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INVESTIGATIONS OF STORM WATER MANAGEMENT PROFESSIONALS' PERCEPTIONS OF PERMEABLE INTERLOCKING CONCRETE PAVERS AS A STORMWATER MANAGEMENT OPTION

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INVESTIGATION OF STORM
WATER MANAGEMENT PROFESSIONALS' PERCEPTIONS OF
PERMEABLE INTERLOCKING CONCRETE PAVERS AS A
STORMWATER MANAGEMENT OPTION

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Accepted by:
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ABSTRACT

This study examined stormwater management professionals' perceptions of PICPs (Permeable Interlocking Concrete Pavement) as a stormwater management option to conventional curb and gutter methodology from years past.

A self-administered survey questionnaire was developed as the primary research methodology. Three hundred stormwater management professionals were randomly selected as research subjects, and qualitative and quantitative methods were used to collect data for the study. Specific statistical gathering methods and tests for this study included: ex post facto experimental design, grounded theory design, correlation coefficients and ANOVA, and Pearson's correlation coefficients.

The survey found through quantitative analysis that although stormwater professionals have very little education on the topic of PICPs, they are very familiar with the benefits of this type pavement over more traditional types of surfacing. The hypothesis that stated PICPs were not well-utilized because stormwater professionals were not familiar with them was rejected and the reason for non-use appeared to be the perceived cost factor.

The survey found through qualitative analysis the following major themes: The most common jobs among survey participants were stormwater administrators, project managers, and environmental engineers. Less runoff and perviousness were the biggest incentives to using PICPs. Cost and potential maintenance were the main deterrents to using PICPs. Reduced runoff, cost, and potential maintenance were the perceived main considerations of municipal governments with regards to PICP implementation. Poor

design or installation, lack of knowledge, and inadequate maintenance are the biggest nuisances in reviewing PICP projects.

Several practical recommendations were proposed in this study to overcome the barriers to using PICPs as a stormwater management tool, including more education of those involved in planning, designing, and implementing PICPs through workshops and training sessions, as well as more training for installers to provide decision makers a quality product from which to choose in the future. The most important aspect of education and training seemed to be the need to focus upon a better understanding of the actual long term costs and maintenance issues associated with PICPs.

DEDICATION

I dedicate this dissertation to the memory of my father, Forrest Poole, and in honor of my mother, Hilda Poole. My parents have always believed in me and supported me in every endeavor. They have encouraged and guided me when I needed help, and allowed me the freedom to do as I wish when I felt confident in my direction.

Neither of my parents were recipients of regular college undergraduate degrees, yet both have taught me more than all of the knowledge I have gained from all of the teachers I have ever had the pleasure of learning from. My love and respect for my parents surpasses all understanding, and I am honored to be the son of Forrest and Hilda Poole.

ACKNOWLEDGEMENTS

I wish to thank my wife Barbara, and son Ian, for their support through a rather “late in life” career change decision, and all of the inconveniences in daily life that resulted. They each deserve a special note of gratitude for their love and support throughout the entire doctoral level studies, late night classes, and long weekends tiptoeing around the house to not disturb an engrossed father and husband. My love for them in unsurpassed.

Four of the most outstanding individuals I have ever known served as my committee members. Of course I am appreciative of the attention they gave me throughout the course of study, but I remain more impressed with their love of teaching, their passion for sharing knowledge, their dedication to students, and their sincere efforts to make professionalism an ultimate priority in dealing with others.

Dr. Curtis White deserves special thanks for arranging his schedule late in the process to help me make this happen. Dr. Cheryl Poston brings with her an incredible amount of hands-on experience that more than supplemented our text books. Her involvement in the field for so many years made our classes much more enjoyable and educational. Dr. Poston is a true educator that puts her students first. Dr. Daryl Wiesman is the ultimate professional communicator. His approach to every detail about every aspect of teaching, learning, writing, and a proper presentation is something that I will use to further my professionalism in every aspect of my life. Dr.Wiesman is living proof that a student and a teacher can become friends without giving up the student/teacher relationship or compromising the teacher’s effectiveness to share knowledge. Last but not least, Dr. Bill Paige, my committee chair, has been a tremendous mentor, supporter, friend and guide throughout all of my years of study at Clemson University. His suggestions for improvement, his patience in working through the details of the paper, and his general helpful and professional attitude, inside and outside of class, have always made him very approachable and a pleasure to work with.

Two incredibly knowledgeable professionals and leaders in the field of my topic are Dr. Bruce Ferguson, the Dan B. Franklin Distinguished Professorship Chair holder at the University of Georgia, and Mr. David Smith, Technical Director of the Interlocking Concrete Pavement Institute. Both of these men assisted me greatly in preparing my focus by helping me address specific needs for research in the filed. They remained supportive throughout the process and were always available to me when I needed them.

Dr. Bill Hunt of NC State University has provided all of us with significant and invaluable research into PICPs. Through his efforts and his student team at NC State University, information regarding stormwater management and the use of PICPs is readily available to educate contractors, builders, architects, and professional stormwater management professionals. His tireless efforts have bridged the gap between what was recently an information void to the current status of plentiful research data with more to come.

I would be remiss in not mentioning six people that helped shaped my life so many, many ways. My piano teacher Mrs. Mary Morrisette, band directors Mr. Gene Ellis and Mr. Homer Haworth, college trombone and theory teacher Mr. Dick Trevarthen, the most incredible and gifted musician I've ever known, and Duquesne University's Mr. Michael Kumer, a friend and colleague extraordinaire, provided me with a basic foundation of musical knowledge that ultimately lead to an outstanding and successful

career in music education. I am convinced that many of their teachings helped to shape me to be a better person and a better educator in general. The sixth person is my grandfather, Mr. O.B. Ivester, who instilled in all of us a love for music.

Finally, I have had the opportunity to teach thousands of students. Each of them allowed me to share knowledge with them, and most of them became better people because of that. I acknowledge all of them because it was the love of my students and the opportunity to teach them that became the true reward in my career and encouraged me to pursue yet another advanced degree.

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INTRODUCTION

Research Background

Stormwater runoff and the accompanying pollutants present significant, long-lasting, and often irreversible problems to our environment. As development continues to expand, stormwater runoff problems intensify, resulting in serious and increased environmental damage and a reduced supply of drinking water. This damage includes, but is not limited to: flooding, eroded stream banks, widened stream channels, negative aesthetics, (dirty water, trash, foul smells), destruction of fish and aquatic life, impaired recreational uses, threatened public health, threatened public safety, and economic impacts. Solving this problem is critical to our environment as well as the health and welfare of our planet's population.

"Water is the essence of life, sustaining every being on this planet. Without water, there would simply be no plants, no animals, and no people. But the global water supply isn't just at risk, it's already in crisis" (World Water Wars, 2008, Introduction section, para. 1). To more fully understand the importance of the role of water in our every day lives, consider the following information. Water covers about 75% of the earth's surface and remains constant at that figure through precipitation and evaporation. Ninety eight percent of earth's water is in the oceans with fresh water being less than 3% of our planet's water. With two thirds of this fresh water being in polar ice caps and glaciers, fresh water lakes and rivers represent only 0.009% of the water on earth while ground water represents only 0.28%. Since water is essential for all living organisms as well as the essential ingredient in photosynthesis, viability of all life is dependent upon the presence of water (World Water Wars, 2008).

Increased awareness of the serious environmental problems caused by extensive development and construction, local, state, and federal governments are proposing and have implemented strict guidelines concerning methods for stormwater management. Fortunately, new technologies have created permeable surfacing, including, and more specifically, Permeable Interlocking Concrete Pavement (PICP), that offers a solution to many of the problems presented by stormwater runoff. Bruce Ferguson (2005) has studied, researched, and written extensively about the benefits of porous surfacing and offers a comprehensive list of nine reasons to make pavements porous:

(1) The Promise of Clean Water:

Porous surfaces house a microecosystem that filters and biodegrades the pollutants that occur generically on residential, commercial, and office pavements; the underlying soil eco system is a backup treatment system that assures high treatment levels.

(2) The Promise of Long-Lived Trees:

A porous pavement is a complete and vital way to allow air and water into rooting media in densely built-up areas. It allows the exchange of air and moisture through the pavement surface similar to that in a healthy natural soil surface.

(3) The Promise of Cool Cities:

Built-up areas in the U.S. are typically 2 to 8 degrees Fahrenheit higher than the surrounding country-side. Over 90 percent of the increase in temperature is due to urban construction materials that absorb and store solar heat without evapotranspirative cooling; only the remaining 1 to 10 percent comes from the active emissions of vehicles, buildings, and factories. Porous grass pavements actively cool the ground surface with their natural evapotranspiration.

(4) The Promise of Quiet Streets:

Porous pavements reduce traffic noise at the source, particularly the noise from tires. A porous surface both absorbs sound energy and allows some of the air around tires to be pressed into the voids, dissipating air pressure before any noise is generated.

(5) The Promise of Safe Driving:

Porous pavements remove water and oil from the surface directly downward through their pores, preventing surface accumulation. The same pores are pressure relief channels where any ponded water escapes from beneath vehicle tires, keeping the tires in contact with the surface.

(6) The Promise of Reducing Costs:

Because porous pavements absorb, store, and treat water within the pavement structure, they reduce or eliminate the need for drainage inlets, storm drainage pipes, and stormwater detention areas.

(7) The Promise of Meeting Development Regulations:

Municipal jurisdictions impose requirements on new developments for their effect on stormwater, tree preservation, and impervious coverage, all of which can be partially or wholly satisfied by the selective and appropriate use of porous pavements.

(8) The Promise of Preserving Native Ecosystems:

Through porous pavement, all drainage is immediately downward to the soil as it is naturally through the forest floor, without the use of curbs, drains, gutters, or drainage swales.

(9) The Promise of Beauty:

The characteristics of a place can make the process through which hydrologic and ecological restoration take place visible and comprehensive. What a system look likes, how it functions, ecologically and socially, and what it symbolizes in the way of stewardship can be congruent.

Problem Statement

There is a problem in America with an incredible amount of surface coverage not allowing stormwater to flow through the earth's soil and be purified, cooled, and controlled prior to reentry into urban watersheds and aquifers. Typically, stormwater runoff has been managed with the curb and gutter methodology, providing no opportunity for controlled reentry, cooling, or purification of water. Decision makers that decide the proper treatment of stormwater and the appropriate method for treatment may be uniformed about the opportunities of particular aspects of permeable surfacing in the treatment of stormwater runoff.

Figure 1.1 shows the proportion of land covered by built structures in contemporary urban land-use districts. The dark portion of each column represents pavements; the white portion represents the roofs of buildings.

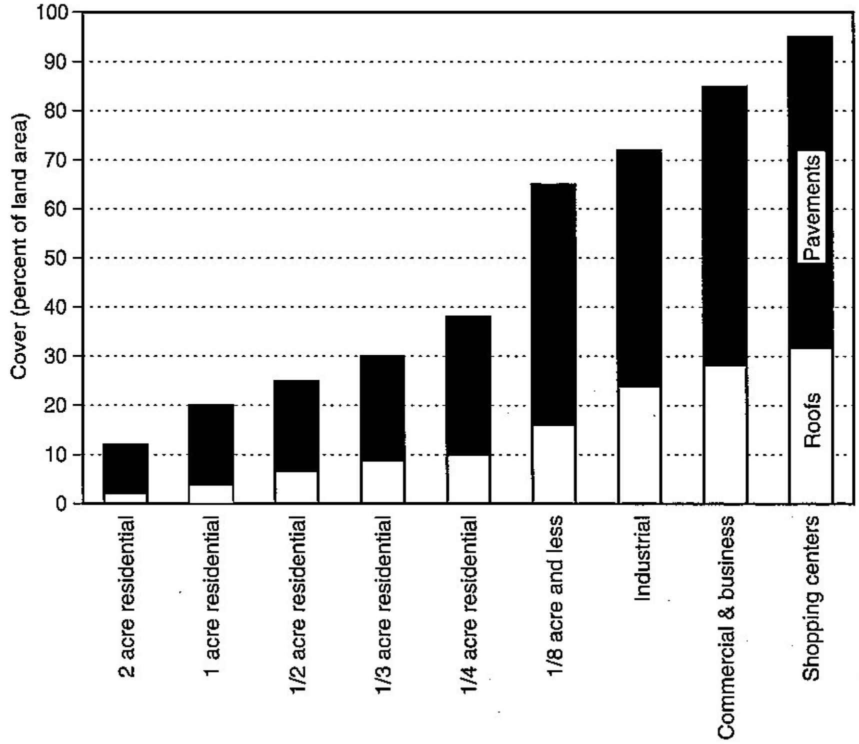


Figure 1.1: Built cover

Source: Ferguson, B.K. (2005) Porous Pavements. In (R.France, Ed.). Boca Raton: Taylor & Francsis.

Local municipalities are somewhat overwhelmed with new and very strict guidelines governing new applications for controlling stormwater runoff problems. Many decision makers, however, supposedly overlook the positive aspects of permeable surfaces, especially PICPs, and continue to favor methods that treat the symptoms and not the solutions.

Two of the leading research professionals in the porous pavement and PICP industry are Mr. David Smith, Educational Director of the Interlocking Concrete Pavement Institute and Dr. Bruce Ferguson, Professor Emeritus at the University of Georgia. Both of these individuals have expressed the need for more research on using

PICPs as stormwater management tools. This correspondence can be seen in Appendix E and Appendix F.

The purpose of this study was to determine:

- what information the decision makers have about PICPs
- what misinformation they have about PICPs
- why they are seemingly adverse, or at least reluctant to the use of PICPs
- what they would like to know about PICPs
- who is responsible for educating the decision makers
- what aspect of educating the decision makers is failing
- in what delivery method(s) would they be best informed

Significance of Study

Numerous studies have been conducted by researchers about the benefits of porous pavements and PICPs, as well as the problems associated with storm water runoff and the need for solutions to the problem. Some of these studies include, but are not limited to, PICP performance in parking lots at Elmhurst College, IL, Seneca College, King City, Ontario, and Dominican University in River Forest, IL. PICP installations at the Hilton Garden in, Calabasas, California, Harbourfront Fire Station, Toronto, Canada, Historic Tree Preservation at Alden Lane Nursery, Livermore, California, the Robson Center, Gainesville, Georgia, and the Jordan Cove Watershed in Waterford, Connecticut have also been sources of significant research in to PICP applications and performance. However, research into why porous pavement and PICPs are not the preferred choice of new technology for storm water management solutions is limited. This research aimed to help fill this void by examining what needs to be done to aide storm water management professionals in making more informed decisions about the possibility of using PICPs as a method of storm water management.

Research Objectives

The objectives of this research effort were to:

1) Investigate the cogency of using permeable interlocking concrete pavers.
2) Investigate the benefits of using porous pavement, specifically PICPs, as a storm water management tool.
3) Investigate the perception storm water management (decision makers) have concerning PICPs as a storm water management tool.
4) Determine the reasons why or why not PICPs are being used as a storm water management tool.
5) Examine what storm water management professionals need to better understand PICPs and what they want to learn about PICPs to make them better decision makers when using this new technology as a storm water management tool.
6) Determine if in fact storm water management professionals are even being offered PICPs as an option in controlling storm water runoff and pollution.

This research was conducted using a survey/questionnaire designed and developed by the researcher with input from several of the nation's leading experts in survey design, storm water management and PICPs. The results of this research were to provide data to be used to develop a set of guidelines for the delivery and application of appropriate and correct information for decision makers (storm water management professionals, land planners, landscape architects, contractors, and installers) in municipalities and watershed jurisdictions concerning the use of PICPs in controlling storm water runoff and pollution.

Research Questions

The following questions were investigated in this study:

1) To what degree are PICPs and porous pavements worthy of being considered as a storm water management option?

2) What did the storm water management professionals indicate was the most significant barrier to using PICPs as a storm water management tool?

3) Were storm water management professionals who were assigned the responsibility of making the decision to use or not to use PICPs, properly trained or informed to make that decision?

4) What were the storm water management professionals' main misconceptions about PICPs?

5) What did the storm water management professionals perceive the future of PICPs to be in their jurisdiction?

6) What was the storm water management professionals' main technical concern with using PICPs as a storm water management option?

7) What are storm water management professionals looking for to help them better understand the role PICPs will play in the future of storm water management?

Research Design and Hypotheses

The research design employed for this study was a mixed methodology that includes both quantitative and qualitative components. By combining the quantitative research design with that of the qualitative research design the researcher was able to explore and examine several different possible relationships that can be triangulated (Tashakkori & Teddlie, 1998). In the context of this study, this means both quantitative and qualitative methods were used in order to collect data for the study so the researcher was able to assess the same relationship or phenomena within the same study (Tashakkori & Teddlie, 1998). The quantitative method used was that of a questionnaire/survey. The qualitative component for this study was that of a questionnaire/survey using a grounded theory design. Grounded theory research begins with a research situation or question and is conducted through observation or interview (Cresswell, 1994).

