STORMWATER BEST MANAGEMENT PRACTICES IN URBAN DEVELOPMENT

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE OF BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

2009

To my parents, thank you for all your support through all the years

ACKNOWLEDGMENTS

I thank my parents for their continued support throughout my years of education. I would also like to think my fiancée for keeping me on track while finishing my research. To Dr. Ries, thank you for giving me direction in my research.

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LIST OF ABBREVIATIONS

CND	Canadian dollar
LCC	Life-cycle cost
BMP	Best management practice
sf	Square feet
cuft	Cubic feet
cy	Cubic yard
lcy	Loose cubic yard
lf	Linear foot
N/A	Not applicable

Abstract of Thesis Presented to the Graduate School
of the University of Florida **{** TC ABSTRACT **}**in Partial Fulfillment of the
Requirements for the Degree of Master of Science of Building Construction

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May 2009

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Major: Building Construction

As the urban environment grows, the need for comprehensive stormwater management grows with it. The conventional method or best management practice (BMP), has been the use of wet or dry retention basins. However, these basins rob developers of useful land. As the value of land increases, the need for alternative BMPs is inevitable. The use of various BMPs such as underground retention vaults, permeable pavement, and green roofs have become more popular in the last few decades. These alternatives can be used to reduce or eliminate a conventional retention pond allowing owners increased use of their valuable land; not to mention the added environmental benefits many provide.

This study selected a pair of retail properties, along with an apartment complex, to determine what would be the most economical BMP over the life of each project. Case 1 is a fresh produce retail market in Titusville, FL. The area has periods of high peak rainfalls requiring extensive stormwater retention efforts to mitigate flooding in the area. Case 2 is a large pharmacy chain located in Gainesville, FL. Case 3 is an apartment complex also in Gainesville, FL in a highly urbanized area of the city. For each case study, life-cycle costs (LCC) and benefits were determined for each alternative. Developers of the projects were

interviewed to obtain their opinion on alternative BMPs, why a specific BMP was chosen, and if life-cycle costing was even a consideration in the decision making process.

In Case 1, where stormwater policies require a very high volume of retention, the value of alternative methods becomes even greater. The use of alternative BMPs would provide the site with an additional 43% of parking spaces. These extra spaces would allow the company to accommodate a higher volume of customers, which would facilitate growth. In particular, the use of permeable pavement would be the most beneficial, with initial cost similar to conventional methods, and low maintenance required over the life of the system.

In Case 2, the project was considerably larger and the volume of water retention needed was low. These factors dissipated the cost effectiveness of alternative BMPs. The area had less than optimal parking available but the added cost over the life of the project proved detrimental to the implementation of alternate methods.

Case 3 employed underground stormwater storage in the original development. The development did not offer vehicle parking for its residents. Because there was no parking area, the largest section for improvement was the structure itself. Green roofing allows for an additional 2,422 square feet of residential space, but the additional initial cost eliminates any life-cycle benefit over the test period. With the added complications that green roofs can bring, the best option is underground storage.

Developers of the projects, along with several other developers in the state, were surveyed. The survey showed that the developers had a good understanding of alternative BMPs, but the use of life-cycle costing is seldom considered in the decision-making process for most of their projects. Although alternative BMPs are used in dense urban areas, the lack of LCC analysis results in low implementation in suburban areas.

CHAPTER 1
INTRODUCTION

Statement of the Problem

As cities grow, the need for stormwater control grows. The building of parking lots, asphalt roads, roofs, and other impermeable surfaces cause water to travel from where it falls to areas where it can be accepted by the surrounding soil. As the total area of these impermeable surfaces grow, the accumulation of water increases, causing flooding and water pollution. Over the last half-century, methods have been put into place to try to control stormwater runoff in new development. These methods have commonly been retention ditches and ponds, which rob developments of useful land. Older cities throughout the United States have little or no runoff systems and must be retrofitted to manage stormwater flow.

As more and more developments are constructed, available land becomes a premium. In many renovation projects and crowded cities, extra land for water retention is often unavailable. Retention methods that do not rely on setting land aside are needed now more than ever. The aim of this study is to analyze the cost effectiveness of some of these methods in various forms of development. Specific case studies of projects in the central Florida area are analyzed to determine the best method of water retention for each case. The developers of the projects will also be surveyed to gain insight on the decision-making process used while choosing a BMP.

Objective of the Study

This research will test the hypothesis that alternate BMPs are being progressively accepted and implemented by developers in urban environments. Additionally, the research will investigate the role that life-cycle costing plays in the decision making of developers regarding stormwater BMPs.

Some BMPs are relatively new, especially in the United States. These innovative methods can be effective even if they are not as time-tested as conventional methods. Possible problems of alternative methods include permeable pavements and underground pipes becoming clogged and a green roof dying, reducing their effectiveness to retain and disperse water slowly. Conventional retention ponds use gravity to fill depressions; a method as old as the oceans. Every method has certainly has limitations. Where newer methods may be less dependable, conventional methods require a large area of land.

Research Methodology

Initial costs and the life-cycle costs of each alternative will be analyzed, including maintaining BMPs, in order to determine their value. The potential benefits of each alternative will be determined and included in the LCC analysis. The economic benefit of each BMP will be discounted to the date of construction. Initial costs, annual costs, and benefits will be analyzed to determine life-cycle costs. A full LCC analysis over a study period of 20 years will be conducted for each case study for each alternative: conventional ponds, underground vaults, green roofs, and permeable pavement. A sensitivity analysis will be conducted to establish how variations on various aspects of the LCC analysis will affect the overall LCC in each case. A survey will be conducted to gain insight on developer's opinions regarding stormwater BMPs.

Hypothesis Statement

The null hypothesis is that the application of one of the alternative BMPs would result in a lower 20 year LCC than the conventional method would. The alternate hypothesis is that the conventional method results in the lowest life-cycle cost and other methods do not result in a net benefit. The focus of this study is to determine what the most economical BMP would be in each case study, and why the method used was chosen. This research will also help establish whether or not alternative BMPs should be pushed for wide-spread use in new developments throughout central Florida. As developers encounter new stormwater problems, they need an array of options to discover which one best suit their needs. This study aims to determine what the most economical method would be in various situations.

CHAPTER 2
LITERATURE REVIEW

Introduction

Many areas of the United States have replaced forest and other natural areas with substantial urbanization. The resulting impervious areas of urbanization and development, such as rooftops and parking areas, do not allow water to absorb into the land. Rainfall in such areas accumulates much faster than pervious areas. As the water drains from these areas, it gathers pollutants and heat. Natural waterways are the eventual receptacles for the pollutants and heat acquired from urban runoff. These can result in a variety of ecological detriments including overgrowth of fungus and algae, killing of local species, and contamination of drinking water. Along with ecological damage, stormwater from developed areas contributes to high volumes of water deposited into waterways. This causes increased erosion and amplifies the potential for flooding. Due to these factors, developments require the use of impoundments to control stormwater runoff (Thrasher, 1985). Controlling in this sense is both lessening the volume and the rate of runoff, along with removing pollutants at their source.

Up to 90 percent of the water that falls in urbanized regions ends up becoming runoff (Snoonian, 2001). Of course, this depends on the percentage of the area that is pervious or impervious. The higher the percentage of impervious surfaces, the more rainwater becomes runoff. Two basic