils in the areas of cores D-1, D-2 and D-3 and infiltration rates typical of type D hydrologic soils in the areas of cores D-4, D-5 and D-6. Infiltration rates of the subsoil ranged from 0 to 20.1 in/hr. in the field and laboratory permeability tests confirmed these rates. Core infiltration rates measured in the laboratory ranged from 0 to 5.2 in/hr. The cores performed in the area of cores 4, 5 and 6 exhibited higher infiltration rates than other areas. This result was anticipated as the condition of the pervious concrete surface in the other areas was compromised due to poor construction practices. Higher than typical unit weights are also indicative of poor construction practices. Low infiltration rates of the subsoil in the areas of Cores 4 through 6 was due to a layer of poorly draining, orange clay encountered directly beneath the pervious concrete. Figure 22 depicts the coring operation performed at this site.

Figure 22: FDEP Parking Lot Core Test

4.2.5: Florida Concrete & Products Association Office

Located in Orlando, Florida, the Florida Concrete and Products Association Office, constructed in 1999, includes 13 parking stalls. The driveway and seven parking stalls located on the south side of the parking lot are constructed of asphalt, which drains onto the remaining six pervious concrete parking stalls. Pervious concrete thickness across this site ranged from 6.8 to 7.6 inches. The site is in good condition with minimal structural damage, including minor cracks throughout the area. However, a significant amount of algae was noted along the north edge of the parking spaces and also along the eastern edge. Figure 23 depicts a general schematic of the parking area.

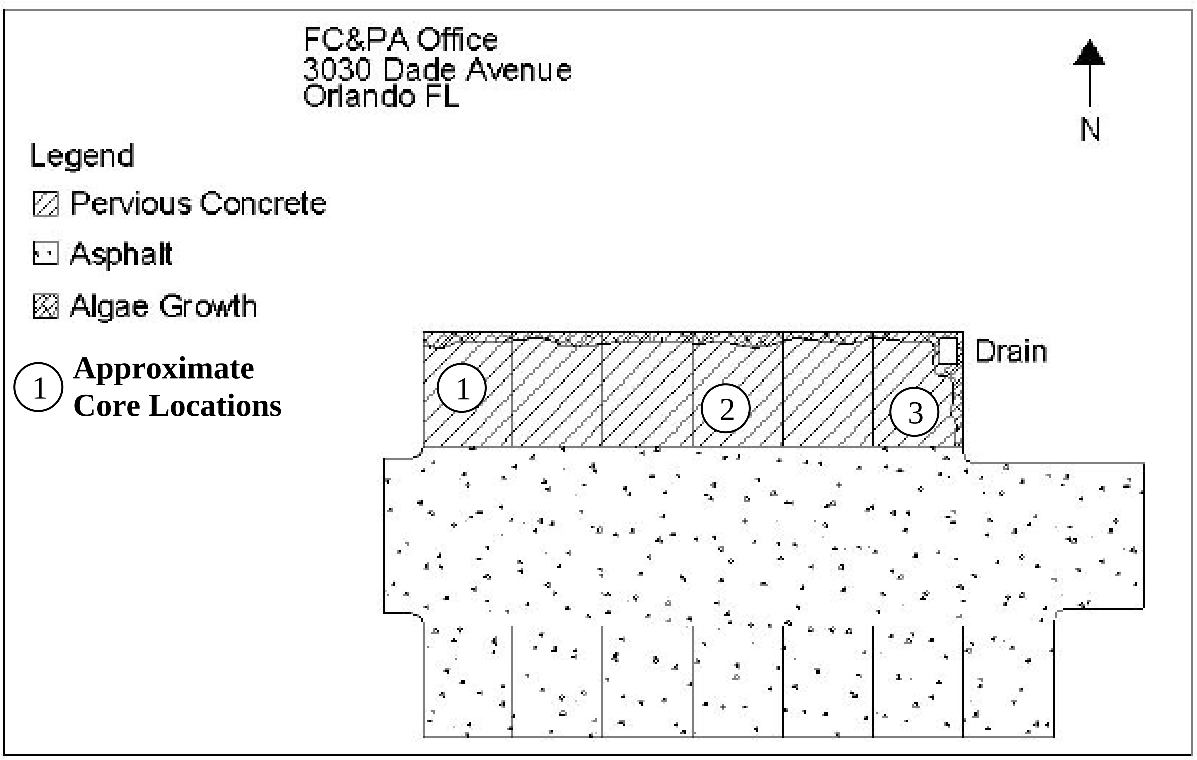


Figure 23: Florida Concrete & Products Association Parking Lot Schematic (Not to Scale) (Mulligan, 2005)

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. The single-ring infiltrometer was used to determine in-situ infiltration rates of the pervious concrete and subsoil system and the subsoil and pervious concrete cores separately. Table 12 summarizes the results of the soil analyses and Table 13 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 12: Summary of FCPA Office soil parameters

Soil Parameter	**Soil Sample Location**					
	Core E-1			**Core E-2**		
Sample Depth (ft)	0-0.8	2-4.5	4.5-5.5	0-1	2.5-4.2	5.5-5.6
Moisture Content (%)	19	7	15	12	7	21
Percent Passing -200 Sieve (%)	--	5	4	4	--	6
Soil Classification (AASHTO)	A-3	A-3	A-3	A-3	A-3	A-3
Permeability Test	Sample Depth: 0-0.8’			Sample Depth: 2.4-4.2’		
Dry Density (lb/ft^3)	96.38			98.96		
Void Ratio, e	0.72			0.67		
Porosity, n	0.42			0.40		
Infiltration rate, (in/hr)	1.89			7.29		

Table 13: Summary of FCPA Office infiltration rates and unit weights

Core No.	**Field System Infiltration Rate (in/hr)**	**Field Soil Infiltration Rate (in/hr)**	**Laboratory Core Infiltration Rate (in/hr)**	**Core Thickness (in)**	**Core Weight (lb)**	**Core Unit Weight (lb/ft^3)**
E-1	--	8.54	4.3	7.6	54	109
E-2	--	--	5.8	7.0	48	105
E-3	--	9.07	1.8	6.8	55	124

The subsoil characteristic to the pervious concrete parking lot at the FCP&A Building exhibited infiltration rates typical of type B hydrologic soils. Infiltration rates of the subsoil ranged from 8.54 to 9.07 in/hr. in the field and laboratory permeability tests confirmed these rates. Core infiltration rates measured in the laboratory ranged from 1.8 to 5.8 in/hr. Field system infiltration rates were not measured due to the lack of access to a power source on the site, which limited the ability to grind the sides of the pervious concrete cores to allow the single-ring infiltrometer to fit around the core. This result indicates that the pervious concrete surface is acting as the limiting factor at this pervious concrete installation. A photograph depicting the condition of the pervious concrete in this area is shown in Figure 24.

Figure 24: FCP&A Parking Lot

4.2.6: Southface Institute

Located in Atlanta, Georgia the Southface Office has a small parking lot constructed in 1996 by the Southface Energy Institute, an organization focused on promoting sustainable development. The pervious concrete surface is a small driveway with three parking spaces with a dumpster on site. Pervious concrete thickness across this site ranged from 7.9 to 8.5 inches. The pervious concrete surface is in good structural condition with very little visible surface clogging. An approximately six inch gravel reservoir underlies the pervious concrete surface followed by a layer of fat clay. Figure 25 depicts a general schematic of the parking area.

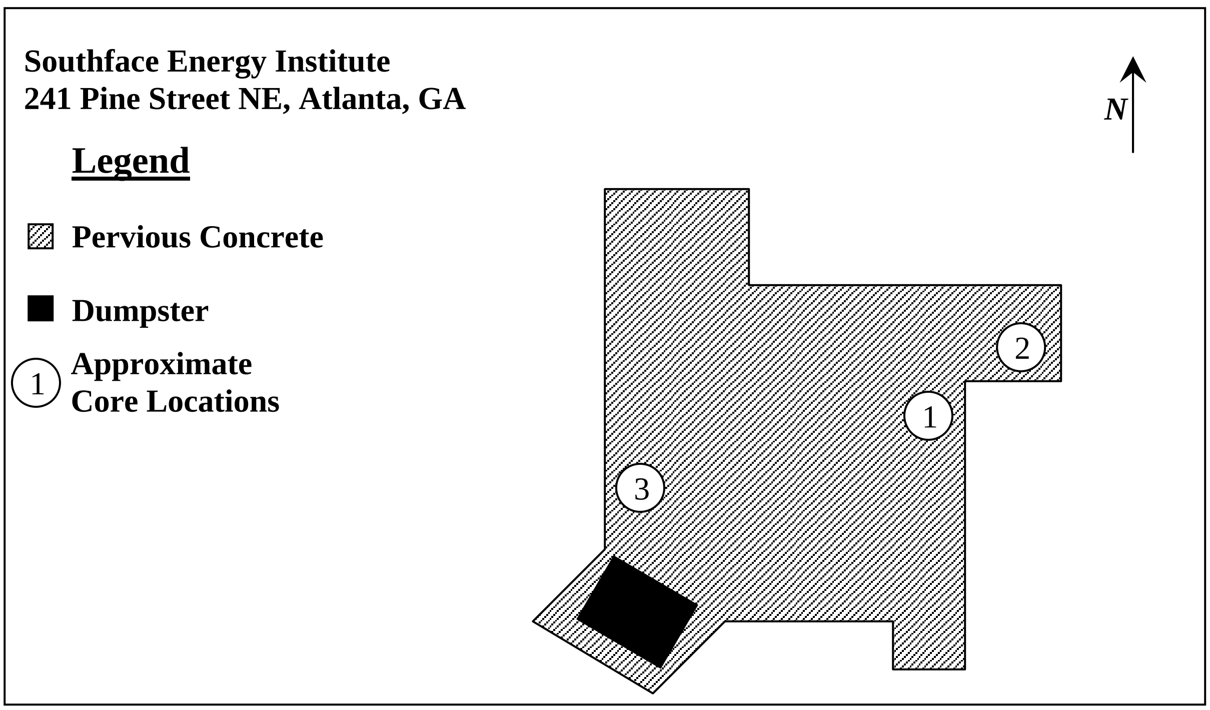


Figure 25: Southface Institute Parking Lot Schematic (Not to Scale)

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. Table 14 summarizes the results of the soil analyses and Table 15 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 14: Summary of Southface Institute soil parameters

Soil Parameter	Soil Sample Location			
	Core AT-1		Core AT-3	
Sample Depth (ft)	0-0.5	0.5-1.5	0-0.6	0.6-1.5
Moisture Content (%)	19	28	13	35
Percent Passing -200 Sieve (%)	3	25	4	72
Soil Classification (AASHTO)	A-1-a	A-2-4	A-1	A-7-6
Permeability Test	Sample Depth: 0.5-1.5’		Sample Depth: 0-0.6’	
Dry Density (lb/ft^3)	101		120	
Void Ratio, e	0.6		0.48	
Porosity, n	0.38		0.32	
Infiltration rate, (in/hr)	0.1		450	
Atteberg Limit Test	AT-1: 0.5-1.5’		AT-3: 0.6-1.5’	
Liquid Limit (%)	Non-Plastic		86	
Plastic Limit (%)	Non-Plastic		36	
Plastic Index	Non-Plastic		50	

Table 15: Summary of Southface Institute infiltration rates and unit weights

Core No.	Field System Infiltration Rate (in/hr)	Field Soil Infiltration Rate (in/hr)	Laboratory Core Infiltration Rate (in/hr)	Core Thickness (in)	Core Weight (lb)	Core Unit Weight (lb/ft^3)
AT-1	--	--	188	8.4	56	102
AT-2	--	--	2.3	7.9	58	112
AT-3	--	--	0	8.5	70	126

The subsoil characteristic to the pervious concrete parking lot at the Southface Institute Building exhibited infiltration rates typical of type D hydrologic soils. The infiltration rate of the subsoil was determined to be approximately 0.1 in/hr. in the laboratory permeability tests. Core infiltration rates measured in the laboratory exhibited a wide range of infiltration rates from 0 to

188 in/hr. This wide range of infiltration rates can be contributed to varying surficial pore sizes and unit weights in pervious concrete due to poor construction techniques. Field system infiltration rates were not measured due to the presence of a gravel reservoir, which the single-ring infiltrometer is unable to penetrate. These results indicate that the subsoil is acting as the limiting factor at this pervious concrete installation, however a gravel reservoir has added storage to the site to allow a longer recharge time. Laboratory tests indicate the gravel reservoir has a porosity of approximately 0.32 or a storage capacity of approximately 2 inches of water. Photographs depicting the condition of the pervious concrete in this area are shown in Figures 26, 27 and 28.

Figure 26: Southface Institute Parking Lot

Figure 27: Southface Institute Gravel Subbase

Figure 28: Southface Institute Parking Lot

4.2.7: Cleveland Park

Located in Greenville, South Carolina at Cleveland Park this approximately 1 acre parking lot was constructed in 1995. The pervious concrete surface is a ten-foot strip located at the edge row of parking stalls that collects the runoff from approximately one third of the asphalt surface. The remainder of the site drains to storm drains installed at the site. Pervious concrete thickness across this site ranged from 6.8 to 8.9 inches. The pervious concrete surface is in good structural condition with some visible surface clogging. A majority of the surface clogging can be attributed to the occasional flooding of the nearby Reedy River, which flooded recently in the summers of 1996 and 2004. An approximately six inch gravel reservoir underlies the pervious concrete surface followed by a layer of sand. Figure 29 depicts a general schematic of the parking area.

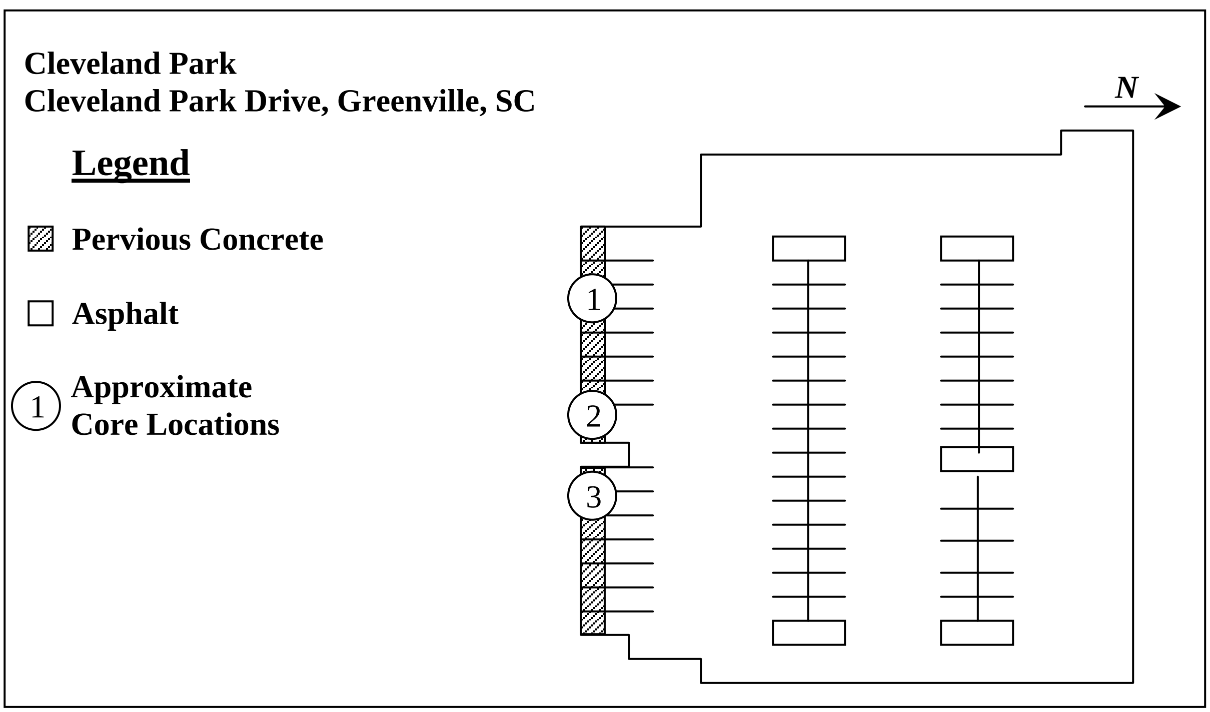


Figure 29: Cleveland Park Parking Lot Schematic (Not to Scale)

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. Table 16 summarizes the results of the soil analyses and Table 17 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 16: Summary of Cleveland Park soil parameters

Soil Parameter	Soil Sample Location	
	Core SC-2	
Sample Depth (ft)	0-1	1-2.5
Moisture Content (%)	8	12
Percent Passing -200 Sieve (%)	3	9
Soil Classification (AASHTO)	A-1-a	A-3
Constant Head Permeability Test	Sample Depth: 0-1’	Sample Depth: 1-2.5’
Dry Density (lb/ft^3)	118.3	105.6
Void Ratio, e	0.47	0.72
Porosity, n	0.32	0.42
Infiltration rate, (in/hr)	143	2.3

Table 17: Summary of Cleveland Park infiltration rates and unit weights

Core No.	Field System Infiltration Rate (in/hr)	Field Soil Infiltration Rate (in/hr)	Laboratory Core Infiltration Rate (in/hr)	Core Thickness (in)	Core Weight (lb)	Core Unit Weight (lb/ft^3)
SC-1	--	--	86.2	6.8	51	115
SC-2	--	--	0	7.5	62	126
SC-3	--	--	84.7	8.9	62	106

The subsoil characteristic to the pervious concrete parking lot at the Cleveland Park parking lot exhibited infiltration rates typical of type B hydrologic soils. The infiltration rate of the subsoil was determined to be 2.3 in/hr. in the laboratory permeability tests. Core infiltration rates measured in the laboratory ranged from 0 to 86.2 in/hr. The measured infiltration rate of zero that was measured was due to a lack of voids present in the concrete due to poor construction techniques as verified by the comparatively high unit weight of the core. Field system infiltration rates were not measured due to the presence of a gravel reservoir, which the single-ring infiltrometer is unable to penetrate. These results indicate that the subsoil is acting as the limiting factor at this pervious concrete installation, however, a gravel reservoir has added storage to the site to allow a longer recharge time. Laboratory tests indicate the gravel reservoir has a porosity of approximately 0.32 or a storage capacity of approximately 2 inches of water. Photographs depicting the condition of the pervious concrete in this area are shown in Figures 30, 31 and 32.

Figure 30: Cleveland Park Parking Lot


Figure 31: Cleveland Park Parking Lot Pavement

Figure 32: Cleveland Park Parking Lot Reservoir

4.2.8: Effingham County Landfill

Located in Guyton, Georgia in the Effingham County Landfill this approximately 0.6 acre concrete slab was constructed in 1999. The slab is primarily made of pervious concrete, except for a 50-foot by 50-foot square area of standard concrete surface in the center. This pervious concrete slab is used for storage and separation of trash into dumpsters. Despite the daily use of a front-end loader on the surface of this concrete the pavement remains in good structural condition with only minimal cracking. Pervious concrete thickness across this site ranged from 5.8 to 6.3 inches. An approximately six inch gravel reservoir underlies the pervious concrete surface followed by a layer of sand. Figure 33 depicts a general schematic of the parking area.

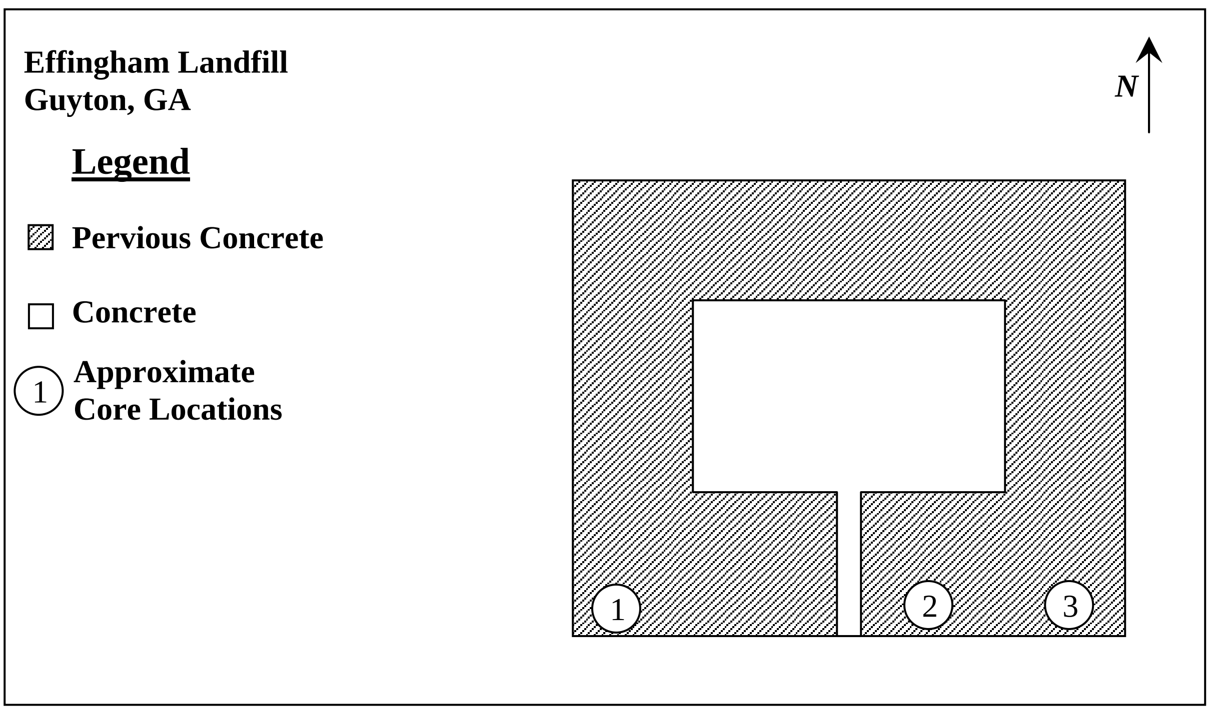


Figure 33: Effingham County Landfill Parking Lot Schematic (Not to Scale)

The field investigation at this site included the collection of three cores and soil samples at two of the core locations. Table 18 summarizes the results of the soil analyses and Table 19 summarizes the results of the pervious concrete infiltration rates measured in the field and laboratory.