In order to assess the relationships in the quantitative component of the study, correlation coefficients and analysis of variance (ANOVA) were conducted. The purpose of the correlation coefficient was to determine whether there was a significant relationship between two continuous variables, while the ANOVA was used to determine whether there is a statistically significant difference between two or more independent populations with respect to a continuous outcome variables (Moore & McCabe, 2006). For the qualitative component, the computer program NVivo® was utilized. The NVivo® program provides qualitative research analysis of non-numerical or unstructured data.

Hypothesis statement 1

Permeable pavements are not given 100% credit as being pervious surfaces.

Hypothesis statement 2

The hydrologic effects of permeable pavements are not given credit in obtaining storm water management approval.

Hypothesis statement 3

Storm water management was not a significant aspect of the collegiate course of study of the respondent.

Hypothesis statement 4

The respondent's experience with PCIPs is limited.

Hypothesis statement 5

Storm water management professionals are unaware of the benefits of permeable pavers as they relate to pollutant and water runoff management.

Hypothesis statement 6

Storm water management officials do not have the authority to approve or decline the use of PICPs.

Hypothesis statement 7

Storm water management professionals indicate the objection to the use of PICPs in their jurisdiction is based upon uninformed state officials and their acceptance of research data as fact.

Hypothesis statement 8

Storm water management professionals find their colleagues as generally opposed to the use of PICPs.

Hypothesis statement 9

Storm water management professionals find a need for better communication between state officials and researchers when making policy about the use of PICPs.

Hypothesis statement 10

Storm water management professionals should encourage workshops and presentations to become better informed about PICPs.

Hypothesis statement 11

Storm water management professionals consider the cost of PICPs to be prohibitive.

Hypothesis statement 12

Storm water management professionals think the sanctioned use of PICPs is a political issue and given little opportunity for consideration from a useful or beneficial approach.

Hypothesis statement 13

Storm water management professionals want to encourage the use of PICPs in their jurisdiction.

Limitations of Study

The limitations were:

1. The population in this study was limited to those municipal and/or government professionals employed to regulate storm water management issues.
2. The sample frame for storm water management professionals was the South Eastern Storm Water Association (SESWA) membership list.

Definition of Terms

Porous pavement

According to Ferguson (2005, p.1), a pavement is any treatment of covering of the earth surface that bears traffic. A porous pavement is one with porosity and permeability high enough to significantly influence hydrology, rooting habit, and other environmental effects.

PICPs

Permeable Interlocking Concrete Pavements

DENR

Department of Environment and Natural Resources

ICPI

Interlocking Concrete Pavement Institute

Permeable

David Smith (2006, p.4) of the Interlocking Concrete Pavement Institute (ICPI), describes the term permeable as a material capable of accepting something and moving it onward.

BMPs

The EPA defines a Best Management Practice (BMP) as a technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm water runoff in the most cost-effective manner.

Storm water runoff

According to the EPA, storm water runoff occurs when precipitation from rain or snowmelt flows over the ground. Impervious surfaces like driveways, sidewalks, and streets prevent storm water runoff from naturally soaking into the ground.

Storm water management professionals

National, state, regional and local officials assigned the responsibility of monitoring storm water runoff and the resulting environmental impact in a particular municipality, jurisdiction, or region.

Organization of the Study

The problem statement, significance of the study, and research objectives are presented in Chapter 1.

A comprehensive literature review of the cogency of the use of PICPs is found in Chapter 2. The benefits and limitations to the use of porous pavements and PICPs by previous research are included in this chapter as well.

The procedures and methodology of the research are presented in Chapter 3. This chapter includes the research questionnaire and the hypotheses for this study. The development of the self-administered survey and a pilot study conducted to test validity and reliability are also discussed. This chapter identifies the population, sampling frame, sampling methods, and statistical methods used in this study.

The findings from the survey respondents as well as a statistical analysis for each hypothesis and research question are presented in Chapter 4.

The conclusions drawn from the statistical testing and data analyses of each hypothesis are in Chapter 5. Conclusions derived from the study and recommendations for further research conclude this chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the complex aspects of storm water runoff and the associated economic and environmental impact issues, the development and use of pervious pavements including Permeable Interconnecting Concrete Pavement (PICPs). Also presented is a comprehensive literature review of storm water management, including aspects of using permeable interconnected concrete pavements in controlling storm water runoff. Examples of past and current utilization of PICPs are provided in detail as they relate to storm water runoff control, impact on aquatic systems, and environmental impact in commercial and residential settings.

Why use Porous Pavements?

Conventional methods of storm water management have centered around a curb and gutter approach to move massive amounts of water away from certain areas to be deposited downstream. Retention ponds, although now more highly regulated and controlled, have been used for decades and added to the list of conventional methods. The latest storm water management tool is that of porous pavements.

Built cover

> The emerging field of urban watershed protection often lacks a unifying theme to guide the efforts of its many participants – planners, engineers, landscape architects, scientists, and local officials. The lack of a common theme has often made it difficult to achieve a consistent result at either the individual development site or cumulatively, at the watershed scale (Schueler, 1994).

According to Schueler (1994), perhaps the unifying theme is based upon a physically defined unit: imperviousness. Built cover, the dense pavements that are impervious (roofs, parking lots, roadways, and all impermeable pavements) represent the physically defined unit of imperviousness. Figure 2.1 shows the types of built cover in three land uses.

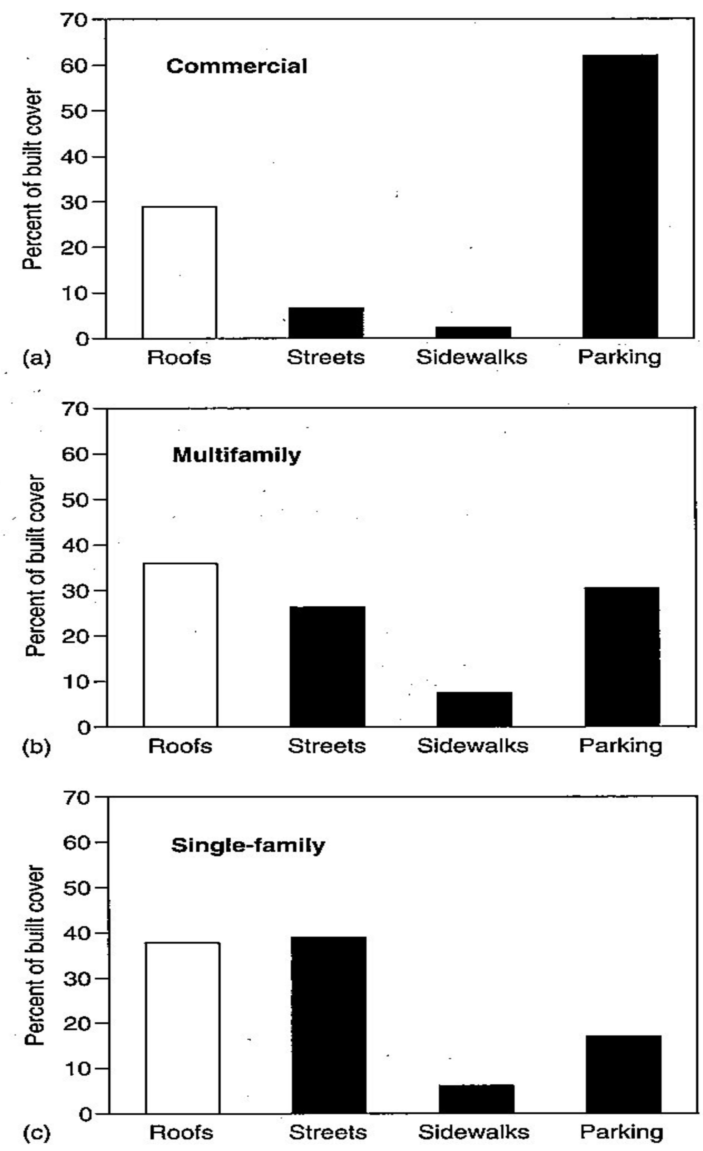


Figure 2.1: Types of built cover in three land uses. Source: Ferguson, B. K. (2005). *Porous Pavements.* (R. France, Ed.). Boca Raton: Taylor & Francis.

The imperviousness of built cover creates the problem of storm water runoff and the underlying consequences of negative environmental impact if such runoff is handled in traditional methods using the old system of curb and gutter storm drainage. Since most engineered curb and gutter storm drainage systems are costly to build and design, and carry water directly back to streams and rivers without any filtering or cooling processes, permeable pavement systems offer a reduction in costs as well as significant positive environmental impacts for developers and municipalities (Toolbase Services, 2007).

Perhaps the most concise and appropriate explanation to the general public for the reasons to use permeable pavers was offered by William James (2002):

> Polluted runoff from impervious road surfaces is a major source of environmental and aquatic degradation. Construction, roads, parking lots, and roofs play a role in reducing the natural ground cover and increasing the impervious area, leading to an accompanying rise in the volume of surface runoff. As a result of urbanization and the accompanying increase in impervious areas, the temperature of surface runoff during storm events increases. The mean summer monthly temperature of receiving water downstream also increases. Urban development often leads to wider channels and more surface ponds and, hence, greater exposure of storm water to solar radiation, further increasing the runoff temperature. The increased impervious pavement and roofs also cause in infiltration and base flow, which reduces the dilution of the heated storm water runoff .Methods to control the thermal enrichment of storm water are becoming available, one of which is the use of permeable pavement, which for several reasons can help reduce the impacts of urbanization on receiving waters. Permeable pavers consist of

interlocking concrete paving blocks separated by holes (pores) that are filled with soil and gravel. These spore spaces between the pavers allow infiltration of storm water into a properly designed storage facility below the surface reducing runoff volume. (p.48-50)

The process of urban development's influence

Figure 2.1 illustrates the pre-development and post-development impact on water balance at a typical development site. Construction alters the local hydrologic cycle beginning with the initial clearing and grading, with continued impact resulting from the built cover of roof tops, driveways, roadways, parking lots, and other surfaces that no longer allow water to soak into the ground. In essence, the site has lost its natural storage capacity (*Why Stormwater Matters*, 2006).

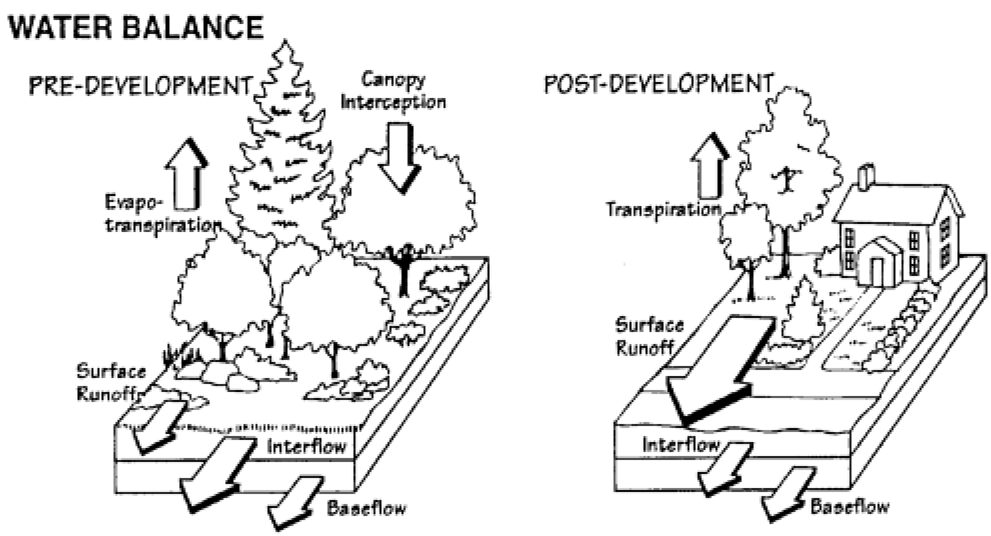


Figure 2.2: Water Balance at a Developed and Undeveloped Site. Source: Why Stormwater Matters Chapter 1 of the Maryland Department of Environment Stormwater Manual. (2006). *Watershed Protection Techniques*, 25-30.

In addition to the volume of water and the associated problems created by its treatment before reaching rivers and streams, there are numerous pollution issues associated with storm water. Storm water gathers pollutants as it crosses impervious surfaces including such things as:

- Sediment from bare areas like construction sites
- Pesticides and fertilizers from lawns, parks and roadsides
- Bacteria and disease causing organisms from pet waste and failing septic systems
- Oil and grease from car leaks, gas stations and industrial areas
- Salt used on roadways and driveways, and
- Toxic chemicals from leaks, spills, and auto wear and exhausts

(Factsheet #9, 2005)

Land undergoes significant changes when being developed, beginning with the simple task of grading. "Trees that had previously intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the forest floor that had absorbed rainfall is scraped off, eroded or severely compacted" (Why Stormwater Matters, 2006, p.25).

With all of these changes to the once undisturbed site, water is now free to flow, uncontrolled, and is labeled storm water runoff. The quick fix method of years past has been to add storm and gutter drainage systems to the site as needed with little or no thought to or concern for the effect of downstream flooding and water quality problems runoff will have downstream.

Why the concern over storm water problems and impacts

Impacts on humans and the environment of uncontrolled water runoff include:

- Flooding-Damage to public and private property, including infrastructure
- Eroded stream banks –Sediment clogs water-ways, fills lakes, reservoirs
- Widened stream channels –Loss of valuable property
- Aesthetics –Dirty water, trash and debris, foul odors
- Fish and Aquatic Life –Impairment/destruction
- Impaired Recreational Uses –Swimming, fishing, boating
- Threatens Public Health-Contamination of drinking water, fish/shellfish
- Threatens Public Safety –Drownings in flood waters
- Economic Impacts –Fisheries, shellfish, tourism, recreation related businesses
- Increased Cost of Water and Wastewater Treatment – Stormwater pollution increases raw water treatment costs and reduces the assimilative capacity of water bodies. (Factsheet #1, 2005)

Increased Imperviousness leads to:	RESULTING IMPACTS				
	Flooding	Habitat Loss	Erosion	Streambed alteration	Channel widening
Increased volume	*	*	*	*	*
Increased peak flow	*	*	*	*	*
Increased peak flow duration	*	*	*	*	*
Increased stream temperature		*			
Decreased base flow		*			
Changes in sediment loadings	*	*	*	*	*

- *Impacts from increases in impervious surfaces (1).*

Table 2.1: Impacts from increases in impervious surfaces Source: Smith, D. R. (2000). *Permeable Interlocking Concrete Pacements* (3rd ed.). Washington,DC: ICPI.

Porous surfacing specifics

Bean & Hunt (2005) noted the following:

Runoff from impervious areas carries pollutants, such as sediments, nutrients, and heavy metals, into our surface waters. These pollutants adversely impact water quality resulting in reduced dissolved oxygen levels, and increased turbidity and toxicity levels. Permeable pavements are an alternative to traditional impermeable surfaces and have the potential to reduce the quantity and improve the quality of stormwater runoff. Permeable pavement allows stormwater to either infiltrate into an underground storage basin or exfiltrate to the soil, providing for groundwater recharge. (p.119)

Applications

Two thirds of all impervious surfaces in developed communities are in the form of pavement put in place for the purpose of automobile usage. Reducing impervious pavement by using impervious alternatives should result in improving the community's water resources. Pervious pavements can be used for the following:

1. Driveways
2. Parking areas
3. Sidewalks
4. Road shoulders and vehicle cross-over lanes
5. Boat launching ramps
6. Pool decks and patios

The use of pervious pavements has been found to:

1. Reduce storm water runoff
2. Replenish groundwater

3. Reduce flooding and prevent overloading combined sewage treatment plants
4. Require less land set aside and cost for development of retention basins
5. Reduce the need for irrigation of planting beds
6. Reduce pollutants in run-off
7. Reduce thermal pollution
8. Lessen evaporative emissions from parked cars
9. Reduce glare and automobile hydroplaning (skidding) accidents
10. Reduce pavement ice buildup

(Lake Superior Streams, 2007)

Porous materials other than PICPs

The popularity of porous concrete and similar surfaces is growing as governmental regulations are constantly changing to encourage and require the use of more environmentally friendly surfacing materials. Porous concrete is comprised of aggregate particles of similar size and a paste like material that forms a bond, but leaves porous openings between the aggregate, thus the voids (15-35%) allowing for water to flow through. The result is typically 2 to 18 gallons per minute per square foot of flow. This material is also extremely lightweight at 100 to 200 lb/ft (Brown, 2003). This type of surfacing allows water to pass through the porous material and percolate into the ground: a process which current built cover does not allow.

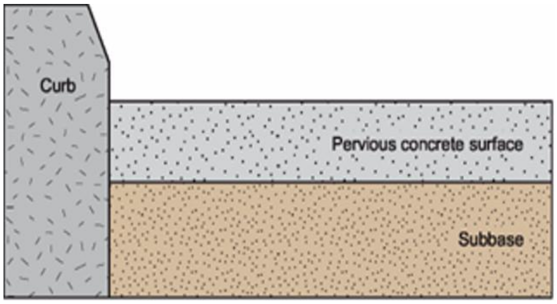


Figure 2.3: Cross section of pervious concrete.