Table 18: Summary of Effingham County Landfill soil parameters

Soil Parameter	**Soil Sample Location**	
	Core LF-1	
Sample Depth (ft)	0-0.5	0.5-4.0
Moisture Content (%)	6	7
Percent Passing -200 Sieve (%)	1	3
Soil Classification (AASHTO)	A-1-a	A-3
Constant Head Permeability Test	Sample Depth: 0-0.5'	Sample Depth: 0.5-4.0'
Dry Density (lb/ft^3)	118.3	112.3
Void Ratio, e	0.47	0.62
Porosity, n	0.32	0.38
Infiltration rate, (in/hr)	169	5.6

Table 19: Summary of Effingham County Landfill infiltration rates and unit weights

Core No.	**Field System Infiltration Rate (in/hr)**	**Field Soil Infiltration Rate (in/hr)**	**Laboratory Core Infiltration Rate (in/hr)**	**Core Thickness (in)**	**Core Weight (lb)**	**Core Unit Weight (lb/ft^3)**
LF-1	--	--	30.8	6.1	45	113
LF-2	--	--	11	5.8	55	145
LF-3	--	--	187	6.3	50	121

The subsoil characteristic to the pervious concrete parking lot at the Effingham County Landfill exhibited infiltration rates typical of type B hydrologic soils. The infiltration rate of the subsoil was determined to be 2.2 in/hr in the laboratory permeability test. Core infiltration rates measured in the laboratory ranged from 11 to 187 in/hr. This wide range of infiltration rates can be attributed to varying surficial pore sizes in the pervious concrete due to poor construction techniques. Field system infiltration rates were not measured due to the presence of a gravel reservoir, which the single-ring infiltrometer is unable to penetrate. These results indicate that the subsoil is acting as the limiting factor at this pervious concrete installation, however, a gravel reservoir has added storage to the site to allow a longer recharge time. Laboratory tests indicate the gravel reservoir has a porosity of approximately 0.32 or a storage capacity of approximately 2 inches of water. Photographs depicting the condition of the pervious concrete in this area are shown in Figures 34, 35 and 36.

Figure 34: Effingham County Landfill

Figure 35: Effingham County Landfill Pervious Pavement

Figure 36: Effingham County Landfill Reservoir

4.3: Summary of Field Investigation Results

The pervious concrete field sites investigated in this study ranged in service life from 6 to 20 years and exhibited regionally similar structural integrity, infiltration rates, pavement cross sections and subsurface soils. It can be concluded from the results of the field investigation that typically the pervious concrete exhibited minor structural distress at all locations investigated. The average infiltration rates of the pervious concrete at the investigated sites ranged from 2.1 to 75.4 inches per hour (Table 20) and includes the zero rates for those pavements not properly installed. Typically the field sites investigated in the Central Florida area exhibited subsoil infiltration rates that were greater than the average pervious concrete rates making the concrete the limiting infiltration value. However, at the sites located in Georgia and South Carolina the infiltration rates of the soils were the limiting infiltration values. The limiting factor is determined by comparison of the average values. Outside of Florida, the pavement cross section included a gravel reservoir to allow for a greater storage since the soils were less permeable.

Table 20: Summary of All Infiltration Rates

Test Locations	Average and (Range) for Concrete Infiltration Rate (in/hr)	Average Soil Rate (in/hr)	Limiting Factor
FDEP Office (1985) - Area 1	0.4 (0 – 1.3)	15.6	Concrete
FDEP Office (1985) - Area 2	3.7 (1 – 5.2)	0	Soil
Murphy Vet Clinic (1987)	15.3 (2.3 – 24)	21.5	Concrete
Sunray Store Away (1991) – Area 1	227.2 (20.2 – 627)	34.5	Concrete
Sunray Store Away (1991) – Area 2	3.8 (3 – 4.8)	14.8	Concrete
Strang Communications (1992)	4.7 (1.4 – 7.1)	5.4	Concrete
Cleveland Park (1995)	57 (0 – 86.2)	2.3	Soil
Southface Institute (1996)	63.4 (0-188)	0.1	Soil
FCPA Office (1999)	4 (1.8 – 5.8)	8.8	Concrete
Effingham County Landfill (1999)	76.3 (11 – 187)	5.6	Soil

At all locations investigated in this study little to no maintenance was performed during the service life of the pervious pavement. This allowed for the opportunity to investigate the loss of infiltration capability of the pervious pavement over time. However, it should be noted that the degree of clogging of the pervious concrete is highly dependant on the location, traffic loading and quality of construction of the pervious concrete making any comparison of these sites very approximate.

4.4: Results of Rehabilitation Methods

A limiting factor in pervious concrete systems is the potential for the pervious concrete to clog during operation. Several clogging rehabilitation techniques have been recommended and are currently practiced, including, pressure washing and vacuum sweeping. Pressure washing dislodges clogging particles, washing a portion offsite while forcing the remaining portion down through the pavement surface. This method of pavement maintenance is historically very effective. However, care should be taken not to use too much pressure, as this can cause damage to the pervious concrete surface. It is recommended to test the pressure of a pressure washer on a small portion of pervious concrete surface before use to ensure it can safely be used on the concrete. Vacuum sweeping removes clogging particles by mechanically dislodging particles with the sweeper and extracting them from the pavement voids. In addition, a combination of these two methods is also a typical method of rehabilitating clogged pervious concrete surfaces.

Current literature from the Mississippi Concrete Industries Association (PCA 2004) predicts recovery of 80 to 90 percent infiltration capability of pervious concrete specimens after rehabilitation techniques have been performed. In addition, research conducted by the Florida

Concrete and Products Association (FCPA, 1990), indicated that brooming the surface of pervious concrete parking lots immediately restored over 50% of the permeability of a clogged pavement. In order to verify these predictions, the effectiveness of these two techniques was analyzed using the cores obtained in the field test investigation portion of this research. By utilizing pervious concrete cores obtained in the field from sites that have been in service for 6 to 20 years an accurate conclusion can be drawn about the effectiveness of these two rehabilitation techniques.

The pervious concrete cores recovered from the field sites investigated in this study were exposed to three methods of rehabilitation including vacuum sweeping, pressure washing and pressure washing followed by vacuum sweeping. Vacuum sweeping was performed using a 6.5 hp wet/dry vacuum and sweeper and the pressure washer was used at a pressure of 3000 psi. The sediment removed during the rehabilitation was collected and determined to be typically a silty fine sand, A-2-4, with an average of 43% passing the No. 200 sieve. Core numbers D2 and SC2 had the appearance of being solid concrete. Thus density tests were done and it was concluded that the installation process must have resulted in regular concrete being poured at these two sites. There was minimal pore space recoreded.

A summary of the results obtained from the rehabilitation laboratory tests performed are presented in the Table 21 and Figures 38, 39 and 40.

Table 21: Summary of Results of Rehabilitation Methods

Core No.	Initial Infiltration Rate (in/hr)	Restored Infiltration Rate (in/hr)	Magnitude of Infiltration Rate Increase	Year Constructed	Method of Rehabilitation
A-1	627	1200	2	1991	Pressure Washed
A-2	35	67	2		Vacuum Swept
A-3	20	84	4		Vacuum & Pressure
A-4	4	96	26		Pressure Washed
A-5	5	30	6		Vacuum Swept
A-6	3	187	62		Vacuum & Pressure
B-1	1	4	3	1992	Pressure Washed
B-2	6	29	5		Vacuum Swept
B-3	7	180	25		Vacuum & Pressure
C-1	2	720	313	1987	Pressure Washed
C-2	20	164	8		Vacuum Swept
C-3	24	655	27		Vacuum & Pressure
D-1	0	5	5	1985	Pressure Washed
D-2	0	0	0		Vacuum Swept
D-3	1	5	4		Vacuum & Pressure
D-4	5	12	2		Pressure Washed
D-5	1	9	9		Vacuum Swept
D-6	5	389	75		Vacuum & Pressure
E-1	4	400	93	1999	Pressure Washed
E-2	6	117	20		Vacuum Swept
E-3	2	758	421		Vacuum & Pressure
At-1	188	655	3	1996	Pressure Washed
At-2	2	62	27		Vacuum Swept
At-3	0	9	9		Vacuum & Pressure
SC-1	86	320	4	1995	Pressure Washed
SC-2	0	0	0		Vacuum Swept
SC-3	85	1440	17		Vacuum & Pressure

LF-1	31	343	11	1999	Pressure Washed
LF-2	11	35	3		Vacuum Swept
LF-3	187	758	4		Vacuum & Pressure

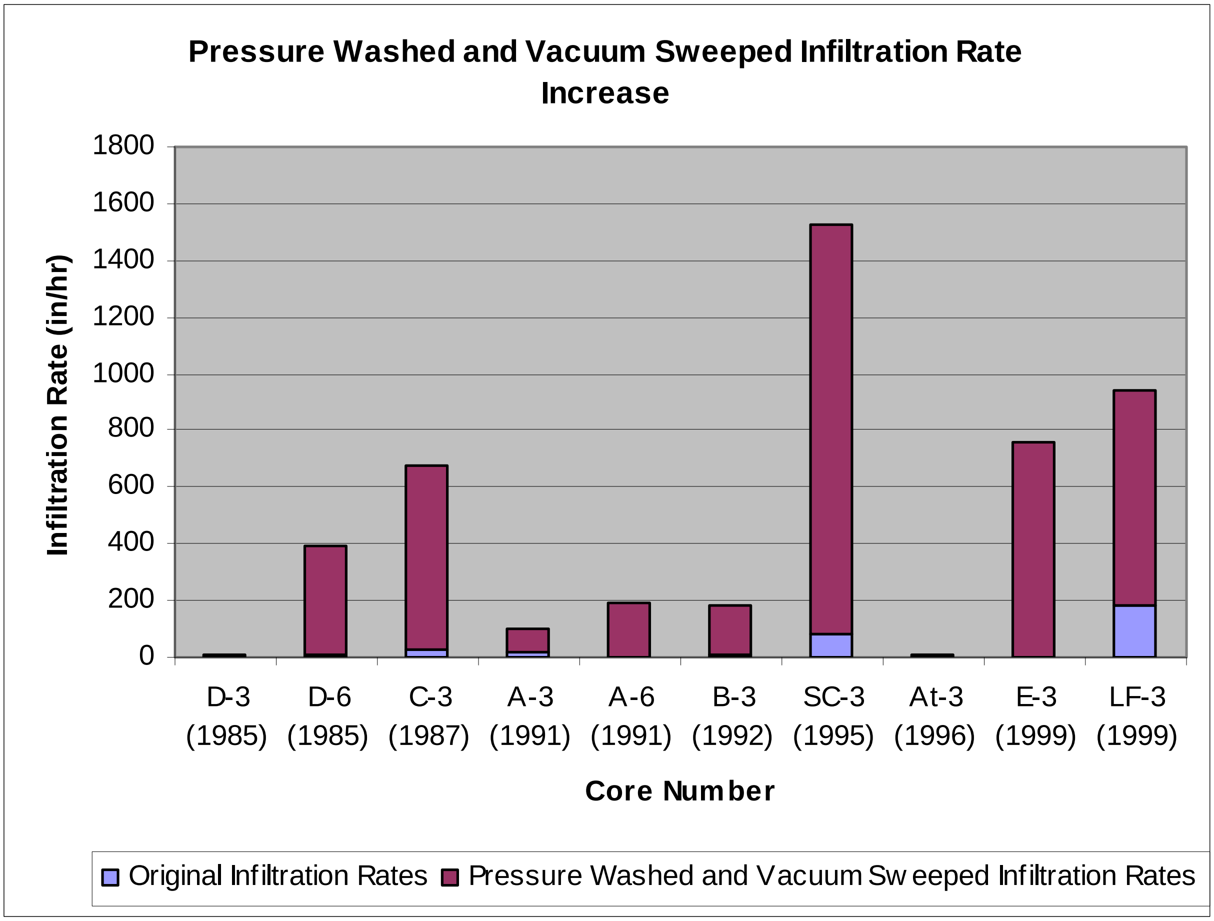


Figure 37: Comparison of Original and Pressure Washed and Vacuum Swept Infiltration Rates

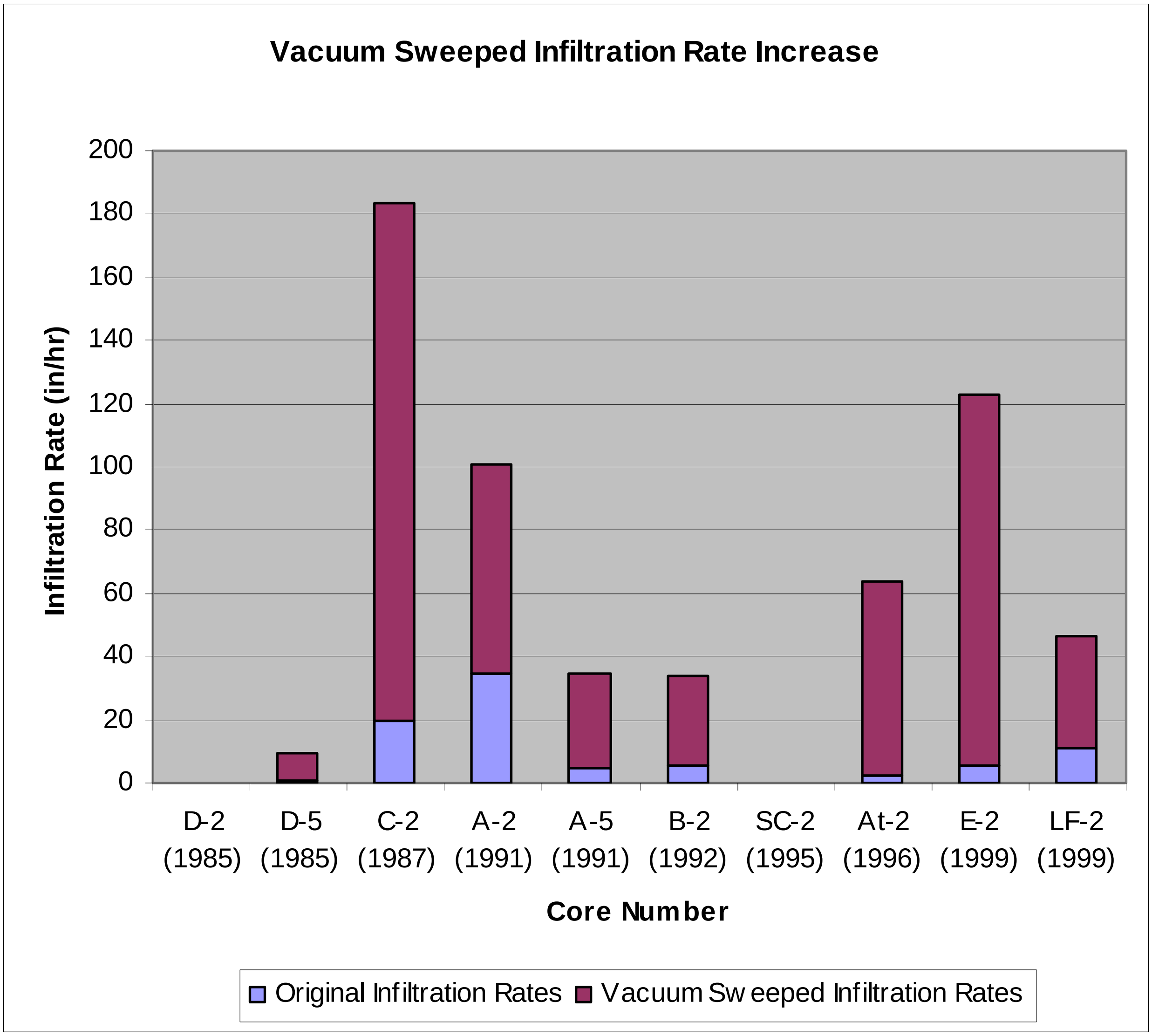


Figure 38: Comparison of original and Vacuum Swept Infiltration Rates

Notes:

The pervious pavement at sites D2 and SC2 were not installed properly and exhibited the density and zero infiltration characteristics common to regular concrete.

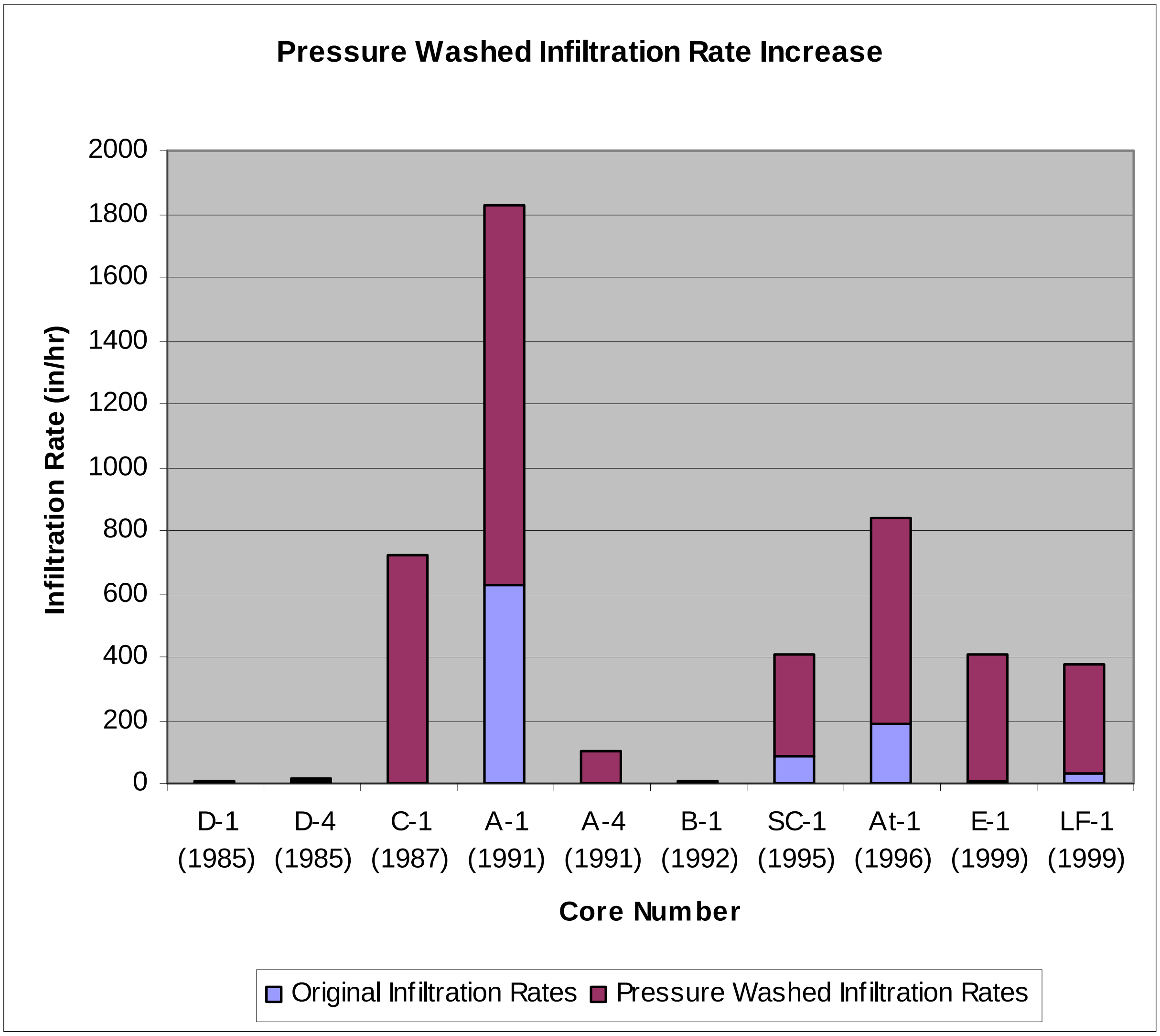


Figure 39: Comparison of Original and Pressure Washed Infiltration Rates

When the pervious concrete was installed properly (infiltration was evident), the three methods of maintenance investigated in this study typically caused at least a 200% increase over the original infiltration rates of the pervious concrete cores. A comparison of the effectiveness of the three methods investigated in this study is shown in Figure 40 below. Based on these results it is concluded that pressure washing and vacuum sweeping typically resulted in an equivalent increase in infiltration rates and the use of both methods of maintenance resulted in the greatest increase in infiltration rates. Pressure washing however did result in the release of sediment and in some cases the pervious aggregate. A site should be tested for release of particulates before pressure cleaning is done. The reason for the significant increase at the FPCA site could have been because the particles blocking the pores were released with added maintenance or the continued maintenance associated with both methods.