Source:http://www.perviouspavement.org/engineering%20properties.htm
(Figure 2.3 and 2.4)

Figure 2.4: Pervious concrete roadway

When water is allowed to pass through permeable concrete the most significant result is that of recharging groundwater in a controlled, erosion free manner. The use of pervious concrete to achieve this goal is among the Best Management Practices (BMPs) recommended by the Environmental Protection Agency (Pervious Concrete, 2007). "This pavement technology creates more efficient land use by eliminating the need for retention ponds, swales, and other storm water management devices. In doing so, pervious concrete has the ability to lower overall project costs on a first-cost basis" (Pervious Concrete, 2007, para. 1). An added benefit of pervious concrete is its natural tendency to aid in roadway safety. Pervious concrete systems allow air to circulate beneath surface areas, thus increasing the melting rate of snow, resulting in a rapidly drying surface with less opportunity for refreezing due to puddles and excess moisture (Pervious Concrete, PC vs. Asphalt, 2007).

Frequently asked questions about pervious concrete

There are three significant questions about pervious concrete performance in problem areas:

(1) What about drainage issues in soils with high clay content?

Typically soil is suitable for pervious concrete if the soil has sufficient percolation to support a septic tank. Percolation rates are the key factor in meeting storm water requirements and determining the suitability for permeable pavement (Pervious Concrete, 2007).

(2) What about clogging?

Fines and vegetation are the main contributors to a clogged pervious drainage system. This problem can be controlled with routine maintenance: vacuuming and sweeping. Pressure washing will restore the porosity of clogged pervious concrete to nearly new conditions (Pervious Concrete, 2007).

(3) What about freeze-thaw issues?

Air entrainment provides a satisfactory response to the detrimental freeze-thaw pressure buildup of water saturation in pervious concrete. Typically, the voids in pervious concrete allow for adequate water movement thus reducing the probability of saturation. Sever clogging of void structures reduces the satisfactory response to freeze-thaw properties of pervious concrete. An inadequate drainable aggregate base of 6-12 inches can also contribute to reduced performance (Pervious Concrete, FAQs, 2007).

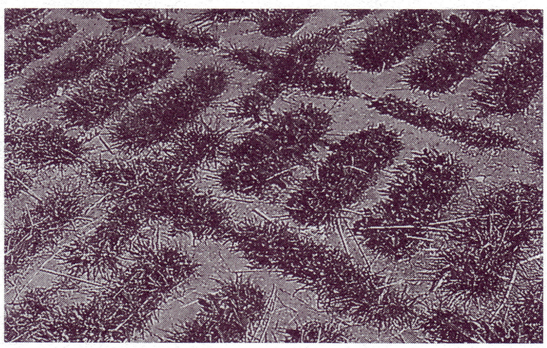
"Uniformity of sub-grade support is a key criterion for placing pervious pavement. Compaction to a minimum density of 90% to 95% of theoretical density (per AASHTO T180, Standard Method of Test for Moisture-Density Relations of Soils) is often recommended for consistent sub-grade support; however, increasing the sub-grade density decreases its permeability" (Pervious Concrete, Construction, 2007, para. 1). "The design of a pervious pavement base should normally provide a 6-to-12 inch layer of permeable sub-base. Special design provisions should be considered in the design of pervious concrete pavement for areas with roadbed soils containing significant amounts of clay, silts of high compressibility, muck and expansive soils" (Pervious Concrete, structural Design Considerations, 2007, p. 1). In terms of hydrological design considerations, there are three main factors to be considered. The three primary considerations are the amount of rainfall expected, pavement characteristics, and underlying soil properties (Pervious Concrete, Hydrological Design Considerations, 2007). The majority of pervious concrete pavements function well with little or no maintenance. Vacuuming annually or more often may be necessary to remove debris from the surface (Pervious Concrete, Inspection and Maintenance, 2007).

Pervious pavements should be placed by an experienced installer and the pavement structure and surrounding details should be designed to accommodate the anticipated water flow and drainage requirements (NRMCA, 2004).

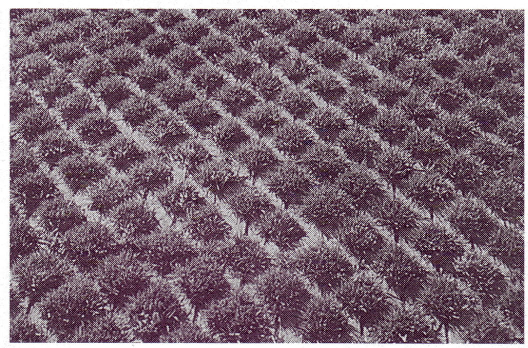
Pervious asphalt

Pervious asphalt uses the same basic mixing and application materials and the same black-top appearance as that of traditional impervious asphalt. Small stones and fine particle matter is removed in the stone mixture resulting in more uniform stone sizes to create voids. The quantity of tar is reduced and sealants to waterproof are not applied (Lake Superior Streams, 2007).

Figure 2.5: Porous asphalt Source: Lake Superior Streams, (2007)



Grids first used in Germany in 1961 for overflow parking were building blocks placed in the ground. They emerged from the need to cool cities and decrease stormwater runoff.



A typical grid pavement for occasional vehicular traffic

Figure 2.6: Grid pavements

Source: *ICPI TECH SPEC Number 8*. "Concrete Grid Pavements." [Book] Washington, DC: Interlocking Concrete Pavement Institute, April 2006. P.1-12.

Another aspect of porous surfaces is found in concrete grid pavements. Concrete grid pavements originated in the early 1960s in Germany and were used primarily to cool cities and reduce storm water runoff. They are used extensively today to reduce erosion, provide parking areas, create road access areas, and stabilize emergency vehicle lanes.

They also help earn credits under green building rating systems such as Leadership in Energy and Environmental Design (LEED) and Green Globes (ICPI TECH SPEC #8, 2006).

Government Involvement

> The EPA Storm Water regulations only allow for certain levels of pollution in the nation's waterways with the consideration of two basic approaches to controlling pollution: (1) reduce overall runoff, and (2) reduce the pollution contained in runoff. Efforts to reduce runoff include zoning ordinances and regulations that reduce the amount of impervious surfaces in new developments; green space requirements, and implementation of "storm water utility districts" that levy an impact fee on a property owner, based on the amount of impervious area. Efforts to reduce the level of pollution from storm water include requirements for developers to provide systems that collect the "first flush" (one inch) of rainfall and treat the pollution prior to release (Brown, 2003, p.2-3).

The Clean Water Act (CWA) is the primary regulatory guideline for all state and federal water quality programs in the United States. Many people are unaware that although the CWA gained momentum and significant regulatory strength through a series of amendments in 1972, the CWA has been in force since 1948. Technical and financial assistance as delegated by Congress is available to states to assist in compliance with certain aspects of controlling storm water runoff, a relatively new aspect of updated programs through the CWA. The Environmental Protection Agency (EPA) sets guidelines for states as to control the standards for federal water quality programs (Fact sheet #3, 2005). The CWA, although the cornerstone of surface water quality protection in the United States, does not deal directly with ground water nor water quality issues. It does, however, regulate point source facilities such as sewage plants and industrial facilities (Clean Water Act/Laws and Regulations/US EPA, 2007). State and local governments are much more involved in the regulatory aspects of storm water runoff from streets, construction sites, farms, and other runoff sources. As the Federal government becomes more involved in the storm water runoff and environmental regulatory issues, organizations such as Interlocking Concrete Pavement Institute (I.C.P.I). are on Capitol Hill informing governmental agencies about interlocking concrete pavement and its abilities to mitigate storm water runoff, enhance flood control, and improve water quality. Randy Pence, ICPI Government Relations Counsel, Capitol Hill Advocates, indicates "during the May 10, 2007 hearing [hearing on Green Transportation Infrastructure: Challenges to Access and Implementation], it became apparent that committee members recognize and accept the environmental benefits of pavements that allow for percolation of storm water *in situ* (Update, 2007).

Initial Approaches/Recommendations to Stormwater Management

Municipal planning

With storm water management responsibilities shifting to local municipalities, storm water management professionals are faced with a very serious responsibility and often find themselves starting a department with few resources and little or no direction. Creating a management plan from which to get started often includes the following:

1. Focusing on cost effective source reduction and pollution prevention activities

2. Getting informed about strategies from the state (and neighboring states) level
3. Defining the problems by determining local water quality
4. Identifying pollution sources
5. Completing an inventory storm sewer system
6. Preventing pollution before it starts by evaluating potential sources
7. Identifying and eliminating illegal sanitary sewer connections
8. Planning and managing all growth to reduce negative impact
9. Establishing used oil and waste collection programs
10. Cleaning streets and catch basins as often as possible
11. Controlling erosion and sediment in developing areas
12. Educating employees and the public about storm water problems, best management practices, and the individual's role in water quality protection

(Factsheet #6, 2005)

More specifically, storm water management professionals have to be aware of the impacts and rules associated with storm water runoff. They should be aware of classifications of sensitive waters and development regulations, hold pre-development meetings, and make decisions to reduce impact downstream. Storm water management personnel should use what is available within a development to make appropriate management decisions. Good site planning is essential and allows for the use of floodplains, wetlands, vegetative stream buffers, and cluster building, some or all of which may be viable options before any plans are drawn. An initial favorable approach for all storm water managers is to minimize curb and gutter usage and infiltrate everything possible (Factsheet #8, 2005).

A new approach

A new soft approach or integrated systems management approach seems to be a consideration of many professionals today. Basically this approach focuses upon maximum site planning and using more natural drainage systems than the typical drain pipe, curbs and gutter systems (Factsheet #2, 2005). It is important to reduce the source of pollution load by minimizing unnecessary grading, stabilize disturbed areas, cover all equipment, provide containment structures, and educate everyone on site (including home owners) about pollution prevention measures. A key rule for any storm water management professional is to develop a good operations and management program and make certain it is well funded and has definite responsibilities by following a pre-determined set of guidelines (Factsheet #8, 2005).

Developing a municipal storm water pollution prevention plan is an invaluable tool for community water specialists. This can best be achieved by adhering to the following guidelines:

1. Identify facilities and activities that could impact storm water quality and receiving waters:

A. Airports

B. Water and sewer treatment plants

C. Vehicle fueling, storage and maintenance facilities

D. Land disturbing facilities

E. Chemical storage and application sites

F. Solid and hazardous waste management facilities

G. Salt and sand storage areas

2. Identify pollution sources

A. Leaking valves on storage tanks

B. Previous spill sites

C. Non-storm water discharge sites

3. Minimize use of potential pollutants

A. Examine all chemicals

B. Review proper procedure for chemical applications on parks, golf courses, roadsides, and municipal landscape areas

4. Reduce pollutant exposure

A. Clean up spills and runoff

B. Cover potential sources such as machines and storage areas

C. Establish vegetative cover

5. Plan for spills

A. Develop a response plan

6. Practice preventative maintenance and good housekeeping

A. Inspect everything that can contribute to pollution

B. Use drip pans for servicing equipment

C. Use dry as opposed to wet cleanup methods

7. Train and reward employees

A. Make everyone aware of pollution sources and prevention techniques

B. Seek input from workers

C. reward participants

8. Plan for new facilities and activities

A. Locate away from streams and water sources

B. Use vegetative surfaces and minimize impervious surfaces

C. Provide spill containment measures

(Factsheet #5, 2005)

Sources of revenue for municipality

1. Tax revenues – property and sales tax
2. Special services districts – district tax revenues for specific area
3. Storm water utility user fees – monthly user fees based upon contribution of storm water runoff
4. Special assessments – one time assessments levied against properties in proportion to the benefit each receives from a storm water management project
5. Powell Bill funds – cities can use these gas tax revenues to construct and maintain storm water drainage systems within city street rights-of-way
6. Grants and loans – very limited, but remain available
7. Permit and inspection fees – set by local governments to cover the cost of inspections
8. Impact/facility fees – special local enabling legislation is needed to charge these one-time fees that are related to the impact generated by the new development project.

A typical county storm water management program

The Gloucester County (NJ) Storm water Management agency provides a comprehensive program for low impact development techniques. The manual includes the following information that should provide any storm water management professional a good basis from which to develop his/her own municipal plan.

Initially, it is recommended that LIDs Low Impact Development techniques (LIDs) include both structural and nonstructural BMPs to first minimize quantitative and qualitative changes to a site's pre-developed hydrology. According to the Gloucester County Storm water Management website (2004), Nonstructural LID-BMPs include:

- Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss.
- Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces.
- Maximize the protection of natural drainage features and vegetation.
- Minimize the decrease in the pre-construction time of concentration.
- Minimize land disturbance including clearing and grading.
- Minimize soil compaction.
- Provide low maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers, and pesticides.
- Provide vegetated open-channel conveyance systems discharge into and through stable vegetated areas.
- Provide preventative source controls

The agency has further broken down LID-BMPs into four main categories:

1. Vegetation and Landscaping: preservation of natural areas, preservation of native ground cover, provisions for vegetative filters and buffers

2. Minimizing Land Disturbance: Plan to use as much of the land in its native state, evaluate site to utilize all positive factors before changing anything, utilize construction techniques that limit ground disturbance, reduce further expansion of buildings beyond new project

3. Impervious Areas Management: Streets – minimize width, and incorporate vegetated islands and curb cuts; Sidewalks – use pervious paving materials; Parking and Driveways – reduce size and use pervious paving materials; Pervious Paving Materials – use wherever possible; Unconnected Impervious Areas – disconnect impervious areas from runoff and allow water to sheet across pervious areas; Vegetated Roofs – install lightweight vegetative planting beds on new or existing roofs

4. Time of Concentration Modification: increase surface roughness areas; reduce slopes in graded areas; create vegetated swales

The agency recommends the following as structural LID-BMPs:

- Bioretention systems
- Constructed Storm water Wetlands
- Dry Wells
- Extended Detention Basins
- Infiltration Basins
- Manufactured Treatment Devices
- Pervious Paving Systems
- Rooftop Vegetated Cover
- Sand Filters

- Vegetative Filters
- Wet Ponds

(Gloucester County, 2004)

Given the options used to work with storm water management controls, there are issues to contemplate with solutions that can be best utilized through better site design, especially, in commercial development. Commercial development presents its own unique set of problems due to local, state, and federal regulations, as well as its impact upon the community in which it is located.

Permeable Paving as a Source Control Technique

Solutions for eliminating or reducing point-source pollutants are not as much of an issue today as we have a better understanding of their dangers and have, for the most part, addressed the accompanying issues and are making concentrated efforts to stop the direct, point source polluting of our streams, rivers, waterways, and oceans. Non-point source issues have become the major concern now as we realize their introduction of pollutants into our waterways is incredibly significant.

During and after rainstorms, on-point sources of runoff pollution flow in huge quantities that render them untreatable by conventional wastewater treatment plants. In many cases, the receiving water cannot process the overwhelming amount of pollutants either. Therefore, the breadth of pollutants is difficult to control, as well as the extent to which they can be treated through nature's process in a lake, stream, or river (Smith, 2000, p.1).

States must now control non- point source water pollution as a result of the National Pollution Discharge Elimination System (NPDES) program and U. S. federal law. Best Management Practices (BMPs) must be identified and used to control these pollution issues in association with new development. BMP's can be divided into two categories: structural (dry ponds, retention ponds, infiltration trenches, sand filtration systems, and permeable and porous pavements); and non-structural (public awareness programs, better site planning, and better site design) (Smith, 2000).

Permeable paving serves as a source control technique in that the point of runoff treatment is at the source as opposed to treatment several miles downstream. Permeable paving also allows pollutants to be trapped immediately at the sub-base or geo-membrane level rather than flowing downstream and waiting for treatment at a later time of distant location (McCormick & son, paverexpert.com, 2006).

The parking lot

The single most significant enemy in the storm water runoff wars is the parking lot, with the greatest environmental impact being hydrological in nature (Why Stormwater Matters, 2000). Parking lots produce incredible amounts of storm water runoff, most of which re-enters the headwater stream with erosive power and causing significant damage downstream.

Parking lots also collect pollutants from automobiles and have been found to have extremely high concentrations of nutrients, trace metals and hydrocarbons. "In summer months, surface temperatures can exceed 120 degrees Fahrenheit, which in turn increase local air temperature five to 10 degrees compared to a shaded forest" (Why Stormwater Matters, 2000).

Information such as this leads to the following question: Could permeable pavers perhaps be the most aesthetically effective, long lasting, affordable, maintenance free storm water management tools available to storm water management professionals?