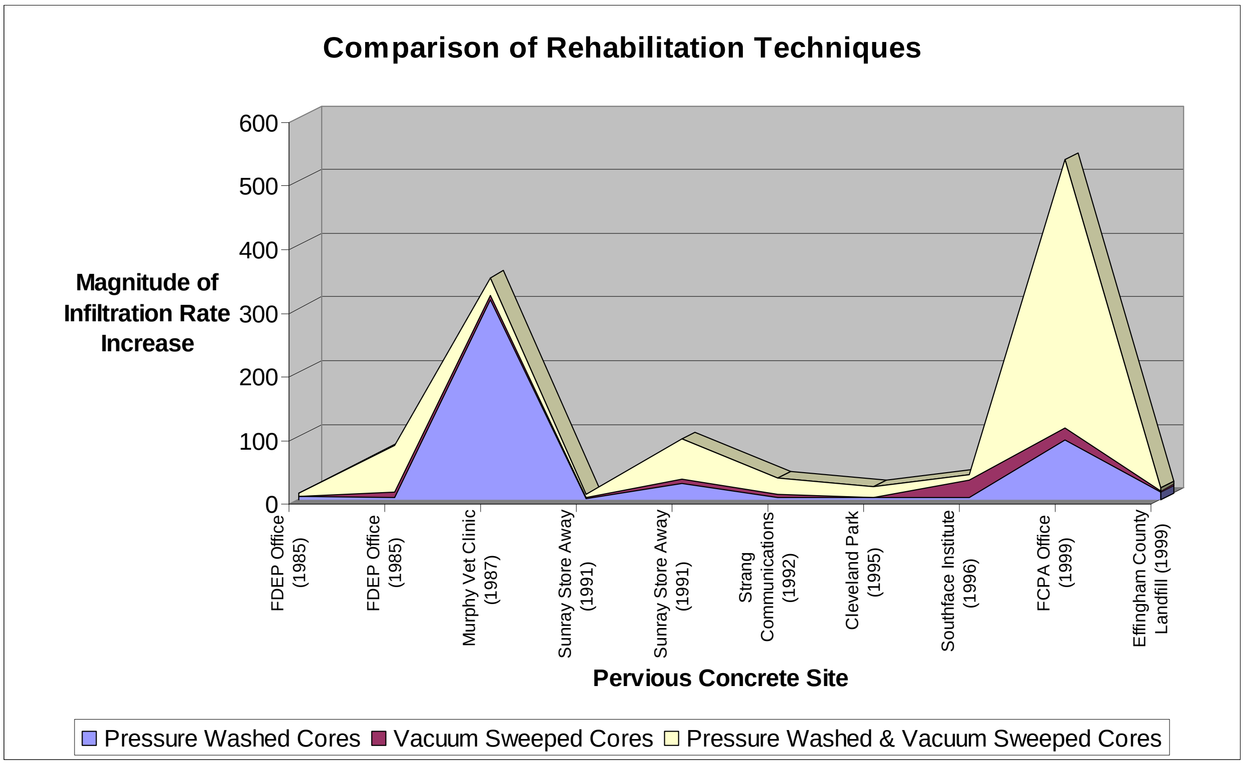


Figure 40: Comparison of Effectiveness of Rehabilitation Techniques

CHAPTER FIVE: CONSTRUCTION SPECIFICATIONS

5.1: Introduction

General specifications and recommendations for the installation of pervious concrete pavements have been prepared by the National Ready Mixed Concrete Association (NRMCA, 2004), the Georgia Concrete and Products Association (GCPA, 1997), the California-Nevada Cement Promotion Council (CNCPC 2004) and the ACI Committee 522 (ACI522, 2006). In the state of Florida, regional specific recommendations for pervious concrete were developed by the Florida Concrete and Products Association (FCPA, 1990). Within this chapter, suggested are specifications for the installation of pervious concrete pavement in regional conditions typical to the geographic locations of the test sites and based on current construction practices and updates as a result of this research. The preliminary specifications are summarized in the follow sections.

5.1: Contractor Qualifications

The placement and finishing techniques for pervious concrete are different from those for standard concrete, and if not properly followed can severely impact the structural and hydrologic properties of the concrete. It is therefore necessary to limit the placement of pervious concrete to only those with the necessary qualifications and past experience in the placement of pervious concrete. Prior to award of contract, contractors shall provide proof of qualifications and experience including ACI Concrete Finisher Certifications, Pervious Concrete Finisher Certifications (e.g. Rinker Materials) and a sample of the product, which can include cores and/or test panels. If either the placing contractor or the producer of the pervious concrete has no prior experience with the material the contractor shall retain an experienced consultant to supervise the base preparation, production, placement, finishing and curing.

5.2: Materials and Mix Design

All materials to be used for pervious concrete pavement construction shall be approved by the Engineer of Record based on laboratory tests or certifications of representative materials which will be used in the actual construction. Cement shall comply with the latest specifications for Portland cement (ASTM C 150 and ASTM C 1157), or blended hydraulic cements (ASTM C 595 and ASTM C 1157).

Unless otherwise approved in writing by the Engineer, the quality of aggregates shall conform to ASTM C 33. Aggregates may be obtained from a single source or borrow pit, or may be a blend of coarse and fine aggregate. The aggregate shall be graded so as to produce an open void structure in the finished pavement with the necessary structural strength.

Mineral admixtures shall conform to the requirements of ASTM C 618 (fly ash), ASTM C 989 (slag) and ASTM C 1240 (silica fume). Unless specifically directed by the Engineer, total mineral admixtures content including the content in blended cements shall not exceed the weight of Portland cement in the no-fines concrete mix. Chemical admixtures including, water reducing and retarding admixtures, shall conform to ASTM C 494 and must be approved by the Engineer prior to use.

Water shall be clean, clear and free of acids, salts, alkalis or organic materials that may be injurious to the quality of the concrete. Non-potable water may be considered as a source for part or all of the water providing the mix design indicates proof that the use of such water will not have any deleterious effect on the strength and durability properties of the RCC.

The proposed No-Fines mix design must be submitted to the Engineer of Record for approval at least one week prior to construction. This mix design shall include details on aggregate gradation, cementitious materials, admixtures (if used), and required unit weight to be achieved.

5.3: Construction

5.3.1: Subgrade Material

Proper preparation of the subgrade material is critical to the functionality of the pervious concrete system. The top six inches shall be composed of granular or gravel, predominantly sandy soil. The subgrade material should have a percolation rate of at least 1 inch per hour. It is desirable for the soil to contain no more than a moderate amount of silt or clay as this may limit the infiltration capability of the soil. If the placement site contains only poorly draining soils then a granular or gravel sub-base may be placed over the subgrade to create a reservoir system to retain and store runoff.

5.3.2: Site Preparation

Subgrade shall be leveled to provide a uniform construction surface with a consistent slope not more than 5%. It is recommended that the slope be as flat as possible (as per EPA 832-

F-99-023). After leveling, soils shall be compacted to a minimum density of 92% of a maximum dry density as determined by ASTM D 698 or AASHTO T 99. Should fill material be required to bring the subgrade to the desired elevation, it shall be a clean sandy soil. Fill shall be placed in eight 8-inch lifts and compacted to a minimum density of 92% of a maximum dry density as determined by ASTM D 698 or AASHTO T 99. The recommended design section showing the curbing, subgrade preparation and pervious concrete pavement is shown in Figure 41.

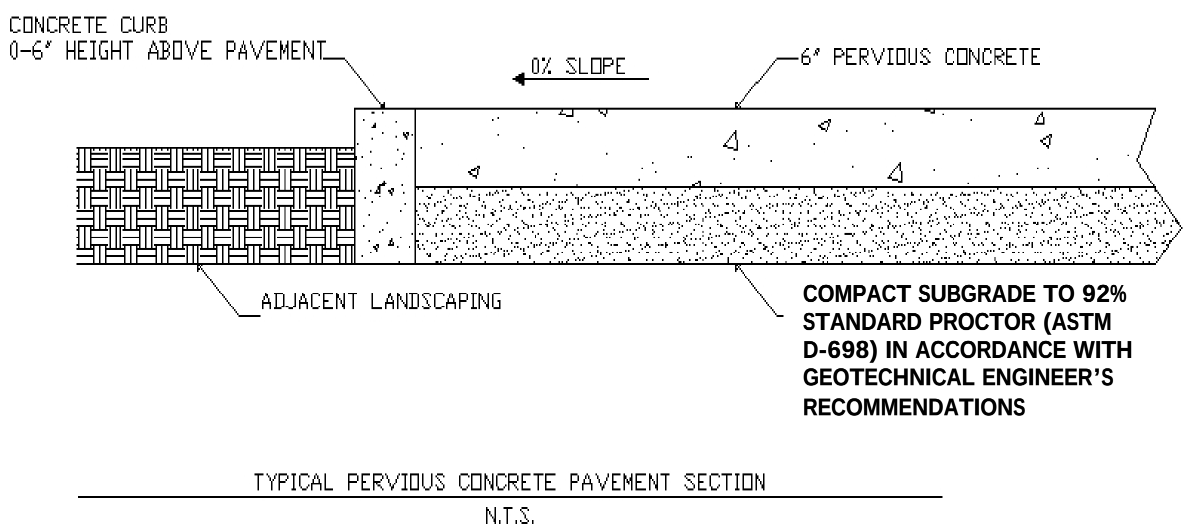


Figure 41: Design Section for Pervious Concrete Pavement System

5.3.3: Reservoir Option

In locations where the required subgrade percolation rate can not be achieved, typically a reservoir system can be installed to proved additional storage and system recovery time. The bottom and sides of the reservoir shall be line with filter fabric prior to placement of aggregate. This prevents upward piping of underlying soils. The fabric should be placed flush with a generous overlap between rolls. Stone aggregate should be thoroughly washed prior to placement. Unwashed stone may have enough associated sediment to pose risk of clogging at the filter cloth interface. Stone aggregate (#4 - #8, ASTM C 33), should be placed in the excavated reservoir, in lifts, and lightly compacted with plate compactors to form the base course.

5.3.4: Embedded Infiltrometer Placement

In order to accurately test the in-situ infiltration capability of pervious concrete installations at any time without the use of the current destructive testing techniques, an embedded infiltrometer can be installed at critical locations in the pervious concrete during the construction process. The embedded infiltrometer installation includes two circular sections of standard concrete with diameters of one and two feet and a thickness of 6 inches. The circular forms may be either wood or steel and shall be installed from the surface of the pervious concrete to a depth of embedment of 4 inches into the subsoil. One embedded infiltrometer installation should be installed for every 250,000 sf of pervious concrete installed. The circular concrete sections within the infiltrometer can be used to accurately test the infiltration rates of the pervious concrete system with the use of a standard Double Ring Infiltrometer following the ASTM D3385 standard. A schematic showing a cross section and plan view of the installation is shown in Figure 42.

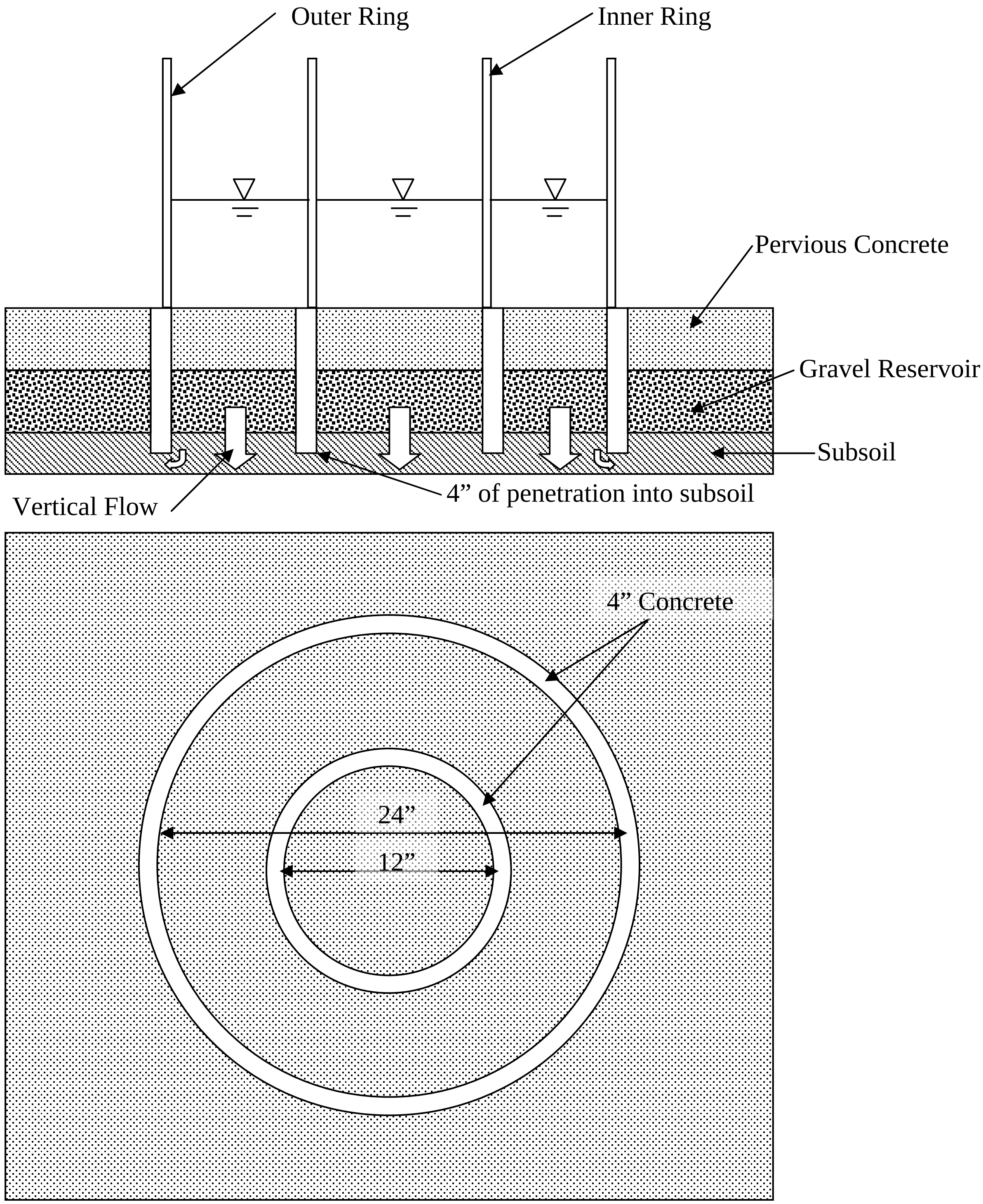


Figure 42: Design profile for Embedded Infiltrometer installation

5.3.5: Forms

Forms may be either wood or steel and shall be the depth of the pavement. Forms shall have sufficient strength and stability to support pavement and mechanical equipment without deformation. The edge of existing pavement may be used as a form.

5.3.6: Placing and Finishing

The unique properties of pervious concrete require stricter control of the mixture proportioning. Mixers shall be operated at the speed designated as mixing speed by the manufacturer. The Portland cement aggregate mixture may be transported or mixed on site and shall be used within 45 minutes of the introduction of mix water, unless otherwise approved by an engineer. Each mixer will be inspected for appearance of concrete uniformity, and water may be added to obtain the required mix consistency. Discharge shall be a continuous operation and shall be completed as quickly as possible to limit loss of water through evaporation. Concrete shall be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete. Concrete shall be deposited directly onto base course to a uniform depth. An internal vibrator should not be used to consolidate concrete.

It is recommended to use a short-handled, square-edged shovel or rake to spread concrete. Excessive spreading of concrete after pouring should be avoided. Foot traffic within plastic concrete during spreading, strike off, and compaction should be minimized to prevent excess compaction. Following strike-off, the concrete shall be compacted to form level, utilizing a steel roller made from nominal 10-inch diameter steel pipe of ¼ -inch thickness. The roller shall have enough weight to provide a minimum of 10 psi vertical force. This compaction secures the surface materials assuring pavement durability. Care shall be taken during compaction that sufficient compaction force is achieved without working the concrete surface enough to seal off the surface porosity. After compaction, the surface of the concrete shall be inspected for defects. Defects are to be remedied immediately.

5.3.7: Curing

As soon as possible after placement, pervious concrete should be covered with impermeable plastic sheeting six mill thickness. When required by ambient weather conditions water may be misted over the surface of the concrete prior to covering. The plastic shall cover all exposed concrete and overlap the edges. The edges of the plastic shall be secured by some means (without the use of loose soil) to prevent premature exposure of the concrete. The pavement should be cured a minimum of seven days.

5.3.8: Jointing

Longitudinal control joints shall be constructed at the midpoint of the travel lanes if the lane width exceeds 15 feet. Construct transverse joints at a maximum 20 feet apart in travel lanes. The joints are to be installed in the plastic concrete by a roller with a flange welded to it, as depicted in Figure 43. The depth of the joints shall be ¼ of the pavement thickness but is not to exceed 1.5 inches.

Figure 43: Roller Used to Create Joints in Pervious Concrete

5.4: Post Construction

After placement, construction and/or heavy vehicle traffic should be limited to ensure the structural and infiltrative integrity of the concrete. Runoff from unfinished or landscaped areas should be restricted from flowing over pervious concrete slab. An acceptable form of curbing shall be constructed to protect the edges of the pervious slab from excessive wear. Pervious concrete areas should be clearly identified with signs.

5.5: Construction Testing and Inspection

Typical construction inspection practices for concrete that base acceptance on slump and cylinder strengths are not applicable to pervious concrete. A unit weight test, ASTM C 29, shall be performed for quality assurance, with acceptable values dependant on the mix design. Accepted unit weight values range between 100 lb/ft^3 and 125 lb/ft^3 with an acceptance criteria of plus or minus 5 lb/ft^3. Material shall be tested once per day, or when visual inspection indicates a change in the concrete.

5.6: Maintenance

As concluded in the field testing portion of this study, the majority of pervious concrete pavements function well with little or no maintenance. Standard practices to prevent clogging of the void structure include directing drainage of surrounding landscaping to prevent flow of materials onto the pavement surfaces. Landscaping materials such as mulch, sand and topsoil should not be loaded on pervious concrete at any time.

Remediation maintenance includes methods such as vacuum sweeping and pressure washing. These remediation techniques are not required. However, if surface ponding is observed after a rain event one or both of these techniques can be applied. The results of this study on the effectiveness of vacuum sweeping and pressure washing indicate that pressure washing, vacuum sweeping and the combination of the two methods can restore infiltration rates of a clogged pervious concrete surface on a magnitude of 100, 90 and 200 respectively. As a general rule of thumb one or a combination of these rejuvenation techniques should be performed on an annual basis to maintain the infiltration capability of pervious concrete pavements. In addition, the Embedded Infiltrometer should be used to annually test the system infiltration capability. If the system infiltration rates are less than acceptable, one of the recommended remediation techniques should be performed.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1: Overview

Pervious concrete pavement was investigated in both field and laboratory environments to study infiltration rates of pervious concrete after years in service and to determine the effectiveness of various pervious concrete maintenance methods, including pressure washing and vacuum sweeping. In addition, construction specifications for use in the placement of pervious concrete were developed. A literature search was conducted and data collected from the field and laboratory explorations.

By investigating existing pervious concrete pavement systems in Florida, Georgia and South Carolina and reviewing previous construction specifications, more detailed construction methodologies were developed for specific soil characteristics. With more accurate definition of the parent soils, the need for a reservoir layer can be evaluated and potentially be eliminated and thus reduce unnecessary soil excavation. Once accepted standards for the design cross-section have been determined, credit can then be given for storage volume within the voids in Portland cement pervious concrete and the coarse aggregate base. This research is intended to contribute to the goal of using pervious concrete for stormwater management. The results were presented to allow the reader to use the conclusions and in anticipation that the reader will want to expand on this research.

6.2: Field Investigation Conclusions

The pervious concrete field sites investigated in this study ranged in service life from 6 to 20 years and exhibited regionally similar structural integrity, infiltration rates, pavement cross sections and depth. The soils varied from sandy to clay. It was concluded from the results of the field investigation that typically the pervious concrete exhibited minor structural distress at all locations investigated. The average infiltration rates of the properly installed pervious concrete were estimated from field and laboratory data. Typically for the field sites investigated in the Central Florida area, the concrete infiltration rates were the limiting infiltration value, because of the sandy soils. However, at the sites located in Tallahassee Florida, Georgia and South Carolina the infiltration rates of the soils were the limiting infiltration values. Outside of Florida the typical pavement cross section included a gravel reservoir to allow for a larger recharge volume for these less permeable soils.

In addition to the data collected from this study, a single-ring infiltrometer was also developed for use in studying the infiltration rates of the pervious concrete and subsoil system. It was determined during the course of this research that the single-ring infiltrometer was an effective tool in determining the infiltration rates of in-situ pervious concrete installations. However, it was limited to only those pavement systems with no gravel reservoir and is also a destructive method of testing pervious pavement installations. It is therefore recommended that the single-ring infiltrometer used in the field evaluations only be used to measure an existing pervious concrete system rather than a tool for infiltration evaluation of newly installed pervious concrete.

At all locations investigated in this study little to no maintenance was performed during the service life of the pervious pavement. There were no recorded use of vacuum or pressure sweeping. This allowed for the opportunity to investigate the loss of infiltration capability of the pervious pavement over time without maintenance. However, it should be noted that the degree of clogging of the pervious concrete is highly dependant on the location, traffic loading and quality of construction making any comparison of the sites contingent upon local conditions.

6.3: Maintenance Investigation Conclusions

Two clogging rehabilitation techniques have been investigated in this study, namely, pressure washing and vacuum sweeping. Pressure washing dislodges clogging particles, washing a portion offsite while forcing the remaining portion down through the pavement surface. This method of pavement maintenance is historically very effective, however, care should be taken not to use too much pressure, as this can cause damage to the pervious concrete surface. It is recommended to test the pressure of a pressure washer on a small portion of pervious concrete surface before use to ensure it can safely be used on the concrete. Vacuum sweeping removes clogging particles by mechanically dislodging particles with a sweeper and extracting them from the pavement voids. In addition, a combination of these two methods is also a typical method of rehabilitating clogged pervious concrete surfaces.

In most cases it was found that the three methods of maintenance investigated in this study typically caused a 200% or greater increase of infiltration rates over the original infiltration rates of the pervious concrete cores. Based on these results it is concluded that pressure washing and vacuum sweeping typically resulted in an equivalent increase in infiltration rates and the use of both methods of maintenance resulted in the greatest increase in infiltration rates. It is therefore recommended that as a general rule of thumb that one or both of these rejuvenation techniques should be performed when the system infiltration rates are below acceptable infiltration rates as measured by an infiltrometer testing the pervious concrete and the soil beneath it as a system. A rate of 1.5 inches/hour was recommended by Wanielista (2007).

6.4: Construction Specification Conclusions

This study recommended specifications for the installation of pervious concrete pavement in regional conditions typical to the States of Florida, Georgia, and South Carolina based on current construction practices and updated as a result of this research. These specifications include details on contractor qualifications, materials and mix design, construction, post-construction and maintenance procedures. The specifications were presented in Chapter 5.

To accurately test the in-situ infiltration capability of pervious concrete installations at any time without the use of current destructive testing techniques a permanent embedded infiltrometer is recommended to be installed at critical locations in the pervious concrete. It is recommended that at least one embedded infiltrometer installation should be installed at each site with a minimum of two per acre of pervious concrete installed. The circular concrete sections can be used to accurately test the infiltration rates of the pervious concrete system with the use of a standard Double Ring Infiltrometer following the ASTM D3385 standard, provided the rings are embedded into the parent materials. The embedded Infiltrometer should be used to annually test the system infiltration capability, and if the infiltration capacity is not acceptable then the pervious concrete should be rejuvenated.

6.5: Recommended Future Research

Several aspects of the pervious concrete system should be investigated further in regards to the clogging potential of pervious concrete as it ages and the methods of maintenance presented in this research. The conclusions of this study indicated that pervious concrete's ability to infiltrate degrades with time. However, these results are very site specific. In order to accurately predict the degradation of permeability it would be necessary to perform an investigation of a newly placed pervious concrete pavement over several years of service. By following the service life of a specific pervious concrete installation from its placement, more accurate conclusions can be drawn in regards to predictions of permeability decay and the effectiveness of maintenance methods. The recommended permanent embedded infiltrometer installations will require additional research to determine the feasibility of construction of these installations.

It is also recommended that further research be conducted in regards to other available methods of pervious pavement maintenance including high volume flushing of pervious concrete. Pervious pavements with embedded infiltrometers can be used to measure the results of rejuvenation techniques. Thus, a more accurate understanding of the success of pervious concrete and maintenance is possible using an embedded infiltrometer.

APPENDIX A: FIELD INFILTRATION TEST DATA

Sun Ray Store-Away

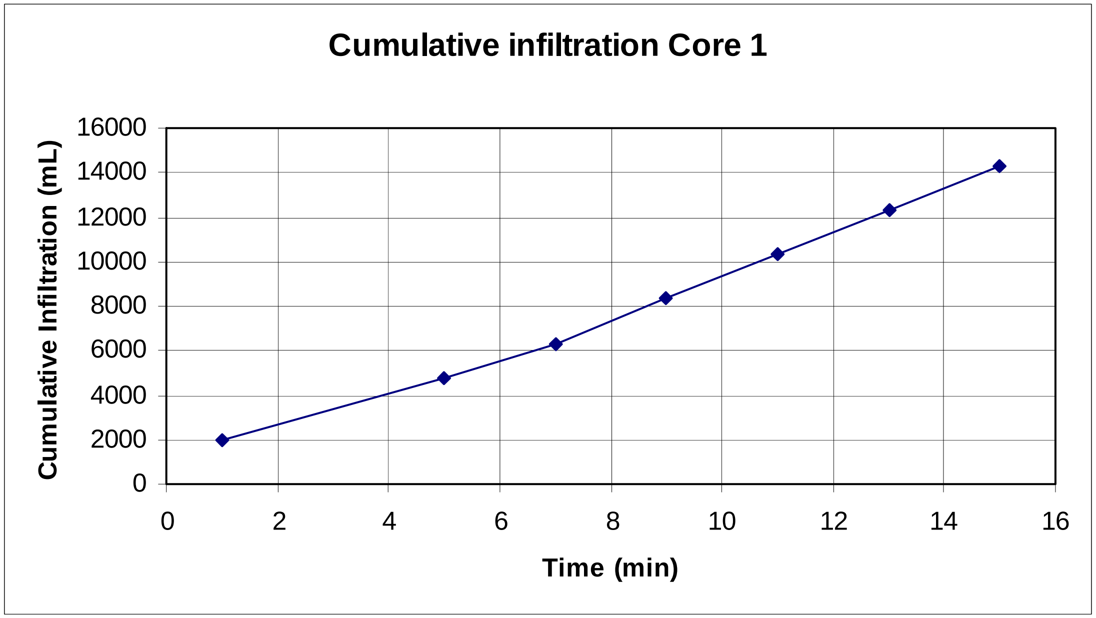
Core 1 (without Core)

1000 -670

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	0	2000	2000	2000
5	210	3000	2790	4790
7	460	2000	1540	6330
9	0	2000	2000	8330
11	0	2000	2000	10330
13	0	2000	2000	12330
15	0	2000	2000	14330

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	1000.00	cm^3/min
	61.02	in^3/min

Infiltration Rate: 34.50 in/hr

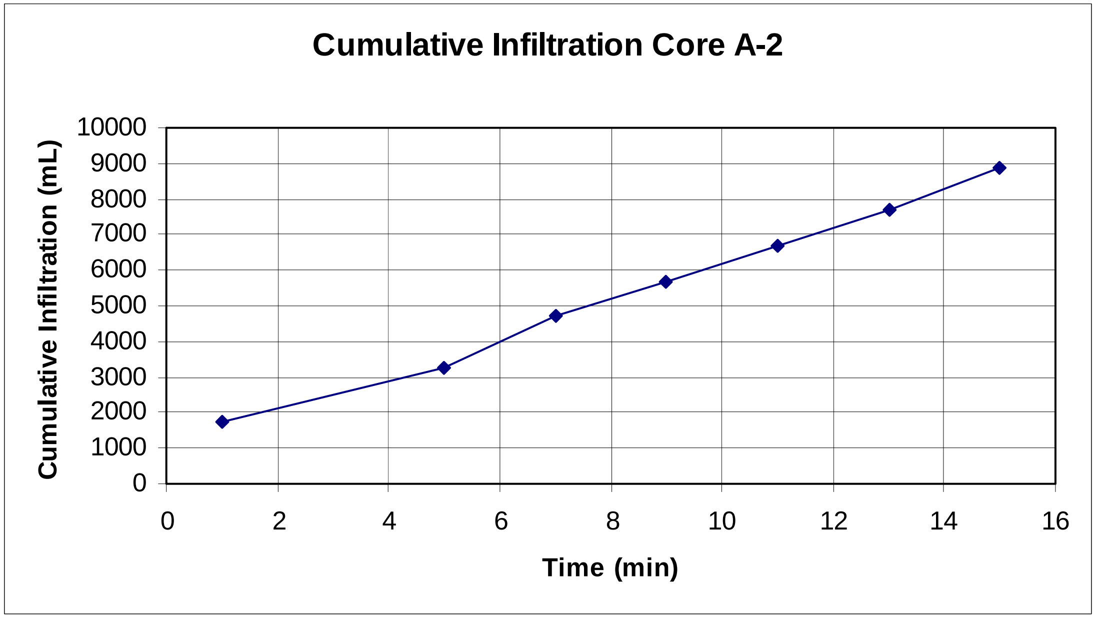


Sun Ray Store-Away
Core 2 (with Core)

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	270	2000	1730	1730
5	460	2000	1540	3270
7	570	2000	1430	4700
9	0	1000	1000	5700
11	0	1000	1000	6700
13	0	1000	1000	7700
15	0	1150	1150	8850

	515	1065
Diameter	11.63	in
Area	106.14	in^2
Vol Rate	515.00	cm^3/min
	31.43	in^3/min

Infiltration Rate: 17.77 in/hr



Sun Ray Store-Away

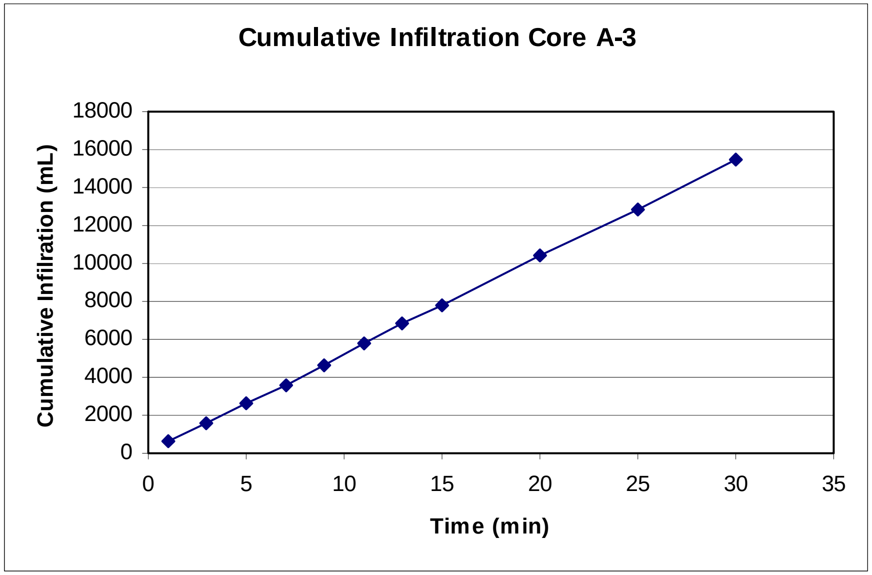
Core 3 (with Core)

513.702 75.9535

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	370	1000	630	630
3	10	1000	990	1620
5	20	1000	980	2600
7	0	1000	1000	3600
9	0	1000	1000	4600
11	785	2000	1215	5815
13	0	1000	1000	6815
15	10	1000	990	7805
20	380	3000	2620	10425
25	550	3000	2450	12875
30	420	3000	2580	15455

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	513.70	cm^3/min
	31.35	in^3/min

Infiltration Rate: 17.72 in/hr



Sun Ray Store-Away

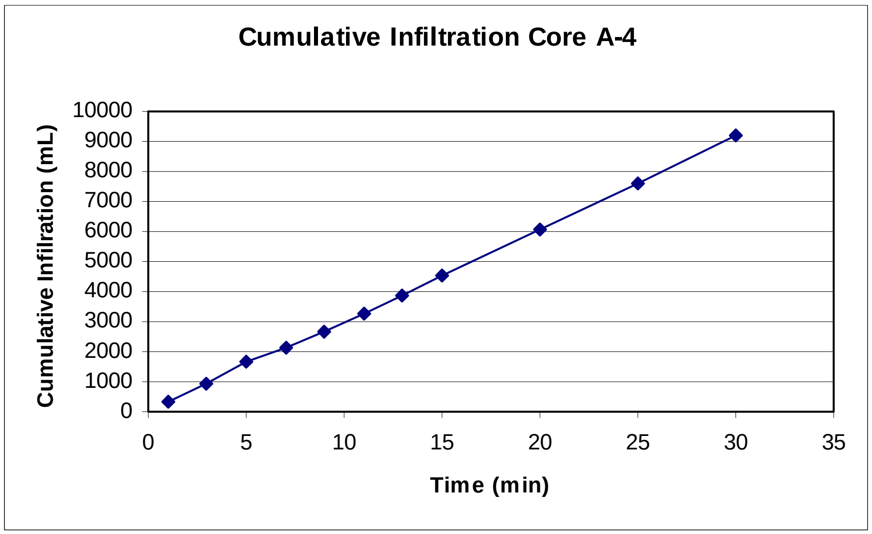
Core A-4 (with Core)

304.236 10.10714

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	660	1000	340	340
3	430	1000	570	910
5	220	1000	780	1690
7	550	1000	450	2140
9	440	1000	560	2700
11	430	1000	570	3270
13	380	1000	620	3890
15	340	1000	660	4550
20	470	2000	1530	6080
25	450	2000	1550	7630
30	430	2000	1570	9200

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	304.24	cm^3/min
	18.57	in^3/min

Infiltration Rate:	10.50	in/hr



Sun Ray Store-Away

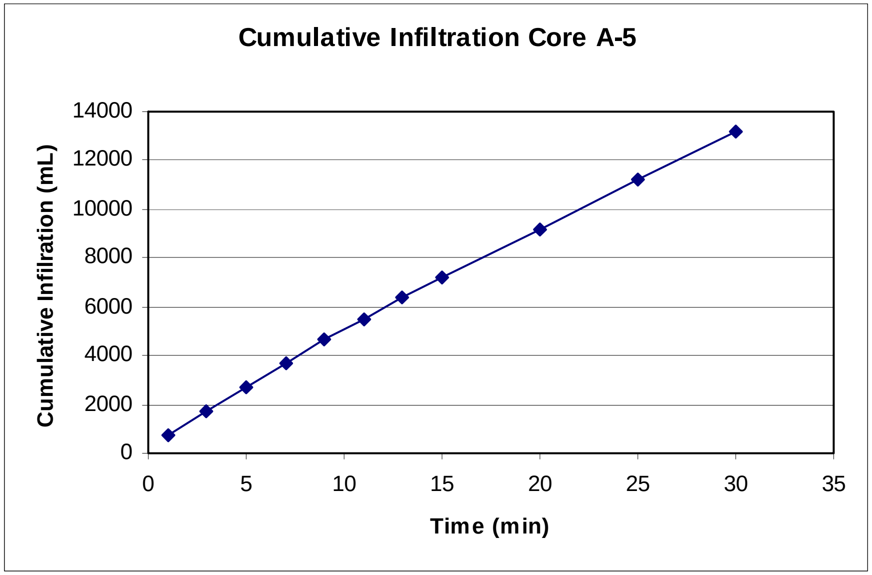
Core 5 (without Core)

427.782 602.5691

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	300	1000	700	700
3	0	1000	1000	1700
5	0	1000	1000	2700
7	20	1000	980	3680
9	30	1000	970	4650
11	170	1000	830	5480
13	100	1000	900	6380
15	180	1000	820	7200
20	0	2000	2000	9200
25	0	2000	2000	11200
30	0	2000	2000	13200

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	427.78	cm^3/min
	26.10	in^3/min

Infiltration Rate:	14.76	in/hr



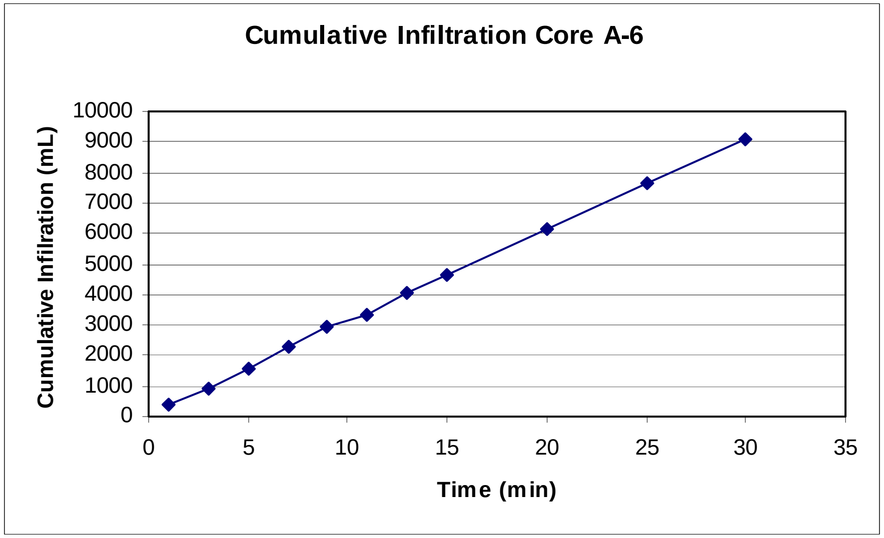
Sun Ray Store-Away
Core 6 (with Core)

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	640	1000	360	360
3	420	1000	580	940
5	370	1000	630	1570
7	260	1000	740	2310
9	390	1000	610	2920
11	560	1000	440	3360
13	320	1000	680	4040
15	390	1000	610	4650
20	500	2000	1500	6150
25	510	2000	1490	7640
30	530	2000	1470	9110

301.71 101.1206

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	301.71	cm^3/min
	18.41	in^3/min

Infiltration Rate: 10.41 in/hr



Strang Communication Office

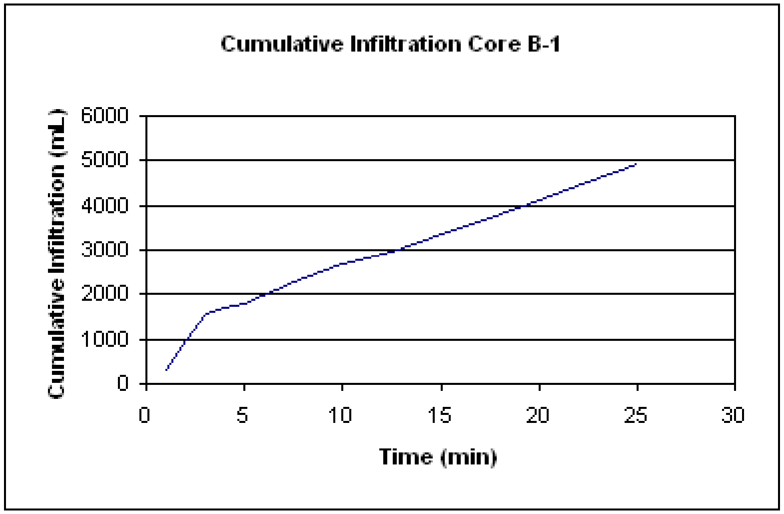
Core 1 - Test Run with no Core

156.8 986.7

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	680	1000	320	320
2	0	680	680	1000
3	450	1000	550	1550
4	290	450	160	1710
5	940	1000	60	1770
7.5	430	940	510	2280
10	600	1000	400	2680
12.5	330	600	270	2950
15	610	1000	390	3340
17.5	220	610	390	3730
20	620	1000	380	4110
22.5	210	620	410	4520
25	610	1000	390	4910

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	156.80	cm^3/min
	9.57	in^3/min

Infiltration Rate: 5.41 in/hr



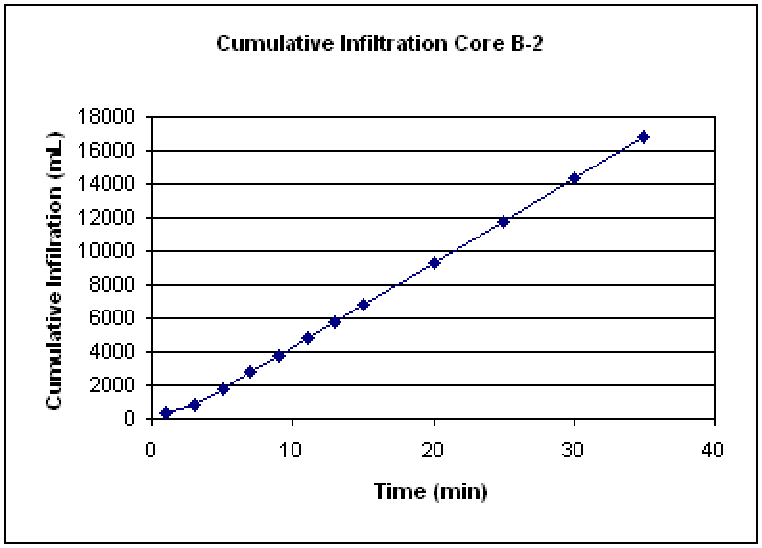
Strang Communication Office
Core B-2

501.095 -712.678

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	700	1000	300	300
3	700	1200	500	800
5	0	1000	1000	1800
7	0	1000	1000	2800
9	0	1000	1000	3800
11	0	1000	1000	4800
13	0	1000	1000	5800
15	0	1000	1000	6800
20	520	3000	2480	9280
25	490	3000	2510	11790
30	460	3000	2540	14330
35	480	3000	2520	16850

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	501.10	cm^3/min
	30.58	in^3/min

Infiltration Rate: 17.29 in/hr



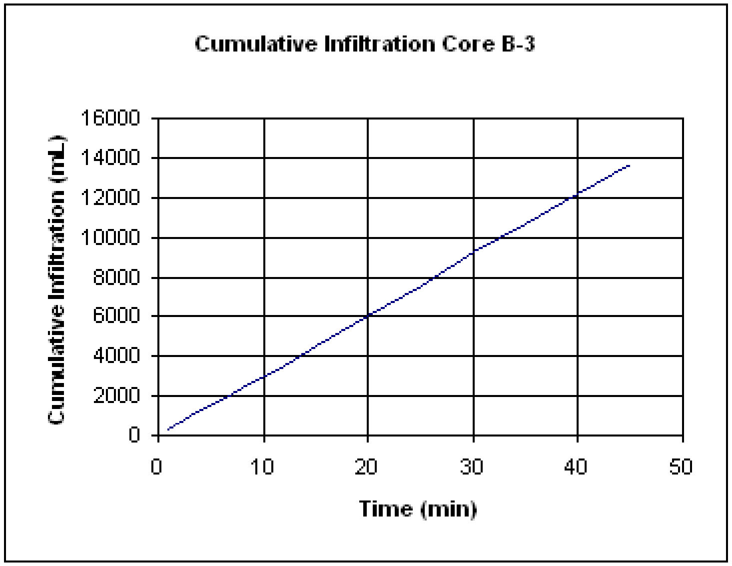
Strang Communication Office
Core B-3

307.139 -116.5

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	720	1000	280	280
3	280	1000	720	1000
5	460	1000	540	1540
7	380	1000	620	2160
9	430	1000	570	2730
11	500	1000	500	3230
13	380	1000	620	3850
15	360	1000	640	4490
20	490	2000	1510	6000
25	450	2000	1550	7550
30	320	2000	1680	9230
35	600	2000	1400	10630
40	500	2000	1500	12130
45	450	2000	1550	13680

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	307.14	cm^3/min
	18.74	in^3/min

Infiltration Rate: 10.60 in/hr



Murphy Vet Clinic

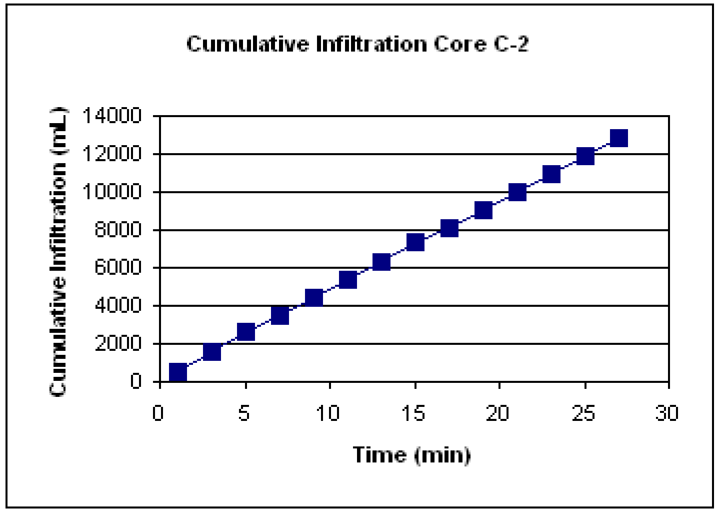
Core 2: No Core

457.5 459.2

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	460	1000	540	540
3	960	2000	1040	1580
5	0	1000	1000	2580
7	100	1000	900	3480
9	10	1000	990	4470
11	100	1000	900	5370
13	50	1000	950	6320
15	0	1000	1000	7320
17	170	1000	830	8150
19	70	1000	930	9080
21	30	1000	970	10050
23	70	1000	930	10980
25	80	1000	920	11900
27	90	1000	910	12810