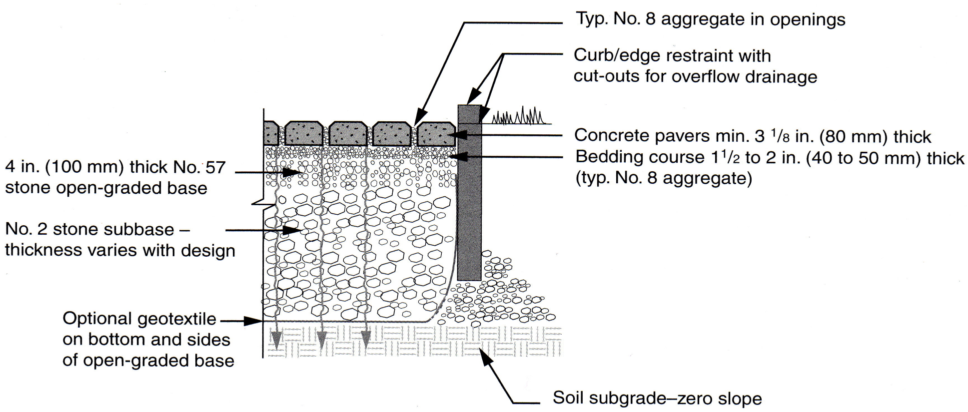
PICPs as an alternative management tool

Och's (2001) article about "pervious" pavers began with the following statement and question: "They're popular for driveways in Europe and Japan. Are pervious pavers ready to take America by storm" (para.1)? In an interview with David Smith of I.C.P.I., Ochs questioned Smith about the future of permeable pavers and their use as a significant alternative to traditional methods of storm water management surfaces. Smith pointed out that the beauty of permeable pavers is in not only in the aesthetics of providing something different from high maintenance, cracking concrete and asphalt, and something that blends in with nature, but in the legality and practicality aspects as well. In certain areas of the country, especially near waterways and coastal areas that have been designated as critical environmental areas, the total amount of impervious materials and built cover is severely limited. Using permeable pavers for a driveway actually allows the homeowner to build a bigger house as the permeable driveway is not included in the square footage area of impervious built cover (Ochs, 2001).

The initial cost of permeable pavers is approximately two to three times that of asphalt. This cost comparison can change as the cost of petroleum products fluctuates. Pavers, however, are virtually maintenance free whereas asphalt is a polluting, cracking surface that has to be sealed on a regular basis and ultimately replaced with more petroleum based surfacing product (Ochs, 2001).

Permeable Pavers- Design, Construction, Maintenance, and More Benefits

Generally speaking, PICPs are installed with major consideration for the preparation and performance of the base and sub-base as the most crucial aspects of the design and installation process. “When carefully constructed and regularly maintained, permeable interlocking concrete pavement should provide 20 to 25 years of service” (Burak, 2007, p.1). The main difference in bases and sub-bases for permeable and impermeable systems is the care in preparation needed to construct a base and sub-base that will support the intended surface traffic while maintaining infiltration capacity in a pervious system. This delicate balance between compaction for strength and modified compaction for increased permeability and minimal damage to base materials can be achieved by considering the importance of measuring density. Smith (2007) noted that “specifications should call for density measurements to ensure that optimum density has been achieved to minimize rutting during pavement life” (para. 1). A cross sample of full exfiltration provided by a permeable paver system with a high drainage sub-base is shown in Figure 2.7.



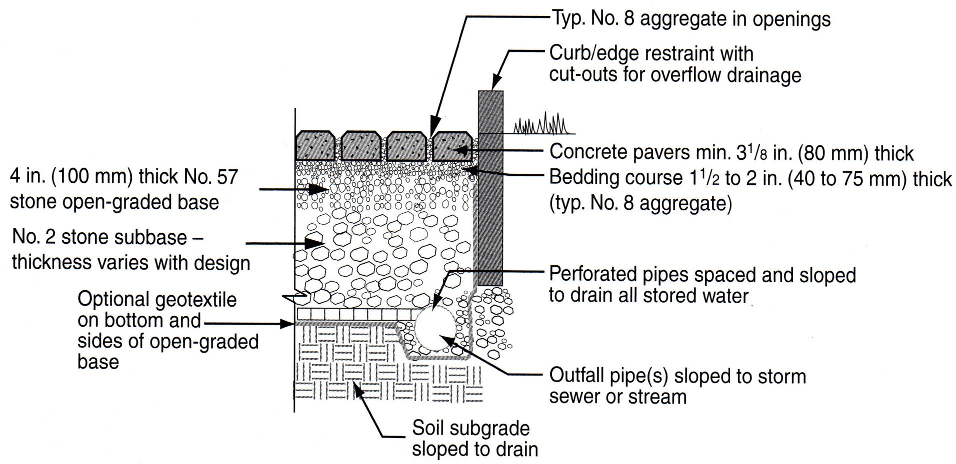
Full exfiltration *through the soil surface. Overflows are managed via perimeter drainage to swales, bio-retention areas or storm sewer inlets.*

Figure 2.7: Full exfiltration cross section

Source: Smith, D. R. (2000). *Permeable Interlocking Concrete Pavements* (3rd ed.). Washington, DC: ICPI.

After installation of a permeable paver, maintenance is relatively minimal but is absolutely necessary to ensure the long lifetime of the system. (Urban Design, 2007) “Porous concrete and interlocking concrete paving blocks require that the surface be kept clean of organic materials (leaves, for example), and periodic vacuuming and low pressure should be used to clear out voids and extend the paver’s functional life (Urban Design, 2007, para. 1).

As would be indicated in Figure 2.8, low-infiltration soils such as some types of clay can accept PICPs. “If soil infiltration is slow (generally under 0.5 in. /hour or 1.3x 10-2 m/sec), perforated plastic pipe drains at the bottom of the base can remove excess water while still allowing some of the water to infiltrate into the soil” (Project Profiles, 2005).



Partial exfiltration *through the soil. Perforated pipes drain excess runoff that cannot be absorbed by slow-draining soil.*

Figure 2.8: Partial exfiltration cross section

Source: Smith, D. R. (2000). *Permeable Interlocking Concrete Pavements* (3rd ed.). Washington, DC: ICPI.

PICPs as a BMP

Because PICPs reduce runoff and treat various pollutants in the water, they are considered structural BMPs. One significant benefit of using PICPs is the support of the water cycle as they help maintain the balance of water in the soil, groundwater, and streams. Research has proven it is more favorable to allow water to return to the soil through in infiltration system rather than retaining it and slowly releasing it into the sewer or waterways (Smith, 2000). An evaluation of applications for concrete permeable pavement is shown in Table 2.

	Interlocking shapes with openings	Enlarged joints & spacers	Porous concrete units	Grid pavers with grass
Low-speed roads	Contact manufacturer	Contact manufacturer	Not recommended	Not recommended
Parking lots*/bays driveways	Excellent	Excellent	Not recommended	Acceptable for low use
Overflow parking, Access and emergency lanes	Excellent	Excellent	Not recommended	Good
Revetments, boat ramps	Good	Good	Not recommended	Good
Bike paths, Sidewalks* Pedestrian areas*	Good	Good (maintain narrow joints)	Excellent	Not recommended

Evaluation of applications for concrete permeable pavement.
**See design considerations for disabled persons on page 10.*

Table 2.2: PICP applications

Source: Smith, D. R. (2000). *Permeable Interlocking Concrete Pavements* (3rd ed.). Washington, DC: ICPI.

Figure 2.9: A street with permeable pavers in Portland, Oregon.

Source: Smith, D. R. (2000). *Permeable Interlocking Concrete Pavements* (3rd ed.). Washington, DC: ICPI.

Economics of PICPs

Initial square footage costs of PICPs are greater than those of impervious surfaces and most alternative pervious surfaces. They can be significantly cost effective, however, when looking at long term effects, what systems they replace or eliminate, and maintenance issues.

The initial cost of installing permeable pavers can be offset by an increase in revenue producing space from buildings which can be built bigger when impervious surfaces are replace with PICPs. PICPs can eliminate the need for retention ponds, thus providing additional building space and an increased revenue possibility. Built cover increases runoff, so when development expansion occurs, PICPs are a better and less expensive option than redesigning and installing new curb and gutter drainage systems (Smith, 2000).

Benefits and limitations of PICPs

Benefits provided by PICPs seem to outweigh the limitations, especially when considering the devastating results of inadequate stormwater management.

Benefits:

- Conservation of space on the site and reduction of impervious cover
- Reduction of runoff by as much as 100% from frequent, low-intensity and short duration storms
- Reduction or elimination of unsightly retention basins in other pars of the drainage system
- Promotes tree survival by providing air and water to roots

- Preserves woods and open space that would have been destroyed for retention basins
- Reduces pollutants and improves water quality
- Reduction of runoff temperature
- Reduced peak discharges and stress on storm sewers
- Increased recharge of groundwater
- Reduction of downstream flows and stream bank erosion due to decreased peak flows and volumes
- Reduced overall project development costs due to a reduction in storm sewers and drainage appurtenances
- Eliminates puddles and flooding on parking lots
- Reduced snow plow costs due to rapid ice melt drainage
- Durable, high-strength, low absorption concrete units resist freeze-thaw and heaving
- Reduces micro-climatic temperatures and contributes to urban heat island reduction
- Eligible for LEED credits
- Immediately ready for traffic (no waiting days for curing)
- Can be placed over underground storm water storage systems

Limitations

- Overall cost compared to other BMPs
- Greater site evaluation and design effort
- A higher level of construction skill, inspection, and attention to detail
- Surface maintenance to minimize clogging to ensure long-term performance

(Smith, 2000)

“The main advantage of permeable concrete block paving stone is their ability to reproduce the flow reduction and water quality improvement properties of natural surfaces and vegetation” (James & von Landsorff, 2003, p. 3). Another important advantage is their ability to reduce the amount of overland flow reaching waters, thereby reducing peak flows in rivers and streams. (Legret et. Al., 1996) An additional advantage of PICPs is in the area of maintenance.

Smith (2006) stated the following:

> Infiltration trenches and detention facilities eventually need to be cleaned out. Under the best conditions, a thorough cleaning will likely be needed every 20 to 30 years. Cleaning means removing the pavement and base, accumulated base sediment and replacing what was removed. While porous asphalt and pervious concrete can be recycled via off-cite sources, permeable interlocking concrete pavements won’t need to be. They can be set aside at the site and reinstated after sediment removal and refreshing the open graded, crushed stone base. Less time, fossil fuels and materials are wasted. (p.10)

A perceived disadvantage of pervious materials is a reduction of infiltration rates over time due to sediment entering the void spaces designed for water to flow through. “These failures have made stormwater managers generally very reluctant to recommend porous pavement as a stormwater practice, rejecting the technology as impossible to apply in the real world” (Cahill, 2000, p.5).

DeLaria (2008) noted the following:

> The cost benefit analysis is variable. For example, at an installation in Florida, permeable paver systems broke even after 22 years when comparing the materials,

construction and maintenance to concrete and asphalt surfaces. On another site in the Chicago area, after 50 years an asphalt surface would have cost 10 times as much as pavers to maintain. Additionally, comparing costs of materials and installation is not a complete and perhaps not an appropriate evaluation. In the Denver area for example, a concrete parking lot would cost approximately 50% more than asphalt and a permeable paver system with the full open-graded aggregate system, would cost two to three times as much as asphalt. Based upon initial investment, asphalt or concrete appear to be more cost effective than pavers. However, the cost of asphalt or concrete does not include the costs of inefficient use of land and associated cost if a detention structure is required. Also not included are costs associated with managing offsite impacts that are generated such as: excess stormwater runoff rate and volume, pollutants washing off of impervious area into receiving waters, and future waterway stabilization needs. Pavers may have a larger initial investment, but the cost of detention is included and offsite impacts are reduced. (p.2)

Investigations/Studies

University of Geulph study

Since 1993, William James and his staff of current and former graduate students at the University of Geulph (Ontario, Canada) have been studying and evaluating the performance of porous pavements versus impermeable pavements as they relate to runoff volume, thermal characteristics, and pollutant levels (James, 2002). In a test conducted in 1995 comparing the performance of four different pavement surfaces, asphalt, concrete brick, and three and four inch thick concrete paver stones with infiltration cells (PICPs), the results indicated PICPs were found to “significantly reduce surface runoff contaminant loads. Surface runoff was reduced, and pollutants were trapped in the permeable pavement” (James, 2002, para 3). Additional tests found that the pH of rain was a more significant factor of pollutant introduction than originally considered, but again, using the same four test surfaces, pavers reduced both contaminants and runoff the most, with asphalt reducing them the least. Permeable pavers were also found to reduce surface runoff temperatures between 2 degrees Celsius and 4 degrees Celsius more than asphalt, even though asphalt was found to cool faster after the storm (James, 2002).

North Carolina State University study

Professor Bill Hunt of North Carolina State University has provided substantial data through research in the area of permeable pavements. Professor Hunt and his staff has conducted research and concluded that when compared to an adjoining asphalt lot, PICP exfiltrates contained significantly lower concentrations of phosphorous and zinc as well as reductions in total nitrogen. This research was a major contributing factor in leading the state of NC to give pervious area credits to permeable pavements used in the eastern part of the state (ICPI Magazine, Nov. 2006).

Bio-Aquifer system

Chuck Taylor of Advanced Pavement Technology has introduced a newer pervious pavement system that takes into consideration North American soil conditions, designs, and construction issues. This system is called the Bio-Aquifer System (BASS) and is a flexible, segmental paver system. This system allows for the collection of runoff as well as the support of heavy axle loads for roads and parking lots (Yelton, 2005). “In addition, due to the types of aggregate used, a natural filtration process will occur, and pollutants that are removed from the runoff will be broken down by bacteria contained in the aggregates” (Yelton, 2005, para. 1).

Lower Cascades Park

Lower Cascades Park in Bloomington, Indiana recently underwent a major reconstruction. Forty thousand square feet of permeable interlocking concrete pavement was used. Toward project completion, the remnants of hurricane Katrina dumped 3 in. (75mm) of rainfall on the park in one day. The proof of the system working was no ponding anywhere in the three parking lots built to accommodate 125 cars (Smith, 2005).

Bialecki study

Developer George Bialecki, a proponent of green building, recently built an independent living community in Moline, Illinois using PICPs in the roadways throughout the entire community. Doing so saved thousands of dollars and created such a significant savings that it made PICPs cost competitive with conventional asphalt and concrete pavements. (PICP in Streets, 2007) Figure 2.1 displays the layout of the entire development, and Table 2.3 represents a cost comparison of different options for paving systems.

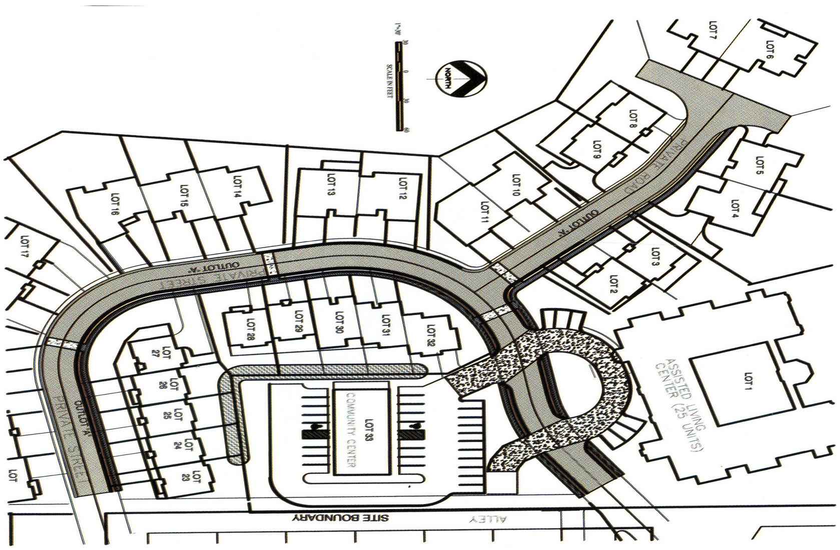


Figure 2.10: Layout of development – Bialecki project

Mr. Bialecki’s main purpose in choosing PICPs was their “fit” with the entire green concept. Going green obviously helped sell units as Autumn Trails sold out before construction began due in part to the operating costs to buyers being 85% less than in conventional building designs. With all of the many green features throughout the entire community, PICPs were a perfect fit for street surfacing. Knowing that buyers are very aware of dwindling fuel sources, rising energy costs, decreasing water resources, and carbon-emissions that impact global warming, Mr. Bialecki realized that customers are willing to pay more for initial construction in exchange for lower operating costs throughout the lifespan of their home (PICP In Streets, 2007).

Item	PICP	Concrete	Asphalt
Paving/sf	$2.25	$8.00	$3.00
Excavating/sf	$1.00	$1.00	$1.00
Stone/sf	$2.00	$1.50	$1.50
Installation/sf	$4.00	(in paving cost)	$1.50
Curbs	$1.50	$1.50	$1.50
Maintenance	$0.20	0	Not known
Replacement	None	None	Every 12 years
Detention/Retention required	None	Yes	Yes
Storm Sewer System/sf paving	None	$3.00	$3.00
Total/sf	$10.95	$14.00	$11.50
Total/linear foot – municipal street	$171	$218	$179
Total/linear ft for 30 ft wide street	$230	$280	$230

Table 2.3: Cost comparison of pavement systems for Autumn Trails

Cost savings from PICP were created by:

- Eliminating storm water runoff fees
- Eliminating the burden on Moline's aged storm sewer system
- Eliminating the need for a detention pond, thus creating more income producing land availability
- Eliminating storm sewer and inlet pipes
- Creating an infiltration rate of 50 in./hr
- Maintaining a 5 in/hr infiltration rate in a worst-case estimate of 90% reduced surface infiltration after decades of use
- Storing water in the base/sub-base of nearly 6 and ½ inches of rainfall coming from rooftops, sidewalks, and driveways

(PICP in Streets, 2007)

Storm Water Management for Urban Environment

Elmhurst College

Elmhurst College in Elmhurst, Illinois, underwent a campus redevelopment project that focused upon innovative water management techniques and reduced negative impact of rainwater. Numerous BMPs were used to better manage rainwater from impervious surfaces, treat that water, and stored it for a systematic reintroduction to recharge groundwater.

Taylor (2007) described the project as follows:

> The keystone for this site plan is a two acre area, with over a two hundred car parking lot that will serve as a detention/retention facility replacing the need for a surface water retention facility there being no land available for such a structure. Underground storage will be provided beneath the permeable pavement surface in the void areas of the aggregates. In addition, this system of aggregate layers will act as an infiltration trench and will collect and treat first-flush pollutants and improve water quality. Because this system will provide more time on site via detention and retention, groundwater recharge will be promoted and also a better microbial action will be established as this system will mimic Mother Nature regarding natural surface infiltration and time on site, while creating a peak time controlled release format. Control structures are integrated in the bio-swales and will also provide access for water samples by the students. (para. 4)

San Francisquito study

Katie Pilat, restoration manager of the San Francisquito (Palo Alto, California) Watershed Council, referred to the first permeable concrete parking lot in Menlo Park as looking like gray Rice Krispies treats. This parking lot and an additional site at a private residence in Palo Alto have been targeted as two demonstration projects used to “show residents how they can reduce urban erosion by converting asphalt areas to permeable surfaces” (Peterson, 2007, p.16).

Pavers are being used on the private driveway with the explanation to the people of the community that they encourage the rain to seep beneath the surface rather than blocking it with an impervious surface. The Watershed Council indicates that these two projects alone “will reduce the amount of runoff into San Francisquito Creek by more than a quarter million gallons of water per year” (Peterson, 2007, p.16).

Victoria study

The University of Victoria (Canada) installed an 8000 square foot parking area in 2004 that exceeded Leadership in Energy and Environmental Design (LEED) criteria by reducing the rate and quantity of runoff by 25% from a 2-year, 24 hour storm design (Permeable Interlocking Concrete Pavement Fits, May 2006). The designers specified an aesthetically pleasing herringbone pattern in the pavers and a perforated pipe at the bottom of the sub-base to drain the retained or stored water within 24 hours. The soil sub-grade is clay, thus requiring the use of the perforated pipe to help in dispersing the retained water over time. Sarah Webb, the University’s Sustainability Coordinator noted that “Paving stones and other permeable products will continue to be used on the University of Victoria’s campus as a part of our green building program and our commitment to our Integrated Storm water Management Plan to reduce water run off and improve water quality” (Permeable Interlocking Concrete Pavement Fits, May 2006, p.40).

Chicago White Sox stadium parking lot

The largest permeable interlocking concrete pavement project in the United States was recently completed at Chicago’s U.S. Cellular field parking facility and totaled 265,000 square feet. This is a sustainable urban drainage project that used no-fines aggregate material for greater water storage. The demands on performance of this project were developed by the City of Chicago Department of Water Management. These demands included such things as specific release-flow rates, water storage in void spaces, and a storage capacity from a design storm of a half a million gallons. An additional added benefit to this project was the determination that a 15% overall savings over traditional bituminous asphalt was realized by using PICP and eliminating drainage systems and underground storage (ICPI Magazine, 2008).

As PICP installations increase, more data is coming on the performance benefits and limitations of such systems. In a published interview, Bruce Ferguson addressed the subject as follows:

> Today, the trial of technical barrier breaking is behind us. We know what the right thing is to do for water itself. The question now is how to integrate natural process artistically and correctly into the urban landscapes where people live and work. Cities, especially densely populated low-income neighborhoods are ripe for sustained attention from landscape architects and other designers. We have to define conclusively what are sound criteria for successful urban design. Unfounded and unexamined agendas for urban design abound, as they have always done for environmental design. The next fundamental contribution to be made is in integrative urban design, using criteria for both the biophysical environment and human communities. (McIntyre, 2007, p.115)

CHAPTER 3

RESEARCH METHODOLOGY

The purpose of this study was to examine the views and perceptions of stormwater management professionals of using Permeable Interlocking Concrete Pavement (PICP) as a stormwater runoff management tool. Stormwater runoff has become a serious problem in America due to a rapid increase in built cover and the inability of stormwater runoff to properly flow through the earth's soil to be purified, cooled, and controlled prior to re-entry into urban watersheds and aquifers. Therefore, when it comes to stormwater runoff there is a need for improved methods that would allow for the proper flow in the water cycle. For this reason, PICP offers a solution to many of the problems presented by stormwater runoff. The aim of this study was to contact stormwater management and decision makers in an attempt to obtain their perceptions and views of using PICP during construction. In order to do this a mixed methods research design was used, which consisted of using a survey instrument designed to collect both quantitative and qualitative responses from the stormwater managers. This chapter examines and discusses the research design that was implemented, the population and sample, the instrumentation and the data analysis conducted to address the research questions and hypotheses of this study.

Research Design and Appropriateness

The research design employed for this study was a mixed methodology that included a quantitative and a qualitative component. By combining the data from the quantitative research questions with the qualitative research questions the researcher was able to explore and examine several different possible relationships that can be triangulated (Tashakkori & Teddlie, 1998). A descriptive quantitative research design was used in this study allowing the researcher to determine whether there is a significant relationship between two or more variables (Cozby, 2001). Therefore, one should be able to determine whether an independent or predictor variable has an affect on a dependent or outcome variable. When the predictor variable is categorical (i.e. has two or more specific categories) and the outcome variable is continuous the researcher would be able to examine the differences that may exist between the categories of the independent variable with respect to the average value of the outcome variable. The researcher then can determine whether there are differences between certain categories of the predictor when it is assessed with the outcome variable.

For the qualitative component for this study, a grounded theory design was employed. Grounded theory research begins with a research situation or question and is conducted through observation or interview (Cresswell, 1994). Codification of responses provided on the survey instrument were necessary for the grounded theory research since it would allow the researcher to return to the responses provided by the participant in the future if required. Open-ended survey questions were used during the study so the results of the survey questions corresponded to the feelings and perceptions of PICP for stormwater management. Asking participants open-ended questions allowed the researcher to obtain a more in-depth response from survey participants. This is because the participants were able to respond to the questions in their own words, which in turn can be more informative (Cozby, 2001).

By using the qualitative research design the researcher was able to obtain a more in depth response than one would be able to obtain with only a quantitative research design. This is because the researcher would be able to obtain more information from the respondent based on the responses provided to the open-ended questions (Cresswell, 1994). By using a qualitative research design the researcher was able to gain more insight into the responses of the individual's experience with the study topic, which is information that one cannot obtain directly from a quantitative study. Another advantage of the qualitative approach was that the researcher received answers to the questions in the respondents' own words (Cozby, 2001). The use of only quantitative designs do not make this directly available and only obtain information based on pre-defined options available on the survey.

Therefore, the use of both the quantitative and qualitative methods was appropriate since this allowed the researcher to be able to not only quantifiably assess the relationships or associations by using a statistical procedure, but it also allowed the researcher to qualitatively define the reasons for these relationships or associations. By using the mixed methodology, the researcher was able to triangulate the methods meaning that both the quantitative and qualitative design were used to assess the same research questions. This provided further evidence for or against the research questions or hypotheses of the study (Tashakkori & Teddlie, 1998). The importance of triangulation in research designs is that the weaknesses of one research method would be offset by the strengths of the other research method (Tashakkori & Teddlie). In other words, what cannot be assessed by the quantitative design may be assessed by the qualitative design, whereas what cannot be assessed by the qualitative design may be assessed by the quantitative design. In this context, it provided a more powerful tool for assessment of the research questions because each one of the issues, weaknesses or problems of one method could be accommodated by the other method.

In order to assess the relationships in the quantitative component of the study, correlation coefficients and analysis of variance (ANOVA) were conducted. The purpose of the correlation coefficient was to determine whether there was a significant relationship between two continuous variables, while the ANOVA was used to determine whether there was a statistically significant difference between two or more independent populations with respect to a continuous outcome variable (Moore & McCabe, 2006). To analyze the qualitative component, a computer program, NVivo®, was utilized. The content analysis was performed by a program designed to assess qualitative responses which in turn reduces the subjectivity that would exist if the researcher coded the themes and results him/her self.

Research Questions and Hypotheses

Research questions

1) To what degree are PICPs and porous pavements worthy of being considered as a storm water management option?

2) What did the storm water management professionals indicate was the most significant barrier to using PICPs as a storm water management tool?

3) Were storm water management professionals who were assigned the responsibility of making the decision to use or not to use PICPs, properly trained or informed to make that decision?

4) What were the storm water management professionals' main misconceptions about PICPs?

5) What did the storm water management professionals perceive the future of PICPs to be in their jurisdiction?

6) What was the storm water management professionals' main technical concern with using PICPs as a storm water management option?

7) What are storm water management professionals looking for to help them better understand the role PICPs will play in the future of storm water management?

Hypotheses

Hypothesis statement 1

Permeable pavements are not given100% credit as pervious surfaces.

Hypothesis statement 2

The hydrologic effects of permeable pavements are not given credit in obtaining storm water management approval.

Hypothesis statement 3

Storm water management was not a significant aspect of the collegiate course of study of the respondent.

Hypothesis statement 4

The respondent's experience with PCIPs is very limited.

Hypothesis statement 5

Storm water management professionals are unaware of the benefits of permeable pavers as they relate to pollutant and water runoff management.

Hypothesis statement 6

Storm water management officials do not have the authority to approve or decline the use of PICPs.

Hypothesis statement 7

Storm water management professionals indicate the objection to the use of PICPs in their jurisdiction is based upon uninformed and old school thinking of state officials and their acceptance of research data as fact.

Hypothesis statement 8

Storm water management professionals find their colleagues as generally opposed to the use of PICPs.

Hypothesis statement 9

Storm water management professionals find a need for better communication between state officials and researchers when making policy about the use of PICPs.

Hypothesis statement 10

Storm water management professionals would encourage workshops and presentations to become better informed about PICPs.

Hypothesis statement 11

Storm water management professionals think PICPs are cost prohibitive.

Hypothesis statement 12

Storm water management professionals think the sanctioned use of PICPs is a political issue and given little opportunity for consideration from a useful or beneficial approach.

Hypothesis statement 13

Storm water management professionals would like to encourage the use of PICPs in their jurisdiction.

Population and Sampling Frame

Participants

The 148 participants in this study were members of the Non Point Source (NPS) Information Exchange. This list and all communication associated with it is highly regulated and controlled by the Environmental Protection Agency. The participants were the individuals who are in the stormwater management /decision makers/ positions. The participants were contacted through a membership blanket email with specific cover letters and general information about the study.

Sampling plan

The sample for this study was based on individuals who are in a stormwater management /decision maker position. In order to obtain a sample of the target population, an email with a specific cover letter and general information was sent to each one of the 316 potential participants. The emails were sent to the individuals work email address that were obtained through the Non Point Source Information Exchange (NPSIE). Included with the initial email was a cover letter that explained the purpose of the study as well as contact information if the potential participant had any questions, comments or concerns about the study. The potential participants were made aware that participation in the study was completely voluntary and that they would be able to withdraw from the study at any time.

Since the participants in this study volunteered to participate in the study, a non-probabilistic sampling plan was used. The sampling plan used was a convenience sampling technique. The advantage of using the convenience sampling plan was that one would be able to obtain a sample of participants without being concerned with randomly selecting potential participants that may not participate in the study (Cozby, 2001). This in turn saved time by being able to distribute mass emails to the potential participants in the study.

Sample size

When calculating the sample size for the study there are usually three main factors to be taken into consideration. These factors include the power of the study, the effect size between the variables in the study, and the level of significance. The power of the study is a measurement of the probability of rejecting a false null hypothesis (Moore & McCabe, 2006). In other words, this is a measurement of the probability of not making Type II errors where one fails to reject the null hypothesis when in fact the null hypothesis is false or the alternative is true. As a general rule of thumb, the minimum power of a study that would be necessary to correctly reject a false null hypothesis would be equal to 80% (Keuhl, 2000). The next factor of importance is the size of the effect, which is a measurement of the strength or magnitude of the relationship between the independent and dependent variables in the analysis (Cohen, 1988). The effect size, as defined by Cohen, is usually divided into three separate groupings which include a small effect, medium effect and a large effect. The last thing that is of importance is the level of significance. This is almost always set at the 5% level of significance.

The sample size is also dependent on the type of analysis that is going to be conducted. This means that one would have to calculate the appropriate number of observations that would be required to make proper statistical inferences based on the type of test that is being conducted. For this study the main statistical procedure used was the ANOVA. This is because the aim was to determine whether there were differences in the perceptions of PICP based on individuals with varying levels of background/demographic characteristics. Based on this information, the sample size, as calculated by the computer program G*Power, the minimum number of subjects that would be required for this study would be 90, based on a large effect, a power of 80% and a level of significance of 5%.

Survey Instrument and Materials

Instrument

The instrument consisted of both closed-ended questions and open-ended questions (attached in Appendix A). Each question was designed to obtain a measurement for the participants' perceptions and feelings towards using PICPs in construction. In total, there are six sections on the survey instrument. The first section is comprised of demographic and background characteristics of the participants. This included information on the participant's level of education, the number of years they have worked in their jurisdiction and the number of years they have worked in the field of stormwater management.

The second section was then designed to measure the jurisdiction of the participants. The questions in this section were comprised of yes/no responses with follow-up open-ended questions if the participant responded yes to any of the questions. The third section, which was designed to measure the participant's experience with PICPs, was comprised of yes/no questions as well as one multiple choice questions. For each of the yes/no responses there is a follow-up open-ended question if the participant responded yes to any of the questions. These are provided so the participant would be able to elaborate on their responses in their own words.

The fourth section is comprised of open-ended questions along with two closed-ended multiple choice questions. These questions were used to obtain insight into the participants' perceptions of using PICPs in construction. The participants' responsibilities in stormwater management are then measured by section five on the survey instrument. Once again, the questions in this section are both open-ended and closed-ended in nature. Finally, the sixth section was designed to measure participants' perceptions on future use of PICPs and necessary training. The closed-ended questions for this section are yes/no responses with follow-up open-ended questions allowing the participants to elaborate on their responses, if they answered yes to any.

Data collection

Data were obtained by using a survey instrument that was distributed to the potential participants in the study. The survey instrument was provided to the subjects via an online link that was sent to them in an initial email. The initial email provided a description of the study that included the purpose of the study as well as the researchers' contact information in case the participant had any questions regarding the study. Along with this initial email was an informed consent form which described the rights of the subjects as a participant as well as the time it would take for them to complete the survey.

The potential participants were advised that at any point in the study, if they wished to not finish the survey, they could discontinue the study without any subsequent consequences. Along with the online consent form was a yes/no option that the potential participant would select if he or she chose to or chose not to participate in the study. If he or she selected "yes" then the participant was directed to the online survey where he or she provided answers to each question. If the potential participant selected "no", the participant was redirected to a different window that thanked them for their consideration in taking part in the study. After a two week period, potential participants that had not responded to the survey instrument were sent a reminder to complete the survey. This was done to potentially obtain a larger response rate. The same was then done one week later, where one final reminder email was distributed to the subjects that had not responded to the survey instrument.

The raw data from the online survey instruments were imported into a Microsoft Excel spreadsheet for analysis. The information obtained from the participants was imported where each row in the Microsoft Excel spreadsheet received a unique identification number. Each row in the spreadsheet represented one individual stormwater manager or decision maker, while each column represented the responses provided by the respondents for each of the variables in the study. The data were saved on a separate flash drive as well as stored in a filing cabinet and stored on a personal computer that was password protected so that only the researcher had access to the information. By doing this, the confidentiality of each participant in the study was maintained so that no personal information was accessible. The data will be kept on file for a period of two years after which it will then be destroyed and deleted from the hard drive.

Operationalization of variables

The operational definition of the variables in this study is important because this is what provided information on the type of analysis that could be conducted. Variables that were used in this study are discussed below.

Demographic/background characteristics:

The demographic and background characteristics of the subject were operationalized as categorical variables. This means that each of the characteristics was comprised of two or more independent categories or levels.

Jurisdiction

The jurisdiction variable for this study was based on the responses provided to the closed-ended questions in section two of the survey instrument. Numerical values were assigned to each one of the responses (2 – yes), (1 – no), (0 – uncertain) and then summed together to provide an overall continuous jurisdiction measurement. In the context of this study a higher score would indicate the jurisdiction in which the participant worked had high standards and knowledge when it comes to stormwater management. To make certain the jurisdiction measurement was reliable, Cronbach's alpha statistics were computed for this variable.