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	457.50	cm^3/min
	27.92	in^3/min

Infiltration Rate: 15.78 in/hr



Murphy Vet Clinic

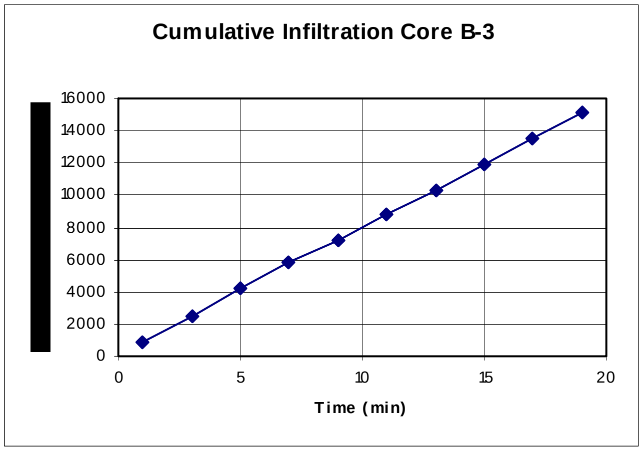
Core C-3: No Core

788.75 86.25

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	160	1000	840	840
3	340	2000	1660	2500
5	270	2000	1730	4230
7	445	2000	1555	5785
9	550	2000	1450	7235
11	400	2000	1600	8835
13	505	2000	1495	10330
15	410	2000	1590	11920
17	430	2000	1570	13490
19	415	2000	1585	15075

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	788.75	cm^3/min
	48.13	in^3/min

Infiltration Rate: 27.21 in/hr



FDEP Office

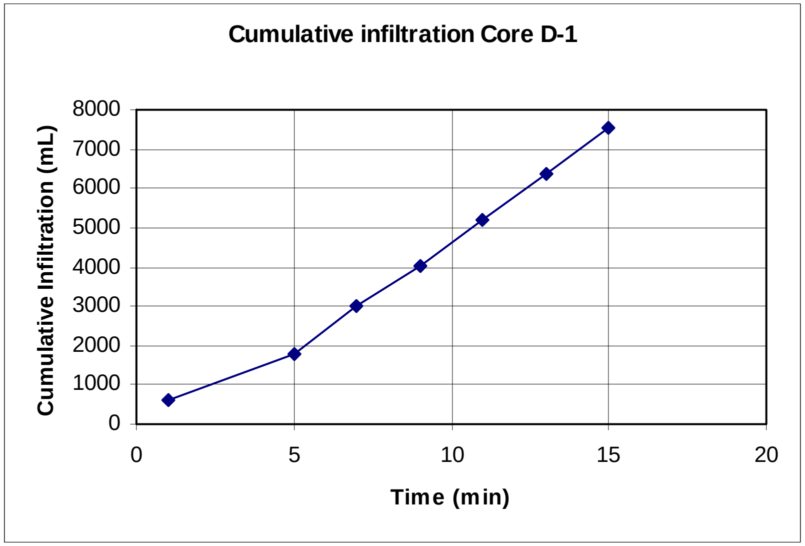
Core D-1 (without Core)

580 -1173.3

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	400	1000	600	600
5	810	2000	1190	1790
7	780	2000	1220	3010
9	0	1000	1000	4010
11	800	2000	1200	5210
13	850	2000	1150	6360
15	830	2000	1170	7530

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	580.00	cm^3/min
	35.39	in^3/min

Infiltration Rate: 20.01 in/hr



FDEP Office

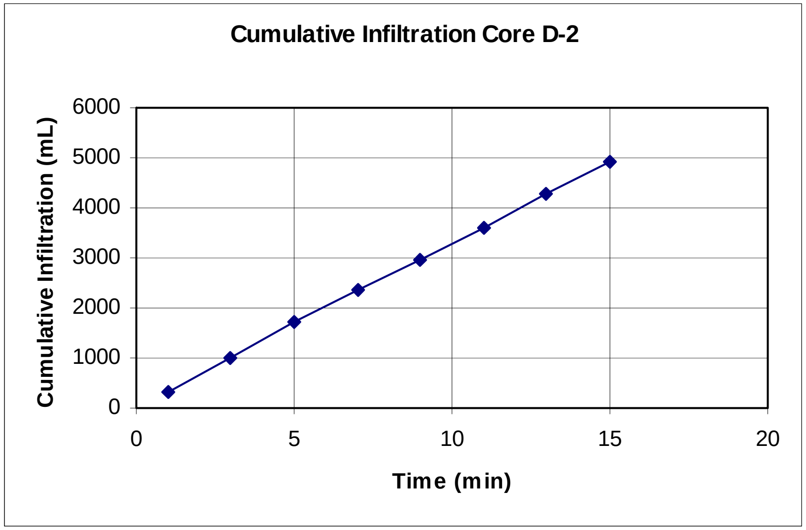
Core D-2 (without Core)

325.5 55.5

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	680	1000	320	320
3	300	1000	700	1020
5	300	1000	700	1720
7	370	1000	630	2350
9	380	1000	620	2970
11	350	1000	650	3620
13	320	1000	680	4300
15	360	1000	640	4940

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	325.50	cm^3/min
	19.86	in^3/min

Infiltration Rate: 11.23 in/hr



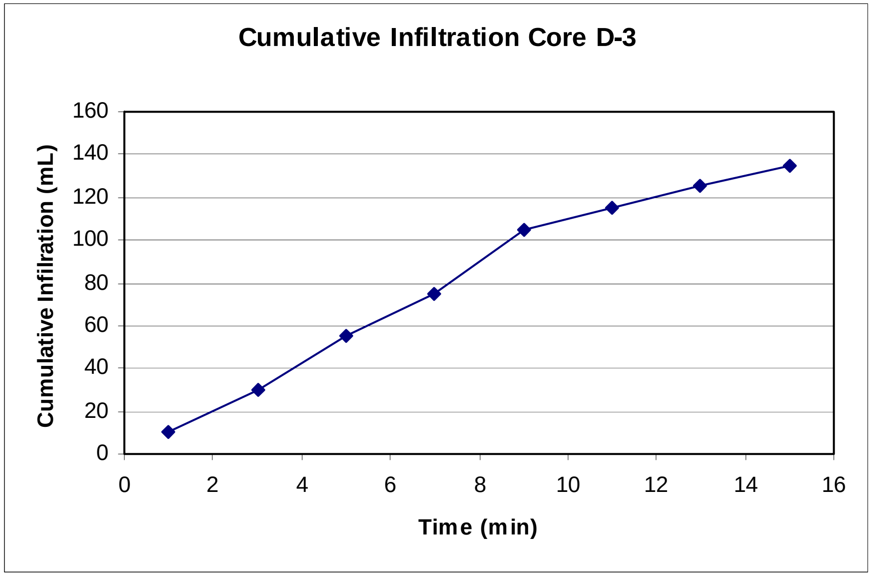
FDEP Office

Core D-3 (with Core) 5 60

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	990	1000	10	10
3	980	1000	20	30
5	975	1000	25	55
7	980	1000	20	75
9	970	1000	30	105
11	990	1000	10	115
13	990	1000	10	125
15	990	1000	10	135

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	5.00	cm^3/min
	0.31	in^3/min

Infiltration Rate:	0.17	in/hr



FDEP Office

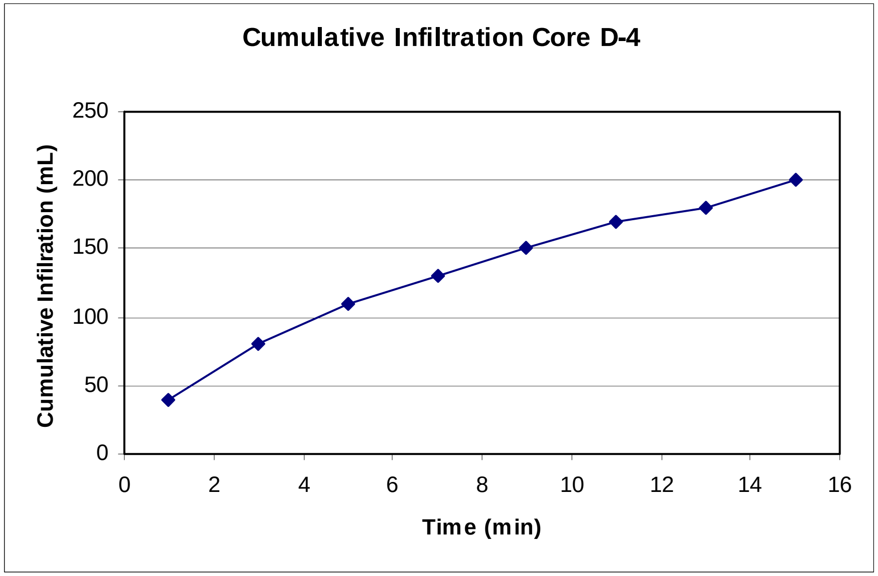
Core D-4 (with Core)

8.5 72.5

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	960	1000	40	40
3	960	1000	40	80
5	970	1000	30	110
7	980	1000	20	130
9	980	1000	20	150
11	980	1000	20	170
13	990	1000	10	180
15	980	1000	20	200

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	8.50	cm^3/min
	0.52	in^3/min

Infiltration Rate:	0.29	in/hr



FDEP Office

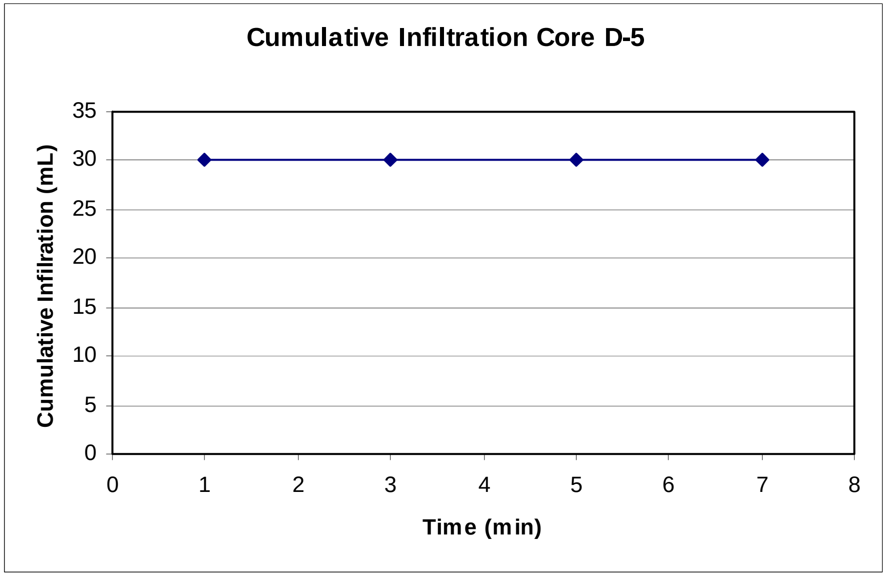
Core D-5 (without Core)

0

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	970	1000	30	30
3	1000	1000	0	30
5	1000	1000	0	30
7	1000	1000	0	30

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	0.00	cm^3/min
	0.00	in^3/min

Infiltration Rate: 0.00 in/hr



FDEP Office

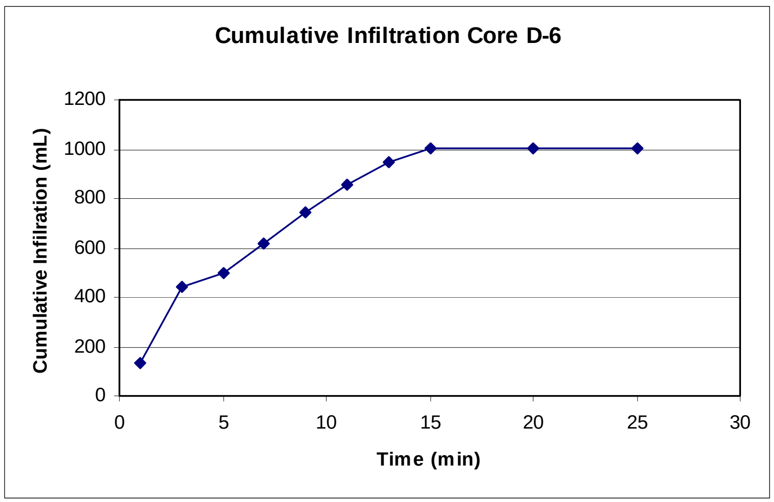
Core D-6 (with Core)

51.5714 262.619

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	870	1000	130	130
3	690	1000	310	440
5	940	1000	60	500
7	880	1000	120	620
9	875	1000	125	745
11	890	1000	110	855
13	910	1000	90	945
15	940	1000	60	1005
20	1000	1000	0	1005
25	1000	1000	0	1005

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	51.57	cm^3/min
	3.15	in^3/min

Infiltration Rate:	1.78	in/hr



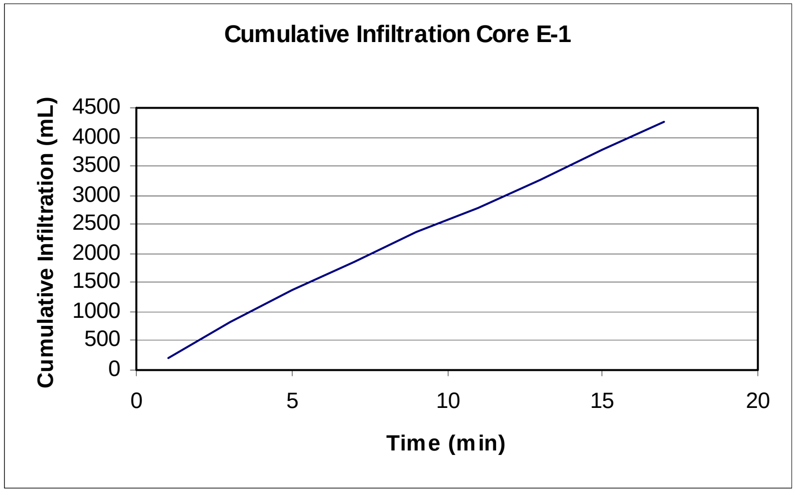
FCPA Office

Core E-1: No Core 247.5 60.8

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	800	1000	200	200
3	370	1000	630	830
5	460	1000	540	1370
7	500	1000	500	1870
9	500	1000	500	2370
11	600	1000	400	2770
13	490	1000	510	3280
15	510	1000	490	3770
17	500	1000	500	4270

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	247.50	cm^3/min
	15.10	in^3/min

Infiltration Rate: 8.54 in/hr



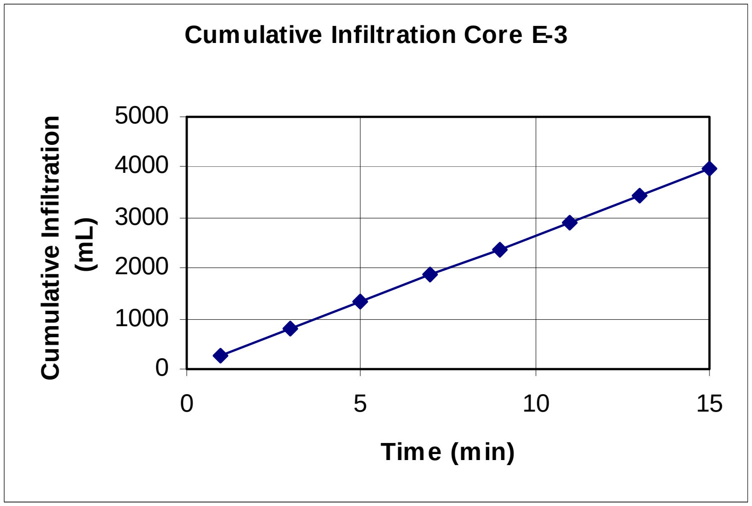
FCPA Office

Core E-3: No Core 263 10

Time (min)	Volume Remaining (mL)	Of (mL)	Volume Added (mL)	Cum Vol Added (mL)
1	740	1000	260	260
3	440	1000	560	820
5	500	1000	500	1320
7	465	1000	535	1855
9	475	1000	525	2380
11	490	1000	510	2890
13	460	1000	540	3430
15	470	1000	530	3960

Diameter	11.63	in
Area	106.14	in^2
Vol Rate	263.00	cm^3/min
	16.05	in^3/min

Infiltration Rate:	9.07	in/hr



APPENDIX B: LABORATORY INFILTRATION TEST DATA

Sun Ray Store-Away

Core A-1

Initial		
Amount	10	Liters
Time	33	Seconds
Rate	303	mL/s
	18182	mL/min
	1109.52262	in^3/min
Infil Rate	627	in/hr

Core A-2

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	590	2000	1410	1410	Average		
2	0	2000	2000	3410	1000	mL/min	
4	0	2000	2000	5410	61	in^3/min	
6	0	2000	2000	7410			
8	0	2000	2000	9410	Infil. Rate	34.5	in/hr

Core A-3

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	200	1000	800	800	Average		
3	360	2000	1640	2440	586	mL/min	
5	560	2000	1440	3880	36	in^3/min	
7	610	2000	1390	5270			
9	480	2000	1520	6790	Infil. Rate	20.2	in/hr
11	900	2000	1100	7890			
13	750	2000	1250	9140			
15	800	2000	1200	10340			
17	860	2000	1140	11480			

Core A-4

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	955	1000	45	45	Average		
3	915	1000	85	130	107.5	mL/min	
5	860	1000	140	270	7	in^3/min	
7	900	1000	100	370			
9	920	1000	80	450	Infil. Rate	3.7	in/hr
11	890	1000	110	560			

Core A-5

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	900	1000	100	100	Average		
3	710	1000	290	390	138	mL/min	
5	700	1000	300	690	8	in^3/min	
7	750	1000	250	940			
9	730	1000	270	1210	Infil. Rate	4.8	in/hr
11	730	1000	270	1480			

Core A-6

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	980	1000	20	20	Average		
3	825	1000	175	195	86.25	mL/min	
5	825	1000	175	370	5	in^3/min	
7	810	1000	190	560			
9	850	1000	150	710	Infil. Rate	3.0	in/hr

Strang Communication Office

Core B-1

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
1	1000	1000	0	0				
3	870	1000	130	130	Average			
5	1000	1000	0	130	40	mL/min		
7	910	1000	90	220	2	in^3/min		
9	1000	1000	0	220				
11	930	1000	70	290	Infil. Rate		1.4	in/hr
13	910	1000	90	380				
15	920	1000	80	460				

Core B-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
1	760	1000	240	240				
3	350	1000	650	890	Average			
5	600	1000	400	1290	163	mL/min		
7	840	1000	160	1450	10	in^3/min		
9	730	1000	270	1720				
11	670	1000	330	2050	Infil. Rate		5.6	in/hr
13	710	1000	290	2340				
15	790	1000	210	2550				
17	700	1000	300	2850				

Core B-3

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
1	790	1000	210	210				
3	610	1000	390	600	Average			
5	580	1000	420	1020	205	mL/min		
7	570	1000	430	1450	13	in^3/min		
9	590	1000	410	1860				
11	600	1000	400	2260	Infil. Rate		7.1	in/hr

Murphy Vet Clinic

Core C-1

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	890	1000	110	110			
3	870	1000	130	240	Average		
5	750	870	120	360	66	mL/min	
7	850	1000	150	510	4	in^3/min	
9	720	850	130	640			
11	870	1000	130	770	Infil. Rate	2.3	in/hr

Core C-2

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	50	1000	950	950			
3	400	2000	1600	2550	Average		
5	450	2000	1550	4100	570	mL/min	
7	860	2000	1140	5240	35	in^3/min	
9	700	2000	1300	6540			
11	860	2000	1140	7680	Infil. Rate	19.7	in/hr
13	870	2000	1130	8810			
15	850	2000	1150	9960			

Core C-3

Time (min)	Initial Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)		
1	100	1000	900	900		
3	480	2000	1520	2420	Average	
5	600	2000	1400	3820	695	mL/min
7	600	2000	1400	5220	42	in^3/min
9	630	2000	1370	6590		

11	610	2000	1390	7980	Infil. Rate	24.0	in/hr

FDEP Office

Core D-1

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)	Average		
1	1000	1000	0	0		0	mL/min
3	1000	1000	0	0		0	in^3/min
5	1000	1000	0	0			
					Infil. Rate	0.0	in/hr

Core D-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	970	1000	30	30			
3	1000	1000	0	30	Average		
5	1000	1000	0	30		0	mL/min
7	1000	1000	0	30		0	in^3/min
9	1000	1000	0	30			
11	1000	1000	0	30	Infil. Rate	0	in/hr

Core D-3

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	980	1000	20	20			
3	960	1000	40	60	Average		
5	938	1000	62	122		38	mL/min
7	890	1000	110	232		2	in^3/min
9	860	1000	140	372			
11	930	1000	70	442	Infil.	1.3	in/hr

					Rate		
13	920	1000	80	522			

Core D-4
Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	915	1000	85	85			
3	710	1000	290	375	Average		
5	790	1000	210	585	139	mL/min	
7.5	690	1000	310	895	8	in^3/min	
10	660	1000	340	1235			
12.5	750	1000	250	1485	Infil. Rate	4.8	in/hr

Core D-5
Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	1000	1000	0	0			
3	940	1000	60	60	Average		
5	920	1000	80	140	28	mL/min	
7	940	1000	60	200	2	in^3/min	
9	940	1000	60	260			
11	950	1000	50	310	Infil. Rate	1.0	in/hr

Core D-6
Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	580	1000	420	420			
3	220	1000	780	1200	Average		
5	500	1000	500	1700	152	mL/min	
7	675	1000	325	2025	9	in^3/min	
9	740	1000	260	2285			
11	700	1000	300	2585	Infil.	5.2	in/hr

					Rate
13	660	1000	340	2925	
15	710	1000	290	3215	
17	470	710	240	3455	

FCPA Office

Core E-1

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	860	1000	140	140			
3	700	1000	300	440	Average		
5	750	1000	250	690	125	mL/min	
7	740	1000	260	950	8	in^3/min	
9	760	1000	240	1190			
11	750	1000	250	1440	Infil. Rate	4.3	in/hr

Core E-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
1	800	1000	200	200			
3	600	1000	400	600	Average		
5	650	1000	350	950	168	mL/min	
7	700	1000	300	1250	10	in^3/min	
9	660	1000	340	1590			
11	670	1000	330	1920	Infil. Rate	5.8	in/hr
13	660	1000	340	2260			

Core E-3

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)
1	0	1000	1000	1000

3	850	1000	150	1150	Average		
5	880	1000	120	1270	52	mL/min	
7	860	1000	140	1410	3	in^3/min	
9	900	1000	100	1510			
11	900	1000	100	1610	Infil. Rate	1.8	in/hr
13	890	1000	110	1720			

Southface Institute

Core ATL-1

Initial

2.33 mins for 8 inches of water to drain through

Vol water	849.1	in^3
Rate	3.1	in/min
	188	in/hr

Core ATL-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Volume/min (mL/min)	Cum Added (mL)			
2	780	1000	220	110	220			
5	600	1000	400	133	400	Average		
6	850	1000	150	150	150	68	mL/min	
8	770	1000	230	115	230	4	in^3/min	
10	740	1000	260	130	260			
12	880	1000	120	60	120	Infil. Rate	2.3	in/hr
14	850	1000	150	75	150			
16	820	1000	180	90	180			
18	910	1000	90	45	90			
20	860	1000	140	70	140			
22	830	1000	170	85	170			
24	900	1000	100	50	100			

Core ATL-3

Initial
Infil
Rate 0 in/hr

Cleveland Park

Core SC-1

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	0	5000	5000	5000			
4	0	4000	4000	9000	Average		
6	0	6000	6000	15000	2500	mL/min	
8	0	5000	5000	20000	153	in^3/min	
10	0	5000	5000	25000			
					Infil. Rate	86.2	in/hr

Core SC-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	820	1000	180	180			
4	1000	1000	0	180	Average		
6	1000	1000	0	180	0	mL/min	
					0	in^3/min	
					Infil. Rate	0	in/hr

Core SC-3

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)

2	440	6000	5560	5560			
4	0	5000	5000	10560	Average		
6	300	5000	4700	15260	2456	mL/min	
8	300	5000	4700	19960	150	in^3/min	
10	400	5000	4600	24560			
					Infil. Rate	84.7	in/hr

<u>Cleveland Park</u>

Core LF-1

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	160	2000	1840	1840			
4	130	2000	1870	3710	Average		
6	310	2000	1690	5400	894	mL/min	
8	200	2000	1800	7200	55	in^3/min	
10	260	2000	1740	8940			
					Infil. Rate	30.8	in/hr

Core LF-2

Initial

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	320	1000	680	680			
4	380	1000	620	1300	Average		
6	370	1000	630	1930	318	mL/min	
8	390	1000	610	2540	19	in^3/min	
					Infil. Rate	11.0	in/hr

Core LF-3

Initial

drained 8" in 2:34 minutes

Vol water	849.1	in^3
Rate	3.1	in/min
	187	in/hr

APPENDIX C: REHABILITATED CORE TEST DATA

Sun Ray Store-Away

Core A-1

Pressure Washed

Time	12	sec
Head change	4	in
Vol water	424.6	in^3
Rate	20.0	in/min
	1200	in/hr

Core A-2

Vacuum Sweeped

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
2	160	5000	4840	4840		Average		
4	0	4000	4000	8840		1931.667	mL/min	
6	180	4000	3820	12660		118	in^3/min	
8	230	4000	3770	16430				
					Infil. Rate		66.6	in/hr

Core A-3

Vacuum Sweeped & Pressure Washed

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
2	510	7000	6490	6490		Average		
4	700	7000	6300	12790		2443	mL/min	
6	0	6000	6000	18790		149	in^3/min	
8	230	5000	4770	23560				
10	0	5000	5000	28560	Infil. Rate		84.3	in/hr

Core A-4

Pressure Washed

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)		
2	0	6000	6000	6000	Average	
4	450	6000	5550	11550	2787.5	mL/min
6	400	6000	5600	17150	170	in^3/min

Infil. Rate 96.2 in/hr

Core A-5

Vacuum Sweeped

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)		
1	0	1000	1000	1000	Average	
4	170	3000	2830	3830	872.5	mL/min
6	260	2000	1740	5570	53	in^3/min
8	250	2000	1750	7320		

Infil. Rate 30.1 in/hr

Core A-6

Vacuum Sweeped & Pressure Washed

Time	77	sec
Head change	4	in
Vol water	424.6	in^3
Rate	3.1	in/min
	187	in/hr

<u>Strang Communication Building</u>

Core B-1

Pressure Washed

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)		
2	730	1000	270	270		
4	790	1000	210	480	Average	
6	770	1000	230	710	118	mL/min

7	in^3/min	
Infil. Rate	4.1	in/hr

Core B-2

Vacuum Sweeped

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)		
2	860	3000	2140	2140		
4	0	2000	2000	4140	Average	
6	230	2000	1770	5910	825	mL/min
8	470	2000	1530	7440	50	in^3/min

Infil. Rate	28.5	in/hr

Core B-3

Vacuum Sweep & Pressure Washed

Time	80	sec
Head change	4	in
Vol water	424.6	in^3
Rate	3.0	in/min
	180	in/hr

<u>Murphy Vet Clinic</u>

Core C-1

Pressure Washed

Time	20	sec
Head change	4	in
Vol water	424.6	in^3
Rate	12.0	in/min
	720	in/hr

Core C-2

Vacuum Sweeped

Time	88	sec
Head change	4	in
Vol water	424.6	in^3
Rate	2.7	in/min
	164	in/hr

Core C-3

Vacuum Sweeped & Pressure Washed

Time	22	sec
Head change	4	in
Vol water	424.6	in^3
Rate	10.9	in/min
	655	in/hr

FDEP Office

Core D-1

Pressure Washed

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)				
					Average			
2	690	1000	310	310	157	mL/min		
4	640	1000	360	670	10	in^3/min		
6	730	1000	270	940				
					Infil. Rate		5.4	in/hr

Core D-2

Vacuum Sweep

Infil. Rate 0 in/hr

Core D-3

Vacuum Sweep & Pressure Washed

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	650	1000	350	350			
4	700	1000	300	650	Average		
6	700	1000	300	950	150	mL/min	
					9	in^3/min	
					Infil. Rate	5.2	in/hr

Core D-4

Pressure Wash

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	410	1000	590	590			
4	390	1000	610	1200	Average		
6	340	1000	660	1860	343	mL/min	
8	290	1000	710	2570	21	in^3/min	
					Infil. Rate	11.8	in/hr

Core D-5

Vacuum Sweep

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	360	1000	640	640			
4	490	1000	510	1150	Average		
6	520	1000	480	1630	250	mL/min	
8	490	1000	510	2140	15	in^3/min	
					Infil. Rate	8.6	in/hr

Core D-6

Vacuum Sweeped & Pressure Washed

Time	37	sec
Head change	4	in
Vol water	424.6	in^3
Rate	6.5	in/min
	389	in/hr

FCPA Office

Core E-1

Pressure Washed

Time	36	sec
Head change	4	in
Vol water	424.6	in^3
Rate	6.7	in/min
	400	in/hr

Core E-2

Vacuum Sweeped

Time	123	sec
Head change	4	in
Vol water	424.6	in^3
Rate	2.0	in/min
	117	in/hr

Core E-3

Vacuum Sweep & Pressure Wash

Time	19	sec
Head change	4	in
Vol water	424.6	in^3
Rate	12.6	in/min
	758	in/hr

Southface Institute

Core ATL-1

Pressure Washed

Time	22	sec
Head change	4	in
Vol water	424.6	in^3
Rate	10.9	in/min
	655	in/hr

Core ATL-2

Vacuum Sweep

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Volume/min (mL/min)	Cum Added (mL)			
2	0	5000	5000	2500	5000			
4	390	5000	4610	2305	4610	Average		
6	0	4000	4000	2000	4000	1785	mL/min	
8	300	4000	3700	1850	3700	109	in^3/min	
10	560	4000	3440	1720	3440			
						Infil. Rate	61.6	in/hr

Core ATL-3

Vacuum Sweep & Pressure Wash

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Volume/min (mL/min)	Cum Added (mL)
2	460	1000	540	270	540

4	600	1000	400	200	400	Average		
6	520	1000	480	240	480	245	mL/min	
8	500	1000	500	250	500	15	in^3/min	
						Infil. Rate	8.5	in/hr

Cleveland Park

Core SC-1

Pressure Washed

Time	45	sec
Head change	4	in
Vol water	424.6	in^3
Rate	5.3	in/min
	320	in/hr

Core SC-2

Vacuum Sweep

Rate	0	in/hr

Core SC-3

Vacuum Sweep & Pressure Washed

Time	10	sec
Head change	4	in
Vol water	424.6	in^3
Rate	24.0	in/min
	1440	in/hr

Effingham County Landfill

Core LF-1

Pressure Washed

Time	42	sec
Head	4	in

change		
Vol water	424.6	in^3
Rate	5.7	in/min
	343	in/hr

Core LF-2

Vacuum Sweeped

Time (min)	Reading (mL)	of (mL)	Volume Added (mL)	Cum Added (mL)			
2	730	4000	3270	3270			
4	130	3000	2870	6140	Average		
6	360	3000	2640	8780	1025	mL/min	
8	640	3000	2360	11140	63	in^3/min	
10	940	3000	2060	13200			
12	960	3000	2040	15240	Infil. Rate	35.4	in/hr

Core LF-3

Vacuum Sweep & Pressure Wash

Time	19	sec
Head change	4	in
Vol water	424.6	in^3
Rate	12.6	in/min
	758	in/hr

APPENDIX D: LABORATORY SOILS TEST DATA

Sun-Ray Store Away

Moisture Content Analysis

Core Number	A-1	A-1	A-1	A-6	A-6	A-6
Depth Sampled (ft)	0-2.1	2.1-2.5	5.0-6.0	0.5-1.7	3.5-4.3	4.3-4.7
Can Number	A-2	A-3	A-4	A-5	A-6	A-7
Wt. of Can (g)	117.50	14.10	13.80	13.80	14.10	13.70
Wt. of Wet Soil + Can (g)	509.80	378.80	371.70	488.90	382.20	140.80
Wt. of Dry Soil + Can (g)	466.60	332.60	356.50	434.70	339.50	114.00
Wt. of Dry Soil (g)	349.10	318.50	342.70	420.90	325.40	100.30
Wt. of Water (g)	43.20	46.20	15.20	54.20	42.70	26.80
Moisture Content (%)	12.37	14.51	4.44	12.88	13.12	26.72

Sieve Analysis

Core Number	A-1
Depth Sampled (ft)	0-2.1
Can Number	A-2
Wt. of Dry Soil (g)	349.10

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0.4	99.89
10	2.000	0.6	99.83
20	0.850	1.2	99.66
40	0.425	8.7	97.51
60	0.250	70.1	79.92
100	0.150	310.6	11.03
120	0.125	330.3	5.39
200	0.075	347.2	0.54
Pan	---	348.2	---

Core Number	A-1
Depth Sampled (ft)	2.1-2.5

Can Number	A-3
Wt. of Dry Soil (g)	318.50

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0.4	99.87
40	0.425	6.8	97.86
60	0.250	70.5	77.86
100	0.150	280.4	11.96
120	0.125	298	6.44
200	0.075	310.5	2.51
Pan	---	316.8	---

Core Number	A-1
Depth Sampled (ft)	5.0-6.0
Can Number	A-4
Wt. of Dry Soil (g)	342.70

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	6	98.25
60	0.250	56.5	83.51
100	0.150	298.7	12.84
120	0.125	321.4	6.22
200	0.075	341.3	0.41
Pan	---	342.7	---

Core Number	A-6
Depth Sampled (ft)	0.5-1.7
Can Number	A-5

Wt. of Dry Soil (g)	420.90

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	5.1	98.79
60	0.250	92.6	78.00
100	0.150	379.4	9.86
120	0.125	402.3	4.42
200	0.075	418.9	0.48
Pan	---	420	---

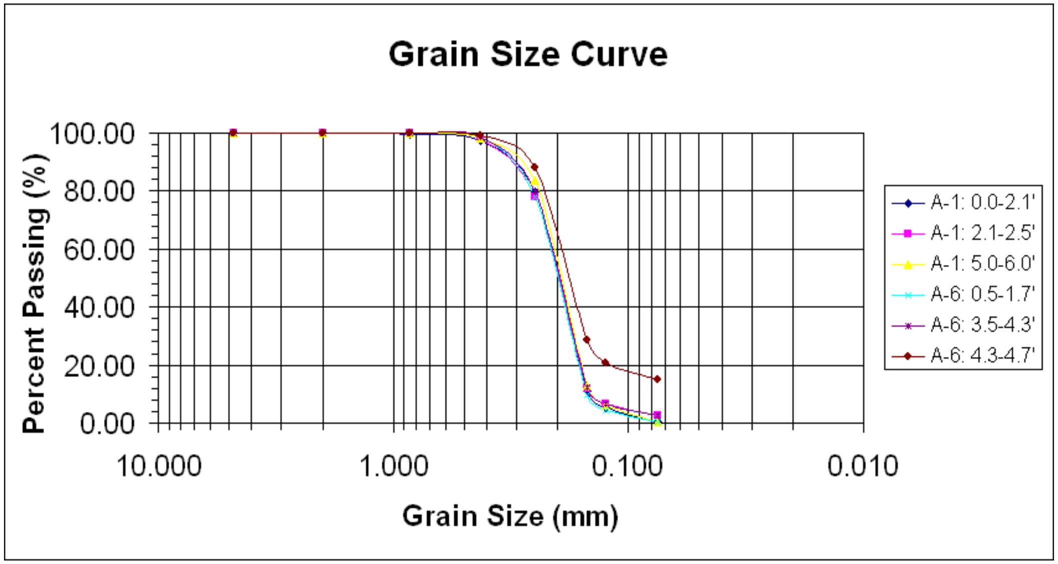
Core Number	A-6
Depth Sampled (ft)	3.5-4.3
Can Number	A-6
Wt. of Dry Soil (g)	325.40

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	3.6	98.89
60	0.250	65.5	79.87
100	0.150	284.9	12.45
120	0.125	304.4	6.45
200	0.075	317	2.58
Pan	---	323	---

Core Number	A-6
Depth Sampled (ft)	4.3-4.7
Can Number	A-7

Pre Wash Dry + Can (g)	112.60
Post Wash Dry + Can (g)	99.50
Wt. Passing # 200 (g)	13.10
Wt. Dry Soil (g)	100.30

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	1	99.00
60	0.250	12	88.04
100	0.150	71.6	28.61
120	0.125	79.5	20.74
200	0.075	85.1	15.15
Pan	---	85.2	---



Constant Head Permeability Test

Core No.	A-1	A-6
Sample Depth (ft)	0-2.1	5.7-6.5
Can No.	A-2	A-3
Can Wt. (g)	117.50	14.10
Can + Soil Wt. (g)	638.40	670.30
Diameter (cm)	6.40	6.40
Length (cm)	10.30	12.50
Volume (cm^3)	331.35	402.12
Specific Gravity	2.65	2.65
Mass of Apparatus (g)	1402.90	1402.90
Soil + Apparatus Wt. (g)	1925.20	2021.30
Dry Density (lb/ft^3)	98.41	96.01
Void Ratio, e	0.68	0.72
Porosity, n	0.40	0.42

Sample Info.	A-1 (0.0-2.1')			A-6 (5.7-6.5')		
Test No.	1	2	3	1	2	3
Volume (ml)	195	175	145	140	120	95
Time of Collection (s)	60	60	60	60	60	60
Water Temp, C	72	72	72	72	72	72
Head Difference (cm)	70.4	60.4	50.4	70.4	60.4	50.4
Area (cm^2)	32.17	32.17	32.17	32.17	32.17	32.17
K (cm/s)	0.015	0.015	0.015	0.013	0.013	0.012
Avg. K (cm/s)		0.015			0.013	
K (in/hr)		21.34			17.76	

Strang Communication Building

Moisture Content Analysis

Core Number	B-1	B-1	B-2	B-2	B-1	B-2
Depth Sampled (ft)	3.0-4.0'	5.5-6.0'	0.0-2.5'	6.3-6.5'	4.7-55'	6.3-6.5'
Can Number	A-8	A-9	B-5	A-1	A-11	A-12
Wt. of Can (g)	14.00	13.80	50.10	117.10	398.00	397.80
Wt. of Wet Soil + Can (g)	341.20	344.40	409.10	430.40	1119.10	969.70
Wt. of Dry Soil + Can (g)	331.40	327.90	368.40	386.50	1042.50	888.10
Wt. of Dry Soil (g)	317.40	314.10	318.30	269.40	644.50	490.30
Wt. of Water (g)	9.80	16.50	40.70	43.90	76.60	81.60
Moisture Content (%)	3.09	5.25	12.79	16.30	11.89	16.64

Sieve Analysis

Core Number	B-1
Depth Sampled (ft)	3.0-4.0
Can Number	A-8
Wt. of Dry Soil (g)	317.40

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	9.6	96.98
60	0.250	88.6	72.09
100	0.150	281	11.47
120	0.125	298.7	5.89
200	0.075	315	0.76
Pan	---	315.8	---

Core Number	B-1
Depth Sampled (ft)	5.5-6.0'

Can Number	A-9
Wt. of Dry Soil (g)	314.10

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	13.8	95.61
60	0.250	129.9	58.64
100	0.150	277	11.81
120	0.125	295.2	6.02
200	0.075	311.5	0.83
Pan	---	312.9	---

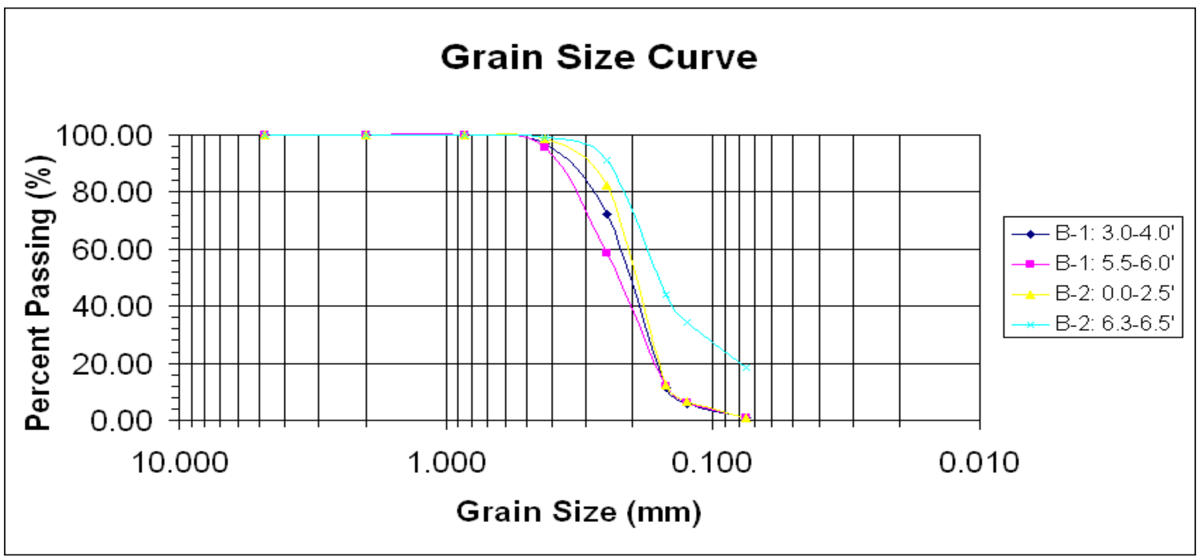
Core Number	B-2
Depth Sampled (ft)	0.0-2.5'
Can Number	B-5
Wt. of Dry Soil (g)	318.30

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	3.9	98.77
60	0.250	55.7	82.50
100	0.150	279.3	12.25
120	0.125	297.5	6.53
200	0.075	315.6	0.85
Pan	---	316.9	---

Core Number	B-2
Depth Sampled (ft)	6.3-6.5
Can Number	A-1

Pre Wash Dry + Can (g)	386.70
Post Wash Dry + Can (g)	337.30
Wt. Passing # 200 (g)	49.40
Wt. Dry Soil (g)	269.40

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	2.5	99.07
60	0.250	23.6	91.24
100	0.150	151.1	43.91
120	0.125	177.2	34.22
200	0.075	219.1	18.67
Pan	---	219.4	---

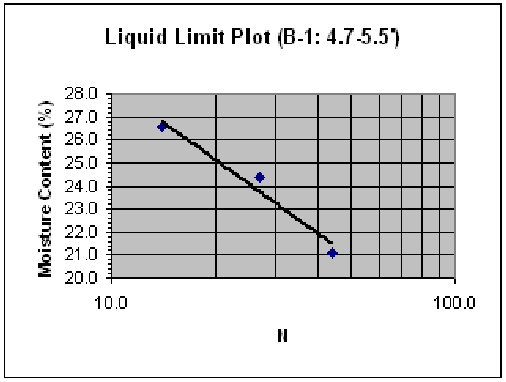


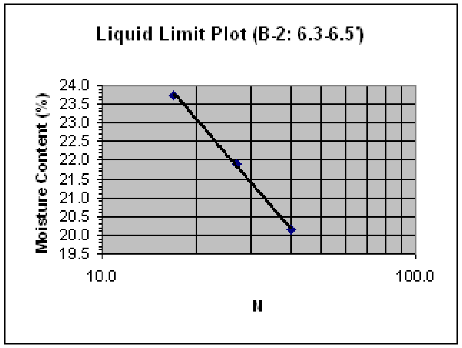
Plastic Limit

Sample No.		B-1 (4.7-5.5')			B-2 (6.3-6.5')	
Test No.	1	2	3	1	2	3
Can No.	3wpwd	3	4+G-1	#1	TNA	4+G-2
Can Wt. (g)	11.1	11.8	11.0	10.9	11.5	11.9
Can + Wet Soil Wt. (g)	13.2	14.0	15.1	15.5	13.8	14.5
Can + Dry Soil Wt. (g)	12.9	13.6	14.3	14.6	13.4	14.0
PL (%)	16.7	22.2	24.2	24.3	21.1	23.8
PL Avg. (%)		23.2			21.1	