Experience with PICPs

The experience with PICPs variable for this study was based on the responses provided to the closed-ended questions in section three of the survey instrument. Numerical values were assigned to each one of the responses (2 – yes), (1 – no), (0 – uncertain). Additionally, question 17 responses were assigned numbers for each of the four responses: (1-Never), (2 – 1-2 times), (3 – 3-4 times) and (4 – Over 5 times), then summed together to provide an overall continuous experience with PICPs measurement. In the context of this study a higher score would indicate that the participant has had more experience with PICPs. To make sure the experience measurement was reliable, Cronbach's alpha statistics were computed for this variable.

Perceptions of PICPs

The perception of PICPs variable for this study was based on the responses provided to the open-ended questions in section four of the survey instrument. The software program NVivo® was used to evaluate the responses to open-ended questions in this section.

Job responsibilities

The job responsibilities variable for this study was based on the responses provided to the closed-ended questions in section five of the survey instrument. Numerical values were assigned to each one of the responses (2 – yes), (1 – no), (0 – uncertain), and then summed together to provide an overall continuous job responsibility measurement. The software program NVivo® was used to evaluate the responses to open-ended questions in this section. In the context of this study a higher score would indicate the participant has good responsibility. To make sure the measurement of job responsibilities was reliable, Cronbach's alpha statistics were computed for this variable.

Future use of PICPs and training

The future use of PICPs variable for this study was based on the responses provided to the closed-ended questions in section six of the survey instrument. Numerical values (2 – yes), (1 – no), (0 – uncertain), were assigned to each one of the responses and then summed together to provide an overall continuous future use of PICPs measurement. The software program NVivo® was used to evaluate the responses to open-ended questions in this section. In the context of this study a higher score would indicate that the participant has more intent to use PICPs in the future. To make sure the measurement of future use of PICPs was reliable, Cronbach's alpha statistics were computed for this variable.

Data Analysis

The data collected from each one of the participants were entered into a computer spreadsheet so that analysis could take place. The data analysis for the study was performed in the statistical software package SPSS Version 16.0®.

The descriptive statistics used in this study included measures of central tendency such as the mean, standard deviation and minimum and maximum values. Additional descriptive statistics used in the analysis were frequency tables that provide information on the number and percentage of participants that make up the different categories for the discrete variables (demographic characteristics).

Pearson's correlation coefficient is a statistical procedure used to determine whether there is a statistically significant relationship between two continuous variables. The values of the correlation coefficient can range from a low of – 1 up to a high of + 1. If a value of – 1 is observed between two variables, this would indicate there is a strong negative relationship between the two variables. Consequently, as one variable increases the other variable would decrease. Whereas, if a positive value of + 1 is observed, this would indicate that there is a strong positive association between the variables. This means that as one variable increases the other variable will tend to increase as well. In both cases, this would provide evidence that there are significant relationships between the two variables. On the other hand, if a value of 0 is observed for the correlation coefficient, this would indicate there is no association between the two variables. This means that the increase or decrease in one variable does not have an impact the other variable. Therefore, in order to assess the first five hypotheses the correlation coefficient was used.

The ANOVA is a statistical method that is used in order to determine whether a predictor variable has a significant impact on a single outcome variable. For analytical purposes, the outcome variable in the ANOVA is a continuous variable that can take on a wide range of values whereas the predictor variables are usually categorical in nature (Moore & McCabe, 2006). This means that the predictor variables are comprised of two or more specific levels or categories. These levels or categories are then compared to one another with respect to the average value obtained for the outcome variable.

If it is found that there is a significant relationship between the predictor and outcome variables then the test statistic will exceed a critical value based on the degrees of freedom observed for the ANOVA. For the ANOVA, the test statistic that is used to assess the relationship is the F-statistic. This F-statistic follows an F-distribution, where the significance of the F-statistic is based on whether it is found to be greater than a critical F-value on $k - 1$ and $n - p - 1$ degrees of freedom (where k is the number of categories for the predictor variable, p is the number of parameters that are estimated in the model and n is the total number of observations) (Tabachnick & Fidell, 2001). Therefore, if the F-statistic is greater than the F-value then it could be concluded that the predictor variables significantly explain the variation in the outcome variable in the study. For this study, the ANOVA was used to determine if there were significant differences between the use of PICPs as measured by the jurisdiction, experience with PICPs, perceptions of PICPs, job responsibilities and future use of PICPs for the different demographic characteristics of the participant.

For the qualitative design, the data analysis by the researcher summarized the characteristics that seemed to be associated with the perceptions and feelings towards PICP use in construction. They were discussed with full acknowledgement of the limitations of informal qualitative research; in particular, the tendency of known outcomes to color recollections of preceding circumstances. The open ended questions on the survey instrument were assessed by using content analysis in order to determine the similarities and themes between the sentence structures and words used by the respondents. Contemporary qualitative software used in the analysis of the open-ended questions was the NVivo 8® data analysis program. By using the qualitative computer software the researcher was able to increase the validity of the research because the implementation of the computer software decreased the chances of obtaining biased results. The results from the program were summarized and conclusions were developed based on the frequency of responses using the codes assigned during the codification process to similar responses.

Summary

Chapter 3 discussed the research methodology employed in this current study. The research methodology employed was that of a mixed methodology which consisted of both a quantitative and qualitative method. By using both a quantitative and qualitative approach the researcher was able to triangulate the results in order to obtain more evidence for or against the research questions and hypotheses (Tashakkori & Teddlie, 1998). The proposed statistical analyses, which included descriptive statistics, ANOVA and Pearson's correlation coefficients were presented. A description of the qualitative data analysis was also presented and NVivo or other similar qualitative computer program will be used to assess the responses to the open-ended questions. Also presented in this chapter were the appropriateness of the mixed methodology research design, the proposed research questions, the participants, sample size, instrumentation and data collection procedures for this study. In Chapter 4, the results for this study were presented.

Chapter IV

FINDINGS

Introduction

This study sought to determine whether PICPs and porous pavements are worthy of being considered as a replacement for standard impervious pavements, what barriers existed for using PICPs, whether storm water professionals were properly informed to select this type of pavement, and whether PICPs could be used in the future. The questionnaire involved a series of yes/no questions or written responses, so a regression is not appropriate in this situation.

Thirteen hypotheses were addressed. Questions that were based on written responses only were omitted for the quantitative part of the analysis Seven hypotheses were judged to be yes/no in nature, and these were the hypotheses selected for this part of the analysis:

Hypothesis statement 1:

> Permeable pavements are not given 100% credit as pervious surfaces (based on question 11). Are permeable pavements given full 100% credit as pervious surfaces?

Hypothesis statement 2:

> The hydrologic effects of permeable pavements are not given credit in obtaining storm water management approval (based on question 12). Are the hydrologic effects of permeable pavements given credit in obtaining stormwater management approval?

Hypothesis statement 3:

Storm water management was not a significant aspect of the collegiate course of study of the respondents (based on question 18). To what degree was stormwater management a significant aspect of your studies (degree program) in the past?

Hypothesis statement 4:

The respondent’s experience with PCIPs is very limited (based on questions 15 and 16). Have you ever seen a permeable interlocking concrete pavement job during installation?

Hypothesis statement 5:

Storm water management professionals are unaware of the benefits of permeable pavers as they relate to pollutant and water runoff management (based on question 14). Are you aware of the benefits of using permeable pavers as they relate to stormwater runoff and pollutant management?

Hypothesis statement 6:

Storm water management officials do not have the authority to approve or decline the use of PICPs (based on question 21). Do you have the authority to approve or decline approval of storm drainage designs on the above mentioned types of projects?

Hypothesis statement 11:

Storm water management professionals think PICPs are cost prohibitive (based on question 36). Have you ever heard that PICPs are cost prohibitive?

Data Cleansing

Since there were no questions asking to assess the relationship between how long a storm water management professional worked in the field and their answers to these questions, only the answers to the questions were recoded. For each yes/no/undecided question, yes was coded as 1, no was coded as 0, and undecided was coded as 0.5. Occasionally, some participants circled more than one answer for some of the questions. If the participant answered yes and no, it was coded as 0.5. If the participant answered yes and undecided, it was coded as 0.75. If the participant answered no and undecided, it was coded as 0.25, as those were the averages of the selected answers.

Analysis of Data

Quantitative analysis

In order to answer the quantitative research questions, a simple comparison of the mean values for each question was used, where 0 would mean all survey participants answered no, and 1 would mean all survey participants answered yes. Since the average for all the yes/no/undecided questions theoretically should have been 0.5, if opinion was exactly evenly split on an issue, to indicate that people tended to answer no on a question, it was necessary to set the null hypothesis to $x = 0.5$ and the alternative hypothesis to $x < 0.5$. If the actual ratio was statistically significant and less than 0.5, that would support the stated hypothesis.

To indicate that people tended to answer yes on a question, the null hypothesis was set to x = 0.5 and the alternative hypothesis to x > 0.5, to see if it was statistically significant at a ratio greater than 0.5. A table of descriptive statistics for this study is found in Table 4.1

	N	Minimum	Maximum	Mean	Std. Deviation
Q11	83	0	1	.2319	.41830
Q12	115	0	1	.6283	.40739
Q14	114	0	1	.9167	.26538
Q15	114	0	1	.7632	.40028
Q16	114	0	1	.6360	.47053
Q18	102	1	5	2.7108	1.21752
Q21	102	0	1	.6176	.47291
Q36	100	0	1	.6600	.45438
Valid N	74				

Table 4.1 Descriptive statistics

Table 4.2 provides results for simple t-tests for the six yes/no/undecided questions. A t-test was preferred to a proportion-type test because basic proportion-type tests require two distinct answers, but some participants selected, and some selected multiple answers. All these t-tests were significant, meaning none of the proportions was equal to 0.5.

	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Q11	-5.839	82	.000	-.26807	-.3594	-.1767
Q12	3.376	114	.001	.12826	.0530	.2035
Q14	16.764	113	.000	.41667	.3674	.4659
Q15	7.019	113	.000	.26316	.1889	.3374
Q16	3.085	113	.003	.13596	.0487	.2233
Q21	2.512	101	.014	.11765	.0248	.2105
Q36	3.521	99	.001	.16000	.0698	.2502

Table 4.2 T-tests for yes/no/undecided variables

H1. Permeable pavements are not given 100% credit as pervious surfaces. A yes answer to question 11 (Are permeable pavements given full 100% credit as pervious surfaces?) would indicate that permeable pavements are given 100% credit compared to other surfaces, but since the t statistic was clearly less than 0, resulting in an average score for that question of less than .5, the answer according to the water professionals was no.

H2. The hydrologic effects of permeable pavements are not given credit in obtaining storm water management approval. Since question 12 (Are the hydrologic effects of permeable pavements given credit in obtaining stormwater management approval?) actually states the inverse of this, H2 is rejected.

H4. The respondent's experience with PICPs is very limited. The definition of very limited is by its very nature vague, but "very limited" would imply answers of no to both questions 15 and 16, (Have you ever seen a completed permeable interlocking concrete pavement job in person? Have you ever seen a permeable interlocking concrete pavement job during installation?) as one with very limited experience with PICPs would likely have never seen such a pavement job in person or during installation. However, questions 15 and 16 have a t-statistic that is easily greater than 0, implying that in fact most participants answered yes to these questions. This would lead to a rejection of H4, implying that most people had some experience with PICPs.

H5. Storm water management professionals are unaware of the benefits of permeable pavers as they relate to pollutant and water runoff management. Again, question 14 (Are you aware of the benefits of using permeable pavers as they relate to stormwater runoff and pollutant management?) had a significant t-statistic. This again indicates a yes answer and leads to a rejection of H5.

H6. Storm water management officials do not have the authority to approve or decline the use of PICPs. Like the other hypotheses except H1, this too is rejected because it was statistically significant, meaning the storm water professionals do have the authority.

H11. Storm water management professionals think PICPs are cost prohibitive. Unlike most of the previous questions, this hypothesis is not inverted and precisely matches question 36. (Have you ever heard that PICPs are cost prohibitive?) Stormwater professionals have heard that PICPs are cost prohibitive as they definitely tended to answer yes on that question, failing to reject the null hypothesis.

The other hypothesis H3 was based on question 18, (To what degree was stormwater management a significant aspect of your studies (degree program) in the past?) which used a 5 point Likert type scale. None was scored as 1, very little was scored as 2, moderate mention was scored as 3, significant was scored as 4, and major focus was scored as 5. Based on the t-test in Table 4.3, where the test statistic was set equal to 4, because that was the value for significance, and H3 is testing whether storm water management was a significant, not moderate, part of college coursework. Clearly, for most, it was not, resulting in failure to reject the null hypothesis.

	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Q18	-10.694	101	.000	-1.28922	-1.5284	-1.0501

Table 4.3 T-tests for scale variable

Quantitative Conclusion

Although PICPs are not the preferred type of pavement, it is clear that water professionals do approve of them. Indeed, despite their limited education on the topic, stormwater management professionals are familiar with the benefits of this type of pavement over the traditional pavement. The study's hypotheses tended to posit that

PCIPs were not well-utilized because storm water professionals were not familiar with them, but the findings with regard to H11 indicates that PICP's cost is the real issue.

Qualitative Analysis

The qualitative data to be analyzed were the participant responses to the open ended questions of the survey instrument. The data were analyzed using content analysis methods to determine commonalities or themes among texts. In this case, the texts were the survey results. Thematic analysis was used to determine themes existing in the data. The process involved examining all the data and separating it into relevant groups. After the data were clustered, themes were developed based on the most commonly occurring constituents throughout the data. For this study, the survey responses were examined and grouped according to content. After clustering occurred, the most prevalent responses were used in the determination of emergent themes regarding participants' views of PICPs.

The six remaining research hypotheses (those not examined by quantitative analyses) that were addressed by qualitative methods were:

Hypothesis statement 7:

> Storm water management professionals indicate the objection to the use of PICPs in their jurisdiction is based upon uninformed state officials and their acceptance of research data as fact.

Hypothesis statement 8:

> Storm water management professionals find their colleagues as generally opposed to the use of PCIPs.

Hypothesis statement 9:

Storm water management professionals find a need for better communication between state officials and researchers when making policy about the use of PICPs.

Hypothesis statement 10:

Storm water management professionals would encourage workshops and presentations to become better informed about PICPs.

Hypothesis statement 12:

Storm water management professionals think the sanctioned use of PICPs is a political issue and given little opportunity for consideration from a useful or beneficial approach.

Hypothesis statement 13:

Storm water management professionals would like to encourage the use of PICPs in their jurisdiction.

Emergent Themes

Ten relevant themes were formed from the open-ended survey question responses. These themes correspond to the open-ended survey questions. These questions were: (1) What is your job title?; (2) What do you think are the biggest potential incentives you foresee in the application of PICPs in your jurisdiction?; (3) What do you think are the biggest potential deterrents you foresee in the application of PICPs in your jurisdiction?; (4) What do you think are the biggest contributors to consideration of using permeable interlocking concrete pavers from the point of view of the municipal government?; (5) What do you find to be the biggest nuisance in the review of projects with permeable interlocking concrete pavers?; (6) If you approved the project with PICPs, what

information was provided by the applicant that convinced you to issue an approval?; (7) If you declined approval, what were the reasons for your decision?; (8) What are your suggestions to improve training people in your position about permeable pavers?;
(9) What is your perception of the cost difference between permeable pavers and conventional paving methods?; and (10) What is your perception of the greatest benefit(s) to the municipality or jurisdiction in allowing permeable interlocking concrete pavement instead of impervious paving material?

Participants' survey responses were grouped according to the topic addressed, then emergent themes were identified. The 10 emergent themes were: (1) Storm water administrators, project managers, and environmental engineers are the most common job titles amongst the surveyed professionals; (2) Less runoff and perviousness are the biggest incentives to use PICPs; (3) Cost and potential maintenance are the main deterrents to PICP use; (4) Reduced runoff, cost, and potential maintenance are the perceived main considerations of municipal government with regards to PICP implementation; (5) Bad design or installation, lack of knowledge, and inadequate maintenance are the biggest nuisances in reviewing PICP projects; (6) Schematic details are important for PICP project approval; (7) Projects are declined for various reasons; (8) Workshops are beneficial in training regarding permeable pavers; (9) Storm water management professionals perceive the cost of permeable pavers as greater than that of conventional paving methods; (10) Storm water management professionals perceive reduced runoff as the greatest benefit to jurisdictions allowing PICPs.

Theme 1:

Storm water administrators, project managers, and environmental engineers are the most common job titles amongst the surveyed professionals.

The first theme was derived after examining the participants' responses with regard to their job titles. A total of 36 job titles were mentioned by responders. See Table 4.4 for a breakdown of the job titles and the frequency of each.

Job Titles	# of participants to offer this response	% of participants to answer this question with this response
Storm water administrator/engineer	25	28.57%
project engineer/manager	17	23.80%
environmental coordinator/engineer	11	11.11%
program manager/watershed program manager	7	5.30%
water resources engineer	7	5.30%
civil engineer	6	4.55%
director/assistant director of public works	6	4.55%
water quality compliance specialist	5	3.79%
environmental health specialist	5	3.79%
total	132	

Table 4.4

Table 4.4 with a complete listing of job titles can be found in Appendix G.

Twelve job titles were mentioned by three or more participants. These were (a) storm water administrator/engineer (25 of 132 participants, or 18.94%), (b) project engineer/manager (17 participants, 12.88%), (c) environmental coordinator/engineer (11 participants, 8.33%), (d) program manager/watershed program manager (7 participants, 5.3%), (e) water resources engineer (7 participants, 5.3%), (f) civil engineer (6 participants, 4.55%), (g) director or assistant director of public works (6 participants, 4.55%), (h) water quality compliance specialist (5 participants, 3.79%), (i) environmental health specialist (5 participants, 3.79%), (j) city engineer (4 participants, 3.03%), (k) general engineer (4 participants, 3.03%), and (l) director of planning and land development (3 participants, 2.44%). The remaining 24 job titles were held by either one or two participants each.

Theme 2:

Less runoff and perviousness are the biggest incentives to the use if PICPs.

The second theme was derived after examining the participants' responses with regard to the incentives of PICP use. A total of 12 incentives were mentioned by responders. See Table 4.5 for a breakdown of the incentives and the frequency of each. Half of these incentives were mentioned by more than two participants each. These were (a) less runoff (18 participants, or 28.57%), (b) perviousness/impervious credit (15 participants, 23.80%), (c) aesthetics (7 participants, 11.11%), (d) increased infiltration (6 participants, 9.52%), (e) cost savings (5 participants, 8.09%), and (f) space savings (4 participants, 6.34%).

Incentives	# of participants to offer this response	% of participants to answer this question with this response
less runoff	18	28.57%
pervious/impervious credit	15	23.80%
aesthetics	7	11.11%
increased infiltration	6	9.52%
cost savings	5	8.09%
space savings	4	6.34%
better environmental protection	2	3.17%
matching pre/post runoff	1	1.58%
easy to install	1	1.58%
usable surface	1	1.58%
allow development	1	1.58%
met 3-5% EIA requirements	1	1.58%
ease of maintenance	1	1.58%
total	63	

Table 4.5 Incentives of PICP use

Theme 3:

Cost and potential maintenance are the main deterrents to PICP use.

The third theme was derived after examining the participants' responses with regard to the deterrents of PICP use. A total of nine deterrents were mentioned by responders. See Table 4.6 for a breakdown of the deterrents and the frequency of each. Possible deterrents mentioned by more than two participants were (a) cost (42 participants or 40.77%), (b) maintenance (34 participants, 33.00%), (c) soil conditions (9 participants, 8.74%), (d) lack of knowledge (6.90%), (e) winter problems (4 participants, 3.88%), and (f) clogging (3 participants, 2.91%).

Deterrents	# of participants to offer this response	% of participants to answer this question with this response
cost	42	40.77%
maintenance	34	33.00%
soil conditions	9	8.74%
lack of knowledge/unfamiliarity	7	6.80%
winter problems	4	3.88%
clogging	3	2.91%
high groundwater	2	1.94%
women in heels	1	0.97%
durability	1	0.97%
total	103	

Table 4.6 Deterrents of PICP use

Theme 4:

Reduced runoff, cost, and potential maintenance are the perceived main considerations of municipal government with regards to PICP implementation.

The fourth theme was derived after examining the participants' responses with regard to the perceived considerations of municipal governments with regard to PICP implementation. A total of 14 considerations were mentioned by responders. See Table 4.7 for a breakdown of the considerations and the frequency of each. Considerations which received mention by more than two participants were (a) reduced runoff (13 participants, or 21.31%), (b) cost (10 participants, 16.39%), (c) maintenance (9 participants, 14.75%), (d) aesthetics (5 participants, 8.19%), (e) soil type (5 participants, 8.19%), (f) questions regarding the effectiveness of PICPs (4 participants, 6.56%), (g) the pervious nature of PICPs (4 participants, 6.56%), and (h) NPDES requirements (3 participants, 4.92%).

Considerations	# of participants to offer this response	% of participants to answer this question with this response
reduce runoff	13	21.31%
cost	10	16.39%
maintenance	9	14.75%
attractiveness/aesthetics	5	8.19%
soil type	5	8.19%
questions	4	6.56%
perviousness	4	6.56%
NPDES requirements/codes	3	4.92%
"green"	2	1.64%
receive credit	2	1.64%
total	61	

Table 4.7 Municipal government considerations of PICP

Table 4.7 with a complete listing of considerations can be found in Appendix H.

Theme 5:

Bad design or installation, lack of knowledge, and inadequate maintenance are the biggest nuisances in reviewing PICP projects.

The fifth theme was derived after examining participants' responses with regard to nuisances in reviewing PICP projects. A total of nine nuisances were mentioned by responders. See Table 4.8 for a breakdown of the nuisances and the frequency of each. Nuisances that were mentioned by more than two participants were (a) bad design and installation (7 participants, 24.14%), (b) lack of knowledge (6 participants, 20.69%), (c) lack of maintenance (6 participants, 20.69%), (d) lack of industry wide standards (3 participants, 10.34%), and (e) cost (3 participants, 10.34%).

Nuisances		# of participants to offer this response	% of participants to answer this question with this response
bad design and installation		7	24.14%
lack of knowledge/questions		6	20.69%
lack of maintenance		6	20.69%
no industry wide standards		3	10.34%
cost		3	10.34%
negativity		1	3.45%
	total	29	

Table 4.8 Nuisances in reviewing PICP projects

Table 4.8 with a complete listing of nuisances can be found in Appendix I.

Theme 6:

Schematic details are important for PICP project approval.

The sixth theme was derived after examining the participants' responses with regard to factors which convinced them to make PICP project approvals. A total of seven invariant constituents were included. See Table 4.9 for a breakdown of the factors and the frequency of each. Only one factor received mention by multiple participants—the presentation of schematic details (4 participants, 5.48%). It should be noted that most participants did not respond to this question or indicated that the question did not apply to them. Other factors receiving mention (one participant each) were (a) groundwater mounding analysis, (b) drainage calculations, (c) load bearing capabilities, (d) soil permeability rates, and (e) maintenance agreement.

Convincing factors	# of participants to offer this response	% of participants to answer this question with this response
n/a	64	87.67%
schematic details	4	5.48%
groundwater mounding analysis	1	1.36%
drainage calculations	1	1.36%
load bearing capabilities	1	1.36%
soil permeable rates	1	1.36%
maintenance agreement	1	1.36%
total	73	

Table 4.9 Convincing factors of PICP approval

Theme 7:

Projects are declined for various reasons.

The seventh theme was derived after examining the participants' responses with regard to factors that caused them to decline PICP projects. A total of nine invariant constituents were included. See Table 4.10 for a breakdown of the factors and the frequency of each. Similarly to the sixth theme, the majority of respondents either did not answer this question or indicated that it did not apply to them. Only eight factors influencing reviewers' decisions to decline projects were mentioned, and each was only mentioned once. These factors were (a) ordinance not allowing for impervious credit, (b) other alternatives available, (c) failed to meet BMP manual requirements, (d) wanted 100% credit, (e) not considered pervious, (f) not enough detail, (g) poor design, and (h) not enough information.

Declination factors	# of participants to offer this response	% of participants to answer this question with this response
n/a or not declined	72	90.00%
ordinance not allowing for impervious credit	1	1.25%
other alternatives available	1	1.25%
failed to meet BMP manual requirements	1	1.25%
wanted 100% credit	1	1.25%
not considered pervious	1	1.25%
Total	80	

Table 4.10 Factors causing project declination

Table 4.10 with a complete listing of declination factors can be found in Appendix J.

Theme 8:

Workshops are beneficial in training regarding permeable pavers.

The eighth theme was derived after examining the participants' responses with regard to their suggestions for training. A total of 11 suggestions were made by responders. See Table 4.11 for a breakdown of the suggestions and the frequency of each. Four suggestions received mention by more than two participants. These were (a) workshops or seminars (11 participants, 26.83%), (b) hands on training or demonstration (7 participants, 17.07%), (c) info on design, installation, and maintenance (7 participants, 17.07%), and (d) teaching science or technology (5 participants, 12.19%).

Training suggestions	# of participants to offer this response	% of participants to answer this question with this response
workshops/seminars	11	26.83%
hands on training/demonstrations	7	17.07%
info on design, installation, and maintenance	7	17.07%
teach science/technology	5	12.19%
more training	2	4.88%
webinars	2	4.88%
local training	2	4.88%
presentation at quarterly meetings	2	4.88%
total	41	

Table 4.11 Suggestions for the training of stormwater management professionals

Table 4.11 with a complete listing of training suggestions can be found in Appendix K.

Theme 9:

Storm water management professionals perceive the cost of permeable pavers as greater than that of conventional paving methods.

The ninth theme was derived after examining the participants' responses with regard to their perception of the difference in cost between PICPs and other methods. A total of five invariant constituents were included. See Table 4.12 for a breakdown of the perceptions and the frequency of each. Only two participants (2.82%) believed PICPs were cheaper to implement than other methods and four (5.63%) felt the costs were similar. Forty-three participants (60.56%) simply indicated that they believed the costs were higher for PICPs. Thirteen (18.31%) felt increased costs were attributed to extra labor, long term maintenance, or installation, while nine participants (12.68%) felt that although costs were higher initially, the benefits of PICPs outweigh the costs over time.

Perceived cost differences	# of participants to offer this response	% of participants to answer this question with this response
higher	43	60.56%
extra labor, long term maintenance, installation	13	18.31%
initially more expensive, but pay off	9	12.68%
similar	4	5.63%
cheaper	2	2.82%
total	71	

Table 4.12 Perceived levels of cost differences between PICPs and conventional methods

Theme 10:

Storm water management professionals perceive reduced runoff as the greatest benefit to jurisdictions allowing PICPs.

The tenth theme was derived after examining the invariant constituents that were the participants' responses with regard to the perceived greatest benefits to jurisdictions allowing PICPs. A total of 10 benefits were mentioned by responders. See Table 4.13 for a breakdown of the benefits and the frequency of each. Eight of these benefits received mention by more than two participants. These benefits were (a) less runoff (23 participants, or 33.33%), (b) improved infiltration (11 participants, 15.94%), (c) groundwater recharge (10 participants, 14.49%), (d) water quality and quantity (5 participants, 7.25%), (e) less impervious (5 participants, 7.25%), (f) pollutant removal (5 participants, 7.25%), (g) environmental benefits (4 participants, 5.80%), and (h) aesthetics (3 participants, 4.35%).

Perceived greatest benefits	# of participants to offer this response	% of participants to answer this question with this response
less runoff	23	33.33%
improved infiltration	11	15.94%
groundwater recharge and wetlands	10	14.49%
water quality and quantity	5	7.25%
less impervious	5	7.25%
pollutant removal	5	7.25%
total	69	

Table 4.13 Perceived greatest benefits of PICP implementation

Table 4.13 with a complete listing of perceived benefits can be found in Appendix L.

Qualitative Conclusion

A content analysis was conducted on the data collected from the participants' open-ended responses to particular survey questions. This qualitative analysis resulted in the discovery of 10 emergent themes related to storm water management professionals' perceptions of PICP implementation. These themes were related to research hypothesis statements seven, eight, nine, ten, twelve, and thirteen. It should be noted that although 132 participants completed surveys, many of the themes were based on a substantially lower number of responses due to many participants providing no response to several questions.

Summary

Quantitative and qualitative analyses were conducted on data collected via a survey of storm water management professionals. These data and their analyses helped to address the 13 research hypotheses presented in Chapter 1. The quantitative analysis found that although PICPs were not the dominant type of pavement, it was clear that was water professionals did approve of them. The real concern for use of PICPs was based on cost issues. The qualitative data found similar findings. Ten themes, based on the responses to open-ended questions, were formulated regarding storm water management professionals' perceptions of PICP implementation.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

"Today new technologies such as permeable block pavements are available for solving stormwater problems economically. Scientific research and on-the-ground experience support their reliability and performance. The biggest remaining hurdle to their widespread implementation is not cost, or availability, or performance. It is a human hurdle: municipal engineering staff who must approve construction plans before a development can be built" (B.K. Ferguson, personal communication, August 31, 2007). There are numerous studies and existing data regarding the performance of PICPs as stormwater management tools. However, until this investigation, no studies have sought information from decision makers in the stormwater management field in an effort to (1) determine what factors limit the use of permeable pavers and, (2) determine why permeable pavers, as a new technology, are seemingly not readily accepted as a stormwater management tool.

Conclusions

This study aimed to examine what should be done to allow stormwater management professionals to make a better informed decision about the possibility of using PICPs as a method of stormwater management. This study used qualitative and quantitative analyses. Seven of the 13 research hypotheses were answered using quantitative methods, the remaining six were addressed using qualitative methods.

Quantitative conclusions

Although PICPs are not the dominate type of pavement, it is clear that stormwater management professionals approve of them. Indeed, despite their limited education on the topic, they are familiar with the benefits of this type of pavement over the traditional pervious pavement. The study's hypotheses tended to posit that PICPs were not well-utilized because stormwater professionals were not familiar with them, but from the t-test with regard to H11 it appears that permeable paver cost is the real issue. Other quantitative conclusions included information that determined permeable pavements are not given 100% credit as pervious surfaces, the hydrologic effects of permeable pavements are given credit in obtaining stormwater management approval, most professionals had some experience with PICPs, and stormwater management professionals are aware of the benefits of using permeable pavers. Additional data indicated stormwater management professionals have the authority to approve the use of PICPs, and, because they have heard PICPs are cost prohibitive, they tend to select/approve other methods of surfacing, even though they may prefer PICPs.

Qualitative conclusions

A content analysis was conducted on the data collected from the participants' open-ended responses to particular survey questions. This qualitative analysis resulted in the discovery of 10 emergent themes related to stormwater management professionals' perceptions of PICP implementation. These themes were related to research hypothesis statements seven, eight, nine, ten, twelve, and thirteen.

The ten emergent themes included:

(1) Stormwater administrators, project managers, and environmental engineers are the most common job titles amongst the surveyed professionals. A total of 36 different job titles were recorded in this survey

(2) Less runoff and pervious/impervious credit are the biggest incentives to the use of PICPs. Top three results: less runoff, pervious/impervious credit, aesthetics

(3) Cost and potential maintenance are the main deterrents to PICP use.

Top three results: cost, maintenance, soil conditions

(4) Reduced runoff, cost, and potential maintenance are the perceived main considerations of municipal government with regards to PICP implementation.

(5) Bad design or installation, lack of knowledge, and inadequate maintenance are the biggest nuisances in reviewing PICP projects.

(6) Schematic details are important for PICP project approval.

(7) Projects are declined for various reasons, including ordinances not allowing for impervious credits, other alternatives being available, BMP manual requirements not being met, 100% credit was not realized, not considered pervious, not enough detail, poor design, and not enough information.

(8) Workshops are beneficial in training regarding permeable pavers.

Top three results: workshops/seminars, hands-on training, info on design and installation

(9) Stormwater management professionals perceive the cost of permeable pavers as greater than that of conventional paving methods.

(10) Stormwater management professionals perceive reduced runoff as the greatest benefit to jurisdictions allowing PICPs

Recommendations

General Recommendations to overcome barriers to the acceptance of PICPs

This section presents six major recommendations that, if adopted, may help stormwater management professionals feel more comfortable using PICPs as a stormwater management tool and improve the environment as well.

(1) Paver manufacturers, the construction industry, and industry specific organizations such as I.C.P.I. should continue to promote education through innovative workshops, seminars, and hands-on activities to architects, designers, engineers, and decision makers in the stormwater management profession. Emphasis should be placed upon the eco-friendly, cost effective approach PICPs offer as a surfacing alternative. Stormwater management is a major concern of state and national governments so alternative methodologies to conventional curb, gutter, and drain systems would be welcomed.

(2) Colleges and Universities could make the study of PICPs in architect, design, landscaping, engineering, and construction degree programs an integral part of the curriculum. In addition to installation procedures, usability, and technical aspects of PICPs, long term costs and benefits should be analyzed.

(3) Municipalities, governing bodies, and contractors could employ consultants to review plans for proposed projects in search of opportunities to use PICPs in lieu of traditional stormwater management tools. Comparative studies concerning initial and long term costs should be implemented.

(4) Environmental concern organizations should promote the use of PICPs as a “green” alternative to conventional paving.

(5) Residential home builders could promote the use of PICPs in development properties.

(6) Contractors, developers, landscapers, paver installers, and landscape architects could work together to improve the quality of design and installation of all aspect of their respective work responsibilities, especially in the new technology field of permeable pavers.