Liquid Limit

Sample No.		B-1 (4.7-5.5')			B-2 (6.3-6.5')	
Test No.	1	2	3	1	2	3
Can No.	7	2	TNA-1	TNA-2	HP6	1
Can Wt. (g)	11.6	11.1	11.1	11.6	11.1	11.8
Can + Wet Soil Wt. (g)	22.5	21.3	25.4	27.7	31.7	31.6
Can + Dry Soil Wt. (g)	20.6	19.3	22.4	25.0	28.0	27.8
Moisture Content (%)	21.1	24.4	26.5	20.1	21.9	23.8
Number of Blows	44.0	27.0	14.0	40.0	27.0	17.0
LL (%)		24.2			22.2	
PI = LL-PL (%)		1.0			1.1	





Constant Head Permeability Test

Core No.	B-1	B-2
Sample Depth (ft)	0.0-3.0	2.5-4.0
Can No.	A-6	A-4
Can Wt. (g)	14.10	13.80
Can + Soil Wt. (g)	730.80	614.20
Diameter (cm)	6.40	6.40
Length (cm)	12.20	12.00
Volume (cm^3)	392.47	386.04
Specific Gravity	2.65	2.65
Mass of Apparatus (g)	1402.90	1402.90
Soil + Apparatus Wt. (g)	2035.70	2004.50
Dry Density (lb/ft^3)	100.66	97.29
Void Ratio, e	0.64	0.70
Porosity, n	0.39	0.41

Sample Info.	B-1 (0.0-3.0')			B-2 (2.5-4.0')		
Test No.	1	2	3	1	2	3
Volume (ml)	90	75	65	190	165	135
Time of Collection (s)	60	60	60	60	60	60
Water Temp, C	72	72	72	72	72	72
Head Difference (cm)	70.4	60.4	50.4	70.4	60.4	50.4
Area (cm^2)	32.17	32.17	32.17	32.17	32.17	32.17
K (cm/s)	0.008	0.008	0.008	0.017	0.017	0.017
Avg. K (cm/s)		0.008			0.017	
K (in/hr)		11.27			23.99	

Murphy Vet Clinic

Moisture Content Analysis

Core Number	C-1	C-1	C-1	C-1	C-3	C-3	C-3	C-1	C-3
Depth Sampled (ft)	0-0.5'	1-1.5'	1.5-2.7'	4.7-5'	4-4.3'	3.1-3.5'	0-3.1'	2.7-4'	4.3-5'
Can Number	A-7	A-3	A-9	A-8	A-5	A-6	A-11	A-4	A-2

Wt. of Can (g)	13.8	14.1	13.7	13.9	13.8	14.2	397.8	13.9	117.5
Wt. of Wet Soil + Can (g)	385.3	443.0	561.5	784.0	346.6	414.4	1187.9	859.1	914.9
Wt. of Dry Soil + Can (g)	359.5	366.1	479.9	599.2	282.6	339.2	1055.1	720.1	762.2
Wt. of Dry Soil (g)	345.70	352.00	466.20	585.30	268.80	325.00	657.30	706.20	644.70
Wt. of Water (g)	25.80	76.90	81.60	184.80	64.00	75.20	132.80	139.00	152.70
Moisture Content (%)	7.46	21.85	17.50	31.57	23.81	23.14	20.20	19.68	23.69

Sieve Analysis

Core Number	C-1
Depth Sampled (ft)	0-0.5'
Can Number	A-7
Wt. of Dry Soil (g)	345.70

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	7.4	97.86
10	2.000	8.6	97.51
20	0.850	10.9	96.85
40	0.425	16.2	95.31
60	0.250	69.9	79.78
100	0.150	292.1	15.50
120	0.125	316	8.59
200	0.075	337.5	2.37
Pan	---	344.6	---

Core Number	C-1
Depth Sampled (ft)	1-1.5'
Can Number	A-3
Wt. of Dry Soil (g)	352.00

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0.7	99.80
40	0.425	14.4	95.91
60	0.250	111.1	68.44
100	0.150	313.4	10.97
120	0.125	330.8	6.02
200	0.075	344.7	2.07
Pan	---	350.4	---

Core Number	C-1
Depth Sampled (ft)	1.5-2.7'
Can Number	A-9
Wt. of Dry Soil (g)	466.20

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0.4	99.91
20	0.850	2.8	99.40
40	0.425	9.5	97.96
60	0.250	105.2	77.43
100	0.150	404.1	13.32
120	0.125	434.6	6.78
200	0.075	457.6	1.84
Pan	---	467	---

Core Number	C-1

Depth Sampled (ft)	4.7-5'
Can Number	A-8
Wt. of Dry Soil (g)	585.30

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0.6	99.90
20	0.850	1.6	99.73
40	0.425	5.4	99.08
60	0.250	66.5	88.64
100	0.150	479.5	18.08
120	0.125	523.5	10.56
200	0.075	553.4	5.45
Pan	---	583.6	---

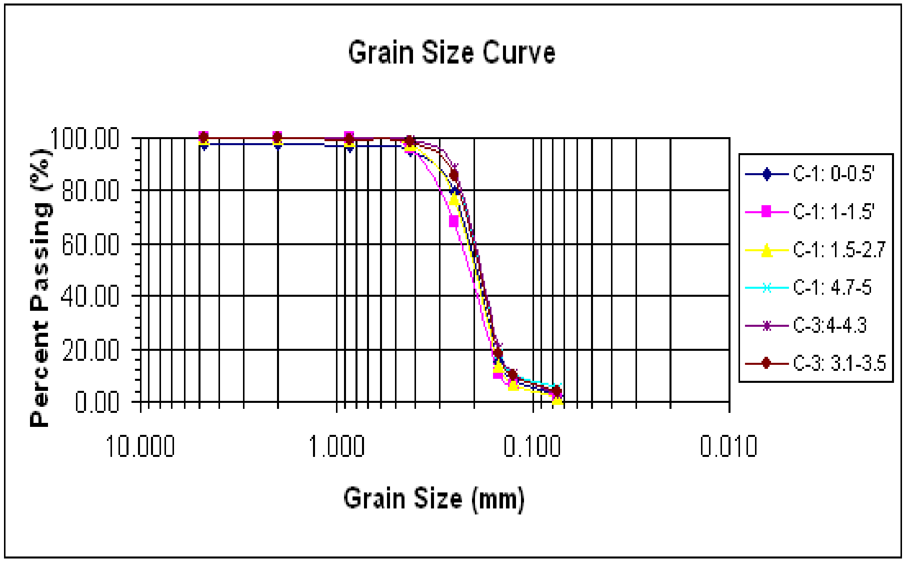
Core Number	C-3
Depth Sampled (ft)	4-4.3'
Can Number	A-5
Wt. of Dry Soil (g)	268.80

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	0	100.00
20	0.850	0	100.00
40	0.425	1.4	99.48
60	0.250	30.8	88.54
100	0.150	214.7	20.13
120	0.125	240.6	10.49

200	0.075	260.9	2.94
Pan	---	267.9	---

Core Number	C-3
Depth Sampled (ft)	3.1-3.5'
Can Number	A-6
Wt. of Dry Soil (g)	325.00

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0.4	99.88
10	2.000	1.1	99.66
20	0.850	1.9	99.42
40	0.425	4.4	98.65
60	0.250	46.1	85.82
100	0.150	266.2	18.09
120	0.125	292.4	10.03
200	0.075	313	3.69
Pan	---	325.8	---



Constant Head Permeability Test

Core No.	C-3	C-1	C-3
Sample Depth (ft)	0.0-3.1	2.7-4	4.5-5
Can No.			
Can Wt. (g)	14.10	13.80	
Can + Soil Wt. (g)	730.80	614.20	
Diameter (cm)	6.40	6.40	6.4
Length (cm)	13.10	12.60	13
Volume (cm^3)	421.43	405.34	418.21
Specific Gravity	2.65	2.65	2.65
Mass of Apparatus (g)	1397.70	1400.20	1404.2
Soil + Apparatus Wt. (g)	2032.30	2013.90	2027.1
Dry Density (lb/ft^3)	94.01	94.52	92.99
Void Ratio, e	0.76	0.75	0.78
Porosity, n	0.43	0.43	0.44

Sample Info.		B-1 (0.0-3.0')			B-2 (2.5-4.0')			B-2 (2.5-4.0')	
Test No.	1	2	3	1	2	3	4	5	6
Volume (ml)	70	55	45	60	45	70	60	50	45
Time of Collection (s)	60	60	60	60	60	120	120	120	120
Water Temp, C	72	72	72	72	72	72	72	72	72
Head Difference (cm)	77.8	67.6	57.8	80.8	69.9	60.2	82.7	72.1	61.7
Area (cm^2)	32.17	32.17	32.17	32.17	32.17	32.17	32.17	32.17	32.17
K (cm/s)	0.006	0.006	0.005	0.005	0.004	0.004	0.002	0.002	0.002
Avg. K (cm/s)		0.006			0.004			0.002	
K (in/hr)		7.91			6.25			3.41	

FDEP Office

Moisture Content Analysis

Core Number	D-6	D-6	D-4	D-4	D-4	D-2
Depth Sampled (ft)	0-0.5	1	1-1.8	2.1-3.5	3.5	0-1
Can Number	A-4	A-9	A-3	A-6	A-7	A-5

Wt. of Can (g)	9.7	13.7	7.9	14.1	13.7	13.8
Wt. of Wet Soil + Can (g)	886.70	1203.60	394.00	887.10	997.10	792.60
Wt. of Dry Soil + Can (g)	772.40	1032.70	360.60	762.90	829.50	699.20
Wt. of Dry Soil (g)	762.70	1019.00	352.70	748.80	815.80	685.40
Wt. of Water (g)	114.30	170.90	33.40	124.20	167.60	93.40
Moisture Content (%)	14.99	16.77	9.47	16.59	20.54	13.63
	Perm	Att	SA	Att	Perm	SA

<u>Sieve Analysis</u>

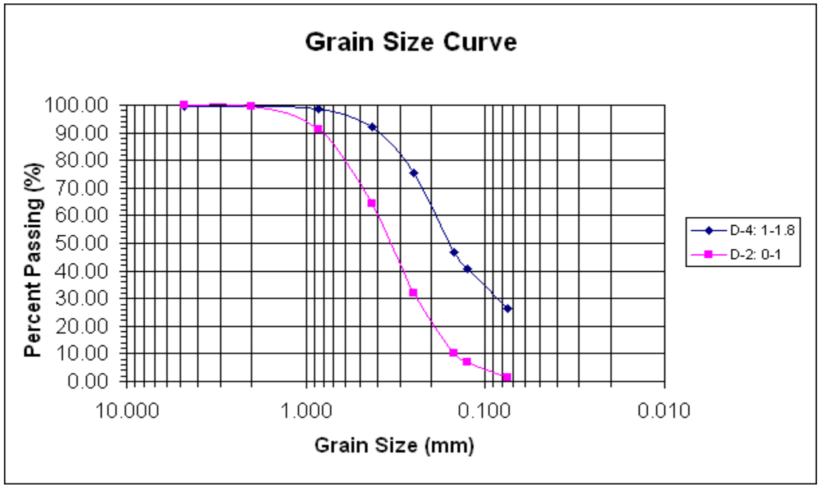
Core Number	D-4
Depth Sampled (ft)	1-1.8
Can Number	A-3
Wt. of Dry Soil (g)	352.70

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	1.2	99.66
10	2.000	1.3	99.63
20	0.850	4.5	98.72
40	0.425	27.4	92.23
60	0.250	86.3	75.53
100	0.150	187.1	46.95
120	0.125	209.5	40.60
200	0.075	259.8	26.34
Pan	---	261.8	---

<u>Sieve Analysis</u>

Core Number	D-2
Depth Sampled (ft)	0-1
Can Number	A-3
Wt. of Dry Soil (g)	685.40

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00
10	2.000	2.6	99.62
20	0.850	60.7	91.14
40	0.425	243.8	64.43
60	0.250	466	32.01
100	0.150	616.4	10.07
120	0.125	638.1	6.90
200	0.075	675.1	1.50
Pan	---	685.2	---



Constant Head Permeability Test

Core No.	D-6	D-4
Sample Depth (ft)	0-0.5	3.5
Can No.	A-4	A-7
Can Wt. (g)	9.7	13.7
Can + Soil Wt. (g)	886.70	997.10

Diameter (cm)	6.40	6.40
Length (cm)	13.00	13.50
Volume (cm^3)	418.21	434.29
Specific Gravity	2.65	2.65
Mass of Apparatus (g)	1451.70	1400.20
Soil + Apparatus Wt. (g)	2152.70	2013.90
Dry Density (lb/ft^3)	104.64	88.22
Void Ratio, e	0.58	0.87
Porosity, n	0.37	0.47

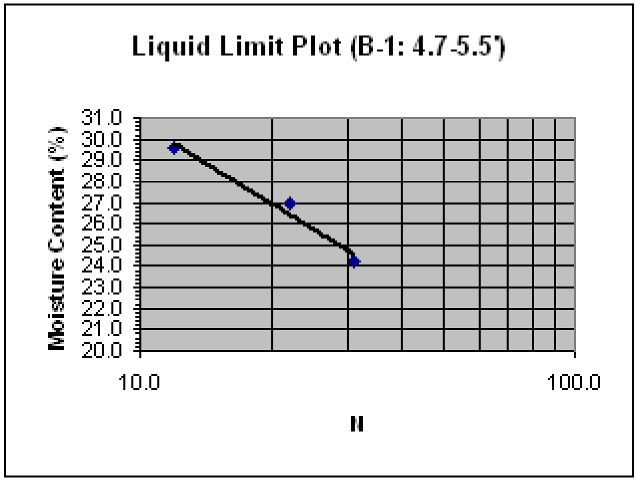
Sample Info.		D-6 (0-0.5)			D-4 (3.5')	
Test No.	1	2	3	Test No.	1	2
Volume (ml)	150	120	100	Beginning Head (cm)	71.2	71.2
Time of Collection (s)	120	120	120	Ending Head (cm)	64.3	61.7
Water Temp, C	72	72	72	Test Duration (s)	213	291
Head Difference (cm)	63.7	53.6	43.6	Volume Of Water (cm^3)	2.18	3
Area (cm^2)	32.17	32.17	32.17	K (cm/s)	0.0001	0.0001
K (cm/s)	0.008	0.008	0.008	Avg K (cm/s)	0.00006	
Avg. K (cm/s)		0.008		Avg K (in/hr)	0.090	
K (in/hr)		10.85				

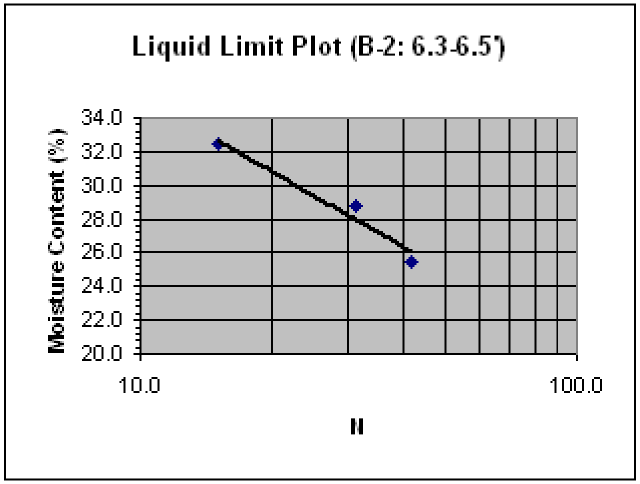
Plastic Limit

Sample No.		D-6 (1')			D-4 (1-1.8')	
Test No.	1	2	3	1	2	3
Can No.	JAY3	TNA1	1-6	HP6	TMNT	MSJ1
Can Wt. (g)	11.7	11.7	10.9	11.1	11.7	11.8
Can + Wet Soil Wt. (g)	13.7	13.4	12.3	13.2	13.3	14.5
Can + Dry Soil Wt. (g)	13.4	13.2	12.2	13.0	13.1	14.2
PL (%)	17.6	13.3	7.7	10.5	14.3	12.5
PL Avg. (%)		12.9			12.4	

Liquid Limit

Sample No.		D-6 (1')			D-4 (1-1.8')	
Test No.	1	2	3	1	2	3
Can No.	3K	7	2WPWD	13	14	MOM
Can Wt. (g)	11.5	11.6	11.8	11.0	11.8	11.5
Can + Wet Soil Wt. (g)	27.4	22.9	24.5	18.4	21.6	19.1
Can + Dry Soil Wt. (g)	24.3	20.5	21.6	16.9	19.2	17.4
Moisture Content (%)	24.2	27.0	29.6	25.4	32.4	28.8
Number of Blows	31.0	22.0	12.0	42.0	15.0	31.0
LL (%)		25.8			29.6	
PI = LL-PL (%)		12.9			17.2	





FCPA Office

Moisture Content Analysis

Core Number	E-1	E-1	E-1	E-1	E-2	E-2	E-2

Depth Sampled (ft)	0-0.8	2-4.5	4.5-5.5	5.5-6.5	0-1	2.5-4.2	5.5-6
Can Number	A-3	A-8	A-9	A-5	A-7	A-4	A-6
Wt. of Can (g)	14.1	14.6	13.7	13.9	13.7	13.9	14.0
Wt. of Wet Soil + Can (g)	846.70	809.80	736.20	1231.50	665.50	945.60	965.80
Wt. of Dry Soil + Can (g)	716.30	758.70	642.70	1020.00	593.70	883.10	799.70
Wt. of Dry Soil (g)	702.20	744.10	629.00	1006.10	580.00	869.20	785.70
Wt. of Water (g)	130.40	51.10	93.50	211.50	71.80	62.50	166.10
Moisture Content (%)	18.57	6.87	14.86	21.02	12.38	7.19	21.14
	Perm	SA	SA	Perm	SA	Perm	SA

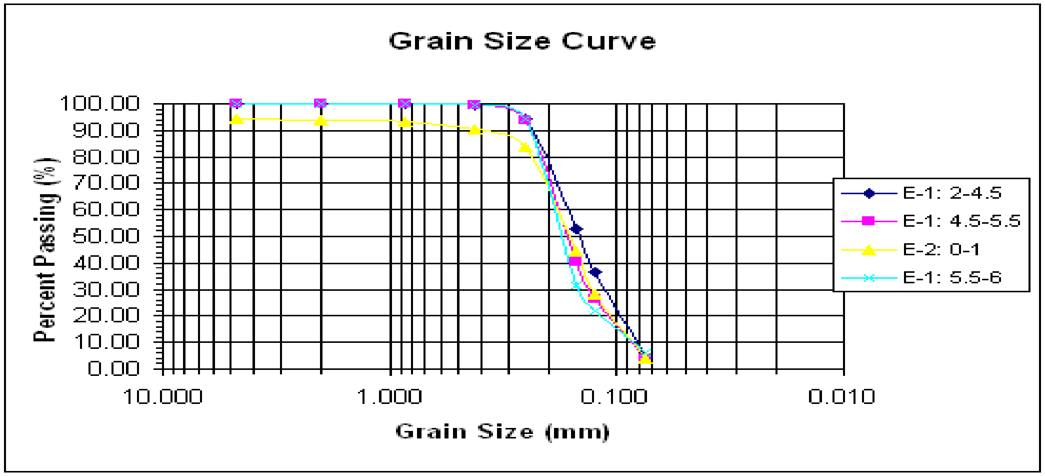
Sieve Analysis

Core Number	E-1			E-1		
Depth Sampled (ft)	2-4.5			4.5-5.5		
Can Number	A-8			A-9		
Wt. of Dry Soil (g)	744.10			629.00		

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	0	100.00	4.750	0	100.00
10	2.000	0	100.00	2.000	0	100.00
20	0.850	0	100.00	0.850	0	100.00
40	0.425	5.3	99.29	0.425	4.6	99.27
60	0.250	39.9	94.64	0.250	40	93.64
100	0.150	349.7	53.00	0.150	373.3	40.65
120	0.125	472.7	36.47	0.125	461.7	26.60
200	0.075	709.2	4.69	0.075	603.8	4.01
Pan	---	742.6	---	---	627.9	---

Core Number	E-2			E-2		
Depth Sampled (ft)	0-1			5.5-6		
Can Number	A-7			A-6		
Wt. of Dry Soil (g)	580.00			785.70		

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	31	94.66	4.750	0	100.00
10	2.000	34.7	94.02	2.000	0	100.00
20	0.850	40.2	93.07	0.850	0	100.00
40	0.425	54.5	90.60	0.425	5.4	99.31
60	0.250	94.6	83.69	0.250	43	94.53
100	0.150	321.7	44.53	0.150	539.2	31.37
120	0.125	417.6	28.00	0.125	612.2	22.08
200	0.075	555.8	4.17	0.075	737.4	6.15
Pan	---	579.7	---	---	783.1	---



Constant Head Permeability Test

Core No.	E-1	E-1	E-2
Sample Depth (ft)	0-0.8	5.5-6.5	2.4-4.2
Can No.	A-3	A-5	A-4
Can Wt. (g)	14.1	13.9	13.9
Can + Soil Wt. (g)	716.30	1231.50	883.10
Diameter (cm)	6.40	6.40	6.40