Findings from this study indicated the cost and maintenance issues associated with PICPs served as the greatest barrier to their use. It would be helpful for industry professionals to work with stormwater management professionals and educate them as to the initial and long-term cost of PICPs, as well as provide information concerning the maintenance issues that are unique to PICPs.

Recommendations for future research

The following recommendations are proposed for further research on the use of PICPs based upon the findings from this study:

(1) Conduct a similar study using a larger sample size. Improvements to this study could include increasing the number of respondents from all levels of stormwater management professionals, including both engineers and non-engineers.

(2) Conduct additional case studies to compare costs of PICPs to traditional surfacing methods from design, to installation, to maintenance.

(3) Conduct research on possible ways of reducing costs in manufacturing, transportation, and installation.

(4) To avoid exclusive attention to commercial projects, it would be important to conduct research in the areas of residential use of PICPs.

All of these recommendations could serve as an impetus to raise awareness of PICPs and encourage their use through established and well documented data concerning costs of all aspects of PICPs. It is through additional research that the stormwater management industry may move beyond the newness of this technology and the misinformation of prohibitive costs.

Appendix A – Survey Questionnaire

SECTION I	**<u>GENERAL WORKPLACE AND JOB RESPONSIBILITIES</u>**

Fill in the blank with the most appropriate response(s):

1. Job title:____

2. How long have you worked in this field? __________________________

3. How long have you worked in your current jurisdiction? ________________________

4. What are your specific responsibilities?

____

____

5. Circle one employment status: FULL TIME PART TIME VOLUNTEER

6. Circle your highest level of formal education:

HS Diploma Associates Degree Bachelors Masters Doctorate

7. Your primary job relates to which one(s) of the following: (circle all that apply)

stormwater management environment erosion planning pollution

8. You are employed at what jurisdiction level: (circle all that apply)

city county state other ______________________________

SECTION II	**<u>JUSRISDICTION</u>**

<u>Circle the most appropriate response: Y = Yes N = No U = Uncertain</u>

<u>Fill in the blank to complete each Y, N, U question.</u>

9. Is your municipality subject to NPDES Phase II requirements? Y N U

Briefly explain how this affects your job requirements:

____

____

____

10. Does your municipality regulate impervious surface cover in addition to stormwater? discharge? Y N U

If yes, for how long: < 1 year 1-2 years 3-5 years 5+ years

11. Are permeable pavements given full 100% credit as pervious surfaces?

Y N U

If yes, what does this mean to your job responsibility?

____

____

____

12. Are the hydrologic effects of permeable pavements given credit in obtaining stormwater management approval? Y N U

If yes, what specific hydrologic effects are considered?

____

____

____

SECTION III EXPERIENCE WITH PICPs

13. Have you ever heard of PICPs: Permeable Interlocking Concrete Pavement?

Y N U

14. Are you aware of the benefits of using permeable pavers as they relate to stormwater runoff and pollutant management? Y N U

If yes , how so?

____

____

____

15. Have you ever seen a completed permeable interlocking concrete pavement job in person? Y N U

16. Have you ever seen a permeable interlocking concrete pavement job during installation?

Y N U

17. How many times have you seen permeable interlocking concrete pavers used in communities such as those in your jurisdiction?

never 1-2 times 3-5 times 5 + times

SECTION IV
JOB RESPONSIBILITIES AND STORMWATER MANAGEMENT

18. To what degree was stormwater management a significant aspect of your studies (degree program) in the past?

none very little moderate mention significant major focus

19. Do you review project plans for compliance to municipal drainage requirements, ordinances, and design standards? Y N U

20. If yes to the question above, circle what types of projects you have reviewed or have the authority to review.

Residential Commercial Municipal Institutional Industrial

21. Do you have the authority to approve or decline approval of storm drainage designs on the above mentioned types of projects? Y N U

22. Have you approved or declined approval of a project with permeable interlocking concrete pavers? Y N U

23. If you approved the project with PICPs, what information was provided by the applicant that convinced you to issue an approval?

____

____

____

If you declined approval, what were the reasons for your decision?

____

____

____

SECTION V PERCEPTIONS OF PICPs

25. What do you think are the biggest potential incentives you foresee in the application of PICPs in your jurisdiction? Why?

____

____

____

26. What do you think are the biggest potential deterrents you foresee in the application of PICPs in your jurisdiction? Why?

____

____

____

____

27. What do you think are the biggest contributors to successful installation of permeable interlocking concrete pavers from the point of view of the municipal government?

____

____

____

28. Can you characterize the view of elected officials toward permeable pavement?

____

____

____

29. How do your colleagues at your workplace generally view permeable interlocking concrete pavers?

____

____

____

30. What do you find to be the biggest nuisance in the review of projects with permeable interlocking concrete pavers?

____

____

____

SECTION VI	**FUTURE USE OF PICPs AND TRAINING**

31. How might you improve the permeable interlocking concrete paving system based upon your jurisdiction's needs?

____

____

____

32. Have you ever attended a seminar or workshop on permeable interlocking concrete pavement? (Circle one answer)   Y   N   U

If so, please locate the year and location.____

33. What are your suggestions to improve training people in your position about permeable pavers?

____

____

____

34. Do you feel a need to attend a permeable interlocking concrete pavement seminar or workshop on design, construction, and maintenance?   Y   N   U

35. Have you ever heard that PICP simply does not work well? Y N U

If yes, please explain:

____

____

____

36. Have you ever heard that PICPs are cost prohibitive? Y N U

If yes, please explain:

____

____

____

37. What is your perception of the cost difference between permeable pavers and conventional paving methods?

____

____

____

38. What is your perception of the greatest benefit(s) to the municipality or jurisdiction in allowing permeable interlocking concrete pavement instead of impervious paving material?

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39. What is your perception of the greatest obstacles in allowing permeable interlocking concrete pavement instead of impervious paving material?

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Appendix B - Cover Letter for Survey Questionnaire

Dear Colleague,

I am a doctoral candidate in Education at Clemson University in Clemson, South Carolina. Currently, I am conducting dissertation research entitled: "Investigation of the cogency of using permeable interlocking concrete pavers and storm water management professionals' perception of PICPs as a storm water management option."

The objectives of this study are:

- Investigate the cogency of using permeable interlocking concrete pavers.
- Investigate the benefits of using porous pavement, specifically PICPs, as a storm water management tool.
- Investigate the perception storm water management (decision makers) have concerning PICPs as a storm water management tool.
- Determine the reasons why or why not PICPs are being used as a storm water management tool.
- Examine what storm water management professionals need to better understand PICPs and what they want to learn about PICPs to help them become better decision makers when using this new technology as a storm water management tool.
- Determine if in fact storm water management professionals are even being offered PICPs as an option in controlling storm water runoff and pollution.

Your opinion on PICPs is crucial to the success of my research. The survey is very straightforward and will take less than 15 minutes. I **will be very** appreciative of your professional involvement if you complete the survey at your earliest convenience and/or before October 17, 2008). The participation is completely voluntary, but again ***I need your help*** to accomplish this effort. If you have any questions about your rights as a research participant, please contact the Clemson University Office of Research Compliance at 864.656.6460.

Please be assured that your response will be held in strictest confidence. Under no circumstances will your organization's information be available to any individual or other organization. If you have any questions about this survey, please feel free to contact Keith I. Poole (pookeith@bellsouth.net) (828-329-2776) or Dr. William Paige at 864.656.7647. I thank you in advance for your support.

Respectfully requested,
Keith I. Poole
Doctoral Candidate
Clemson University

Appendix C – IRB Compliance Approval Letter

Dear Dr. Paige,

The Chair of the Clemson University Institutional Review Board (IRB) validated the protocol identified above using Exempt review procedures and a determination was made on **August 18, 2008,** that the proposed activities involving human participants qualify as Exempt from continuing review under **Category B2,** based on the Federal Regulations (45 CFR 46). You may begin this study.

Please remember that no change in this research protocol can be initiated without prior review by the IRB. Any unanticipated problems involving risks to subjects, complications, and/or any adverse events must be reported to the Office of Research Compliance (ORC) immediately. You are requested to notify the ORC when your study is completed or terminated.

Attached are documents developed by Clemson University regarding the responsibilities of Principal Investigators and Research Team Members. Please be sure these are distributed to all appropriate parties.

Good luck with your study and please feel free to contact us if you have any questions. Please use the IRB number and title in all communications regarding this study.

Sincerely,
Becca

Rebecca L. Alley, J.D.
IRB Coordinator
Office of Research Compliance
Clemson University
223 Brackett Hall
Clemson, SC 29634-5704
ralley@clemson.edu
Office Phone: 864-656-0636
Fax: 864-656-4475

Appendix D - Information Letter to Survey Participant
October 7, 2008
Dear Colleague,

You are invited to participate in a doctorate dissertation research conducted by Dr. William Paige and Keith I. Poole in the education department at Clemson University. The research is entitled: "Investigation of the cogency of using permeable interlocking concrete pavers and storm water management professionals' perception of PICPs as a storm water management option."

The objectives of this study are:

- Investigate the cogency of using permeable interlocking concrete pavers.
- Investigate the benefits of using porous pavement, specifically PICPs, as a storm water management tool.
- Investigate the perception storm water management (decision makers) have concerning PICPs as a storm water management tool.
- Determine the reasons why or why not PICPs are being used as a storm water management tool.
- Examine what storm water management professionals need to better understand PICPs and what they want to learn about PICPs to help them become better decision makers when using this new technology as a storm water management tool.
- Determine if in fact storm water management professionals are even being offered PICPs as an option in controlling storm water runoff and pollution.

The time estimated to complete this survey is less than fifteen minutes. There are no known risks associated with this research. However, your participation is crucial to the success of this research effort. As an expression of my gratitude for your participation you will be provided a summary of the study's findings.

Please be assured that your response will be held in strictest confidence. Under no circumstances will result specific to your organization or yourself be made available to any individual or organization. Your participation in this research study is completely voluntary. You may withdraw your consent to participate at any time. However, your input is critical to this study.

If you have any questions or concerns about this study, please feel free to contact Dr. William Paige at Clemson University at 864.656.7674. If you have any questions or concerns about your right as a research participant, please contract the Clemson University Office of Research Compliance at 864.656.6460.

Thanks in advance for your participation in this research effort.

Respectfully requested,
Keith I. Poole Clemson University
Appendix E – Email correspondence from Dr. Bruce Ferguson

From: Bruce Ferguson <bfergus@uga.edu>
Subject: Re: GREETINGS
Date: August 31, 2007 9:06:12 AM EDT
To: keith i poole <incredibleimpact@bellsouth.net>
Keith:
Today new technologies such as permeable block pavements are available for solving stormwater problems economically. Scientific research and on-the-ground experience support their reliability and performance. The biggest remaining hurdle to their widespread implementation is not cost, or availability, or performance. It is a human hurdle: municipal engineering staff who must approve construction plans before a development can be built. My own experience and that of designers I have worked with in conferences and design offices confirm the existence and importance of this distinctive hurdle. A common response from such staff, upon being presented with a new technology, is that they are unfamiliar with it, and therefore they cannot approve it in their jurisdiction. Another common response is that they will allow it to be built, but they will not give credit for its stormwater effects, and the developer must install all the conventional features alongside it; in this case the new technology would be a wasted expense, and so the developer chooses not to implement it. It would be possible to combat such refusal in court, using scientific evidence to prove the technologies' reliability and performance. However to do so would delay a project for years and cost hundreds of thousands of dollars, so as far as I know that approach has never been taken. Instead, developers comply with the regulators' decisions; their projects proceed without the benefits of the new technologies, and the technologies remain underutilized. The municipal staff who present this hurdle work within legal, bureaucratic, and technical constraints. To break through this hurdle is not a legislative problem. It is rather a problem of communication or education. The approval of scientifically proven new technologies has to come from the desks of those staff. It will take very informed and able communication to break through in a planned, consistent manner. Knowledge about how to do so will have real value for both the economy and the environment.
- Bruce Ferguson

Appendix F – Email correspondence from Mr. David Smith

From: David Smith [mailto:dsmith@bostrom.com]
Sent: Monday, September 17, 2007 2:23 PM
To: incredibleimpact@bellsouth.net
Subject: Research needs

Dear Keith:

This email is to confirm a need for research into the institutional barriers to municipalities accepting permeable interlocking concrete pavement or PICP. Recent developments in legislation at the federal and state levels, has encouraged the use of infiltration-based best management practices (BMPs) for decreasing runoff and water pollution. This legislation has benefited the PICP, porous asphalt and pervious concrete pavement industries.

As one who works with municipal agencies, resistance to PICP can be expressed by municipal agencies responsible for development, engineering, and stormwater management. This is certainly a normal reaction to any new product or system. However, the PICP industry which I represent takes great interest in your proposed dissertation. We realize there are numerous factors that might discourage PICP use. However, the industry would benefit from knowing which issues are the most important, and, from the agency perspective, would like to know how to address their questions in order gain further PICP use..

We trust that your proposed research will examine some of these questions and provide user/agency recommendations to move forward.

Please don’t hesitate to contact me should you need further information.

Regards,
David

David R. Smith, Technical Director
Interlocking Concrete Pavement Institute
1444 I Street NW - Suite 700
Washington, DC 20005-6542 USA
Tel: 202-712-9036
Fax: 202-408-0285
www.icpi.org

Appendix G -Table 4.4: Survey respondents' job titles

Job titles	# of participants to offer this response	% of participants to offer this response
Storm water administrator/engineer	25	18.94%
project engineer/manager	17	12.88%
environmental coordinator/engineer	11	8.33%
program manager/watershed program manager	7	5.30%
water resources engineer	7	5.30%
civil engineer	6	4.55%
director/assistant director of public works	6	4.55%
water quality compliance specialist	5	3.79%
environmental health specialist	5	3.79%
city engineer	4	3.03%
engineer	4	3.03%
director of planning and land development	3	2.44%
hydrologist	2	1.52%
surface water	2	1.52%
urban conversationalist	2	1.52%
environmental tech	2	1.52%
engineering operations manager	2	1.52%
code enforcement	2	1.52%
storm water outreach and education coordinator	2	1.52%
planner	2	1.52%

Job titles	# of participants to offer this response	% of participants to offer this response
regulatory engineer	1	0.76%
principal	1	0.76%
watershed restoration coordinator	1	0.76%
phase II liaison	1	0.76%
product manager	1	0.76%
inspector	1	0.76%
director of commercial sales	1	0.76%
extension agent	1	0.76%
public works engineer	1	0.76%
county engineer	1	0.76%
supervisor	1	0.76%
landscape architect	1	0.76%
engineering inspector	1	0.76%
associate	1	0.76%
storm water program analyst	1	0.76%
president of engineering firm	1	0.76%

Appendix H - Table 4.7: Municipal government considerations of PICP

Considerations	# of participants to offer this response	% of participants to offer this response
reduce runoff	13	9.85%
cost	10	7.58%
maintenance	9	6.82%
attractiveness/aesthetics	5	3.79%
soil type	5	3.79%
questions	4	3.03%
perviousness	4	3.03%
NPDES requirements/codes	3	2.27%
"green"	2	1.52%
receive credit	2	1.52%
observing successful applications	1	0.76%
durability	1	0.76%
strength	1	0.76%
reduce detention needs	1	0.76%

Appendix I - Table 4.8: Nuisances in reviewing PICP projects

Nuisances	# of participants to offer this response	% of participants to offer this response
bad design and installation	7	5.30%
lack of knowledge/questions	6	4.55%
lack of maintenance	6	4.55%
no industry wide standards	3	2.27%
cost	3	2.27%
negativity	1	0.76%
acceptance	1	0.76%
overestimated water quality and quantity control	1	0.76%
soil permeability	1	0.76%

Appendix J - Table 4.10: Factors causing project declination

Declination factors	# of participants to offer this response	% of participants to offer this response
n/a or not declined	72	54.55%
ordinance not allowing for impervious credit	1	0.76%
other alternatives available	1	0.76%
failed to meet BMP manual requirements	1	0.76%
wanted 100% credit	1	0.76%
not considered pervious	1	0.76%
not enough detail	1	0.76%
poor design	1	0.76%
not enough information	1	0.76%

Appendix K - Table 4.11: Suggestions for the training of storm water management professionals

Training suggestions	# of participants to offer this response	% of participants to offer this response
workshops/seminars	11	8.33%
hands on training/demonstrations	7	5.30%
info on design, installation, and maintenance	7	5.30%
teach science/technology	5	3.79%
more training	2	1.52%
webinars	2	1.52%
local training	2	1.52%
presentation at quarterly meetings	2	1.52%
more exposure	1	0.76%
more info	1	0.76%
pilot projects	1	0.76%

Appendix L - Table 4.13: Perceived greatest benefits of PICP implementation

Perceived greatest benefits	# of participants to offer this response	% of participants to offer this response
less runoff	23	17.42%
improved infiltration	11	8.33%
groundwater recharge and wetlands	10	7.58%
water quality and quantity	5	3.79%
less impervious	5	3.79%
pollutant removal	5	3.79%
environmental	4	3.03%
aesthetics	3	2.27%
maintenance	2	1.52%
less clogging	1	0.76%

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