Length (cm)	13.20			13.30			12.30		
Volume (cm^3)	424.64			427.86			395.69		
Specific Gravity	2.65			2.65			2.65		
Mass of Apparatus (g)	1451.90			1452.90			1450.40		
Soil + Apparatus Wt. (g)	2107.50			2124.30			2077.60		
Dry Density (lb/ft^3)	96.38			97.97			98.96		
Void Ratio, e	0.72			0.69			0.67		
Porosity, n	0.42			0.41			0.40		

Sample Info.		E-1 (0-0.8)			E-1 (5.5-6.5)			E-2 (2.4-4.2)	
Test No.	1	2	3	1	2	3	1	2	3
Volume (ml)	63	52	45	20			110	100	100
Time of Collection (s)	300	300	300	300			128	148	182
Water Temp, C	72	72	72	72			72	72	72
Head Difference (cm)	63.8	53.9	44.9	65.4			65.4	53.7	44.8
Area (cm^2)	32.17	32.17	32.17	32.17			32.17	32.17	32.17
K (cm/s)	0.001	0.001	0.001	0.0004			0.005	0.005	0.005
Avg. K (cm/s)		0.001			0.0004			0.005	
K (in/hr)		1.89			0.59			7.29	

Southface Institute

Moisture Content Analysis

Core Number	AT-1	AT-1	AT-3	AT-3
Depth Sampled (ft)	0-0.5	0.5-1.5	0-0.6	0.6-1.5
Can Number	A-4	A-9	A-3	A-6
Wt. of Can (g)	9.7	13.7	7.9	14.1
Wt. of Wet Soil + Can (g)	886.70	690.00	680.00	856.00
Wt. of Dry Soil + Can (g)	745.00	541.00	601.50	638.00
Wt. of Dry Soil (g)	735.30	527.30	593.60	623.90
Wt. of Water (g)	141.70	149.00	78.50	218.00
Moisture Content (%)	19.27	28.26	13.22	34.94
	Perm	Att	SA	Att

Sieve Analysis

Core Number	AT-1			AT-1		
Depth Sampled (ft)	0-0.5			0.5-1.5		
Can Number	A-4			A-9		
Wt. of Dry Soil (g)	735.30			527.30		

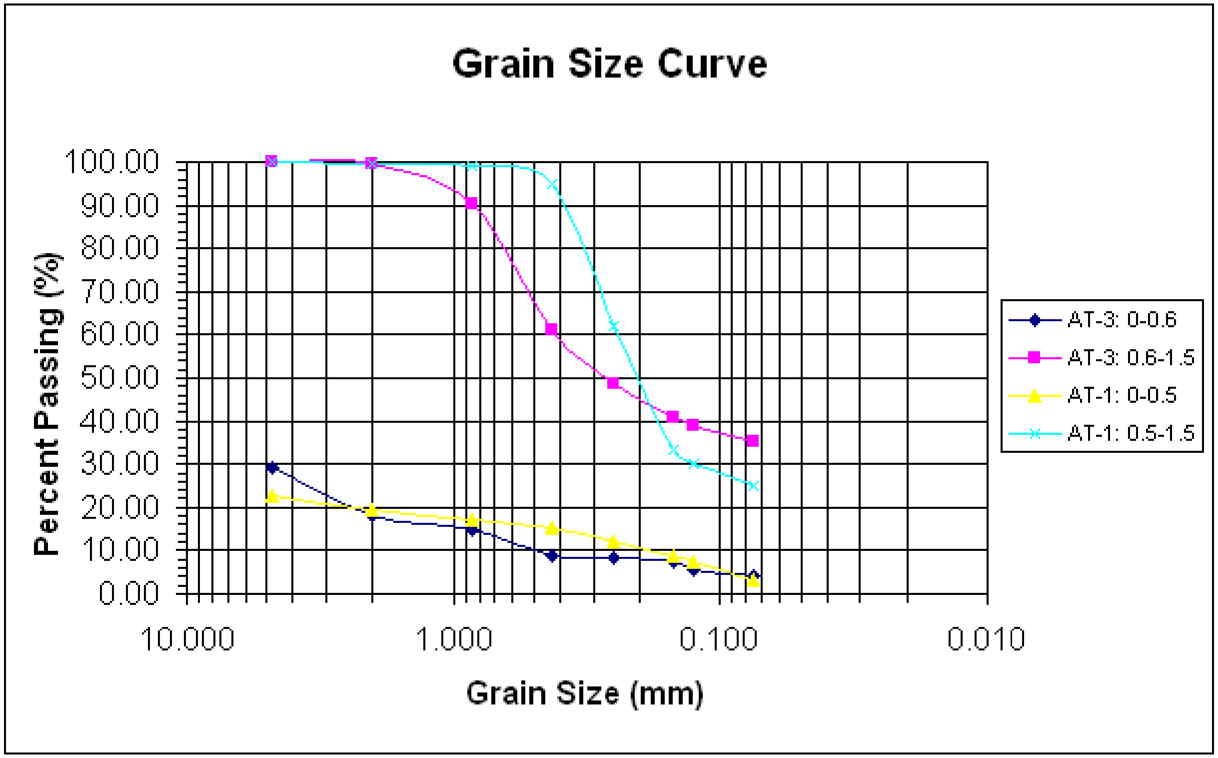
Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	570	22.48	4.750	1.2	99.77
10	2.000	592	19.49	2.000	1.3	99.75
20	0.850	610	17.04	0.850	4.5	99.15
40	0.425	623.2	15.25	0.425	27.4	94.80
60	0.250	648.2	11.85	0.250	200	62.07
100	0.150	670.6	8.80	0.150	351	33.43
120	0.125	680	7.52	0.125	368	30.21
200	0.075	710	3.44	0.075	395	25.09
Pan	---	735.2	---	---	527	---

Sieve Analysis

Core Number	AT-3			AT-3		
Depth Sampled (ft)	0-0.6			0.6-1.5		
Can Number	A-3			A-6		
Wt. of Dry Soil (g)	593.60			623.90		

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	421.3	29.03	4.750	0	100.00

10	2.000	485.5	18.21	2.000	2.6	99.58
20	0.850	505.6	14.82	0.850	60.7	90.27
40	0.425	540.1	9.01	0.425	243.8	60.92
60	0.250	545.2	8.15	0.250	321	48.55
100	0.150	550.2	7.31	0.150	371	40.54
120	0.125	561.1	5.48	0.125	380	39.09
200	0.075	568	4.31	0.075	403	35.41
Pan	---	593.4	---	---	623.1	---



Constant Head Permeability Test

Core No.	AT-1	AT-3	
Sample Depth (ft)	0.5-1.5	0-0.6	
Can No.	A-4	A-7	
Can Wt. (g)	9.7	13.7	
Can + Soil Wt. (g)	761.50	897.10	
Diameter (cm)	6.40	6.40	
Length (cm)	13.00	13.50	32.16991
Volume (cm^3)	418.21	434.29	
Specific Gravity	2.65	2.65	
Mass of Apparatus (g)	1475.00	1178.20	
Soil + Apparatus Wt. (g)	2152.70	2013.90	
Dry Density (lb/ft^3)	101.17	120.13	
Void Ratio, e	0.63	0.48	
Porosity, n	0.39	0.32	

Sample Info.		AT-1 (0.5-1.5)			AT-3 (0-0.6)		
Test No.	1	2	3	Test No.	1	2	3
Volume (ml)	150	120	100	Beginning Head (cm)	71.2	71.2	71.2
Time of Collection (s)	120	120	120	Ending Head (cm)	64.3	61.7	58.8
Water Temp, C	72	72	72	Test Duration (s)	213	291	410
Head Difference (cm)	63.7	53.6	43.6	Volume Of Water (cm^3)	2.18	3	3.93
Area (cm^2)	32.17	32.17	32.17	K (cm/s)	0.3300	0.3200	0.3120
K (cm/s)	0.000	0.000	0.000	Avg K (cm/s)	0.32067		
Avg. K (cm/s)		0.000		Avg K (in/hr)	450.216		
K (in/hr)		0.14					

Plastic Limit

Sample No.		AT-3 (0.6-1.5')	
Test No.	1	2	3
Can No.	JAY3	TNA1	1-6
Can Wt. (g)	11.7	11.7	10.9
Can + Wet Soil Wt. (g)	13.7	13.4	12.3
Can + Dry Soil Wt. (g)	13.4	13.2	12.2

PL (%)	37.0	36.0	35.0
PL Avg. (%)		36.0	

Liquid Limit

Sample No.		AT-3 (0.6-1.5')	
Test No.	1	2	3
Can No.	3K	7	2WPWD
Can Wt. (g)	11.5	11.6	11.8
Can + Wet Soil Wt. (g)	27.4	22.9	24.5
Can + Dry Soil Wt. (g)	24.3	20.5	21.6
Moisture Content (%)	83.0	86.0	89.0
Number of Blows	31.0	22.0	12.0
LL (%)		86	
PI = LL-PL (%)		50.0	

Cleveland Park

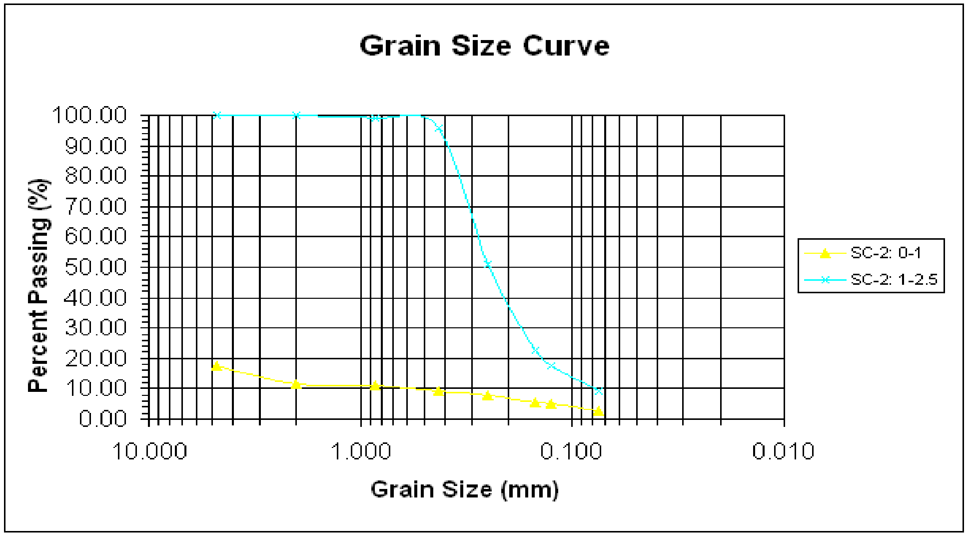
Moisture Content Analysis

Core Number	SC-2	SC-2
Depth Sampled (ft)	0-1	1-2.5
Can Number	D-6	A-5
Wt. of Can (g)	10.5	12.8
Wt. of Wet Soil + Can (g)	875.40	721.20
Wt. of Dry Soil + Can (g)	810.20	645.80
Wt. of Dry Soil (g)	799.70	633.00
Wt. of Water (g)	65.20	75.40
Moisture Content (%)	8.15	11.91
	Perm	Perm

Sieve Analysis

Core Number	SC-2	SC-2
Depth Sampled (ft)	0-1	1-2.5
Can Number	D-6	A-5
Wt. of Dry Soil (g)	799.70	633.00

Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	658.2	17.69	4.750	1.2	99.81
10	2.000	706.2	11.69	2.000	1.3	99.79
20	0.850	712.2	10.94	0.850	4.5	99.29
40	0.425	725.2	9.32	0.425	27.4	95.67
60	0.250	735.2	8.07	0.250	310	51.03
100	0.150	754.2	5.69	0.150	490	22.59
120	0.125	760	4.96	0.125	520.2	17.82
200	0.075	778	2.71	0.075	575.6	9.07
Pan	---	799.5	---	---	527	---



Constant Head Permeability Test

Core No.	SC-2				SC-2		
Sample Depth (ft)	0-1				1-2.5		
Can No.	D-6				A-5		
Can Wt. (g)	10.5				12.8		
Can + Soil Wt. (g)	861.20				797.20		
Diameter (cm)	6.40				6.40		
Length (cm)	13.00				13.50		32.16991
Volume (cm^3)	418.21				434.29		
Specific Gravity	2.65				2.65		
Mass of Apparatus (g)	1475.00				1178.20		
Soil + Apparatus Wt. (g)	2152.70				2013.90		
Dry Density (lb/ft^3)	101.17				120.13		
Void Ratio, e	0.63				0.48		
Porosity, n	0.39				0.32		

Sample Info.		SC-2 (0-1)			SC-2 (1-2.5)		
Test No.	1	2	3	Test No.	1	2	3
Volume (ml)	150	120	100	Beginning Head (cm)	71.2	71.2	71.2
Time of Collection (s)	120	120	120	Ending Head (cm)	64.3	61.7	58.8
Water Temp, C	72	72	72	Test Duration (s)	213	291	410
Head Difference (cm)	63.7	53.6	43.6	Volume Of Water (cm^3)	2.18	3	3.93
Area (cm^2)	32.17	32.17	32.17	K (cm/s)	0.0016	0.0015	0.0019
K (cm/s)	0.104	0.102	0.101	Avg K (cm/s)	0.00167		
Avg. K (cm/s)		0.102		Avg K (in/hr)	2.340		
K (in/hr)		143.68					

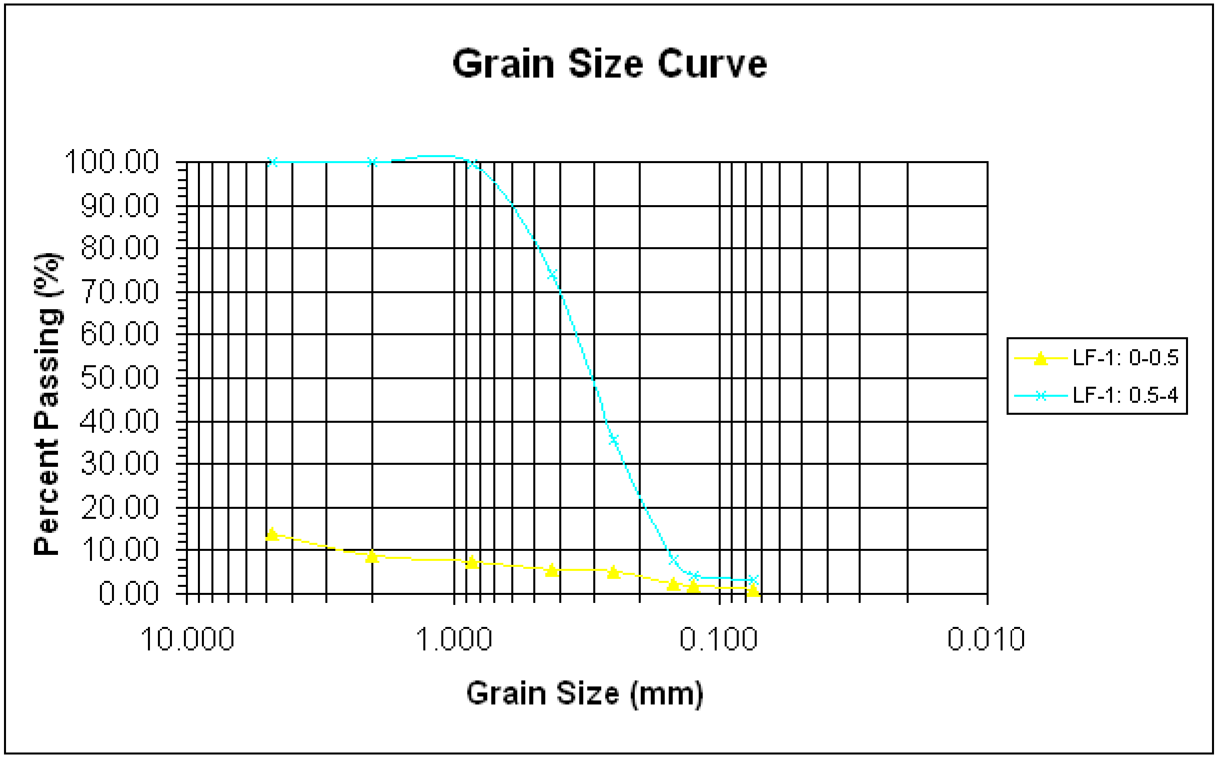
Effingham County Landfill

Moisture Content Analysis

Core Number	LF-1	LF-1
Depth Sampled (ft)	0-0.5	0.5-4
Can Number	H-8	H-9
Wt. of Can (g)	11.7	9.9
Wt. of Wet Soil + Can (g)	921.10	874.50
Wt. of Dry Soil + Can (g)	870.20	815.10
Wt. of Dry Soil (g)	858.50	805.20
Wt. of Water (g)	50.90	59.40
Moisture Content (%)	5.93	7.38
	Perm	Perm

Sieve Analysis

Core Number	LF-1			LF-1		
Depth Sampled (ft)	0-0.5			0.5-4		
Can Number	H-8			H-9		
Wt. of Dry Soil (g)	858.50			805.20		
Sieve Number	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)	Sieve Opening (mm)	Cumulative Mass Retained (g)	Percent Passing (%)
4	4.750	741.2	13.66	4.750	1.2	99.85
10	2.000	784	8.68	2.000	1.3	99.84
20	0.850	796.2	7.26	0.850	4.5	99.44
40	0.425	810.5	5.59	0.425	210.2	73.89
60	0.250	816	4.95	0.250	520	35.42
100	0.150	840.2	2.13	0.150	740.6	8.02
120	0.125	842	1.92	0.125	770	4.37
200	0.075	851	0.87	0.075	780.2	3.10
Pan	---	858.4	---	---	805.2	---



Constant Head Permeability Test

Core No.	LF-1	LF-1	
Sample Depth (ft)	0-0.5	0.5-4	
Can No.	H-8	H-9	
Can Wt. (g)	11.7	9.9	
Can + Soil Wt. (g)	861.20	797.20	
Diameter (cm)	6.40	6.40	
Length (cm)	13.00	13.50	32.16991
Volume (cm^3)	418.21	434.29	

Specific Gravity	2.65	2.65
Mass of Apparatus (g)	1475.00	1178.20
Soil + Apparatus Wt. (g)	2152.70	2013.90
Dry Density (lb/ft^3)	118.30	112.30
Void Ratio, e	0.47	0.62
Porosity, n	0.32	0.38

Sample Info.		LF-1 (0-0.5')	
Test No.	1	2	3
Volume (ml)	150	120	100
Time of Collection (s)	120	120	120
Water Temp, C	72	72	72
Head Difference (cm)	63.7	53.6	43.6
Area (cm^2)	32.17	32.17	32.17
K (cm/s)	0.149	0.110	0.100
Avg. K (cm/s)		0.120	
K (in/hr)		168.01	

	LF-1 (0.5-4;)		
Test No.	1	2	3
Beginning Head (cm)	71.2	71.2	71.2
Ending Head (cm)	64.3	61.7	58.8
Test Duration (s)	213	291	410
Volume Of Water (cm^3)	2.18	3	3.93
K (cm/s)	0.0040	0.0040	0.0040
Avg K (cm/s)	0.00400		
Avg K (in/hr)	5.616		

LIST OF REFERENCES

1) ASTM International, ASTM D3385-03, “Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, 2003.

2) Bean, E.Z., W.F. Hunt, D.A. Bidelspach. “A Monitoring Field Study of Permeable Pavement Sites in North Carolina.” Eighth Biennial Stormwater Research and Watershed Management Conference, pp. 57-66, 2005.

3) California-Nevada Cement Promotion Council. “Pervious Concrete Pavement Specification”.

4) Field, R., Masters, H. & Singer, M., “An Overview of Porous Pavement Research”, Water Resources Bulletin, Vol. 18, No. 2, 1982, pp. 265-270.

5) Field, R., Masters, H. & Singer, M., “Porous Pavement: Research; Development; and Demonstration”, ASCE Transportation Engineering, Vol. 108, No. 3, 1982, pp. 244-258.

6) Florida Concrete & Products Association, Inc., “Portland Cement Pervious Pavement Manual”, www.fcpa.org, 1990.

7) Georgia Stormwater Management Manual, 1^{st} Edition, 2001.

8) Legret, M. & Colandini, V., “Effects of a Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals”, Water Science and Technology, Vol. 39, No. 2, 1999, pp. 111-117.

9) Meininger, R.C. “No-Fines Pervious Concrete for Paving.” Concrete International, Vol. 10, No. 8, pp. 20-27, 1988.

10) Minton, Gary, Stormwater Treatment, Seattle, Washington, 2002, pp. 231-251.

11) Mulligan, Ann, “Attainable Compressive Strength of Pervious Concrete Paving Systems”. University of Central Florida, 2005.

12) Offenberg, M. “Producing Pervious Pavements.” Concrete International, Vol. 27, No. 3, pp. 50-54, 2005.

13) PCI Systems, LLC. “Specifications for Pervious Concrete Infiltration™ System”.

14) Personal Communications with Mr. Mike Register, Saint Johns River Water Management District, January, 2004.

15) Pratt, C.J., “Design Guidelines for Porous/Permeable Pavements”, Sustaining Water Resources in the 21st Century: ASCE Conference proceedings, Malmo, Sweden, September 1997, pp. 196-211.

16) Rushton, B., “Infiltration Opportunities in Parking-Lot Designs Reduce Runoff and Pollution”, Stormwater, 2002.

17) Spence, Joshua, “Pervious Concrete A Hydrologic Analysis for Stormwater Management Credit”. University of Central Florida, 2006.

18) Tennis, P., Leming, M., & Akers, D., “Pervious Concrete Pavements”, Portland Cement Association, 2004.

19) United States Environmental Protection Agency, Office of Water, “Storm Water Technology Fact Sheet Porous Pavement”, EPA 832-F-99-023, Washington D.C., September 1999.

20) Wanielista, M.P., M.B, Chopra, J. Spence, and C. Ballock. “Hydraulic Performance Assessment of Pervious Concrete Pavements for Stormwater Management Credit”. Final Report. University of Central Florida, Stormwater Management Academy, January 2007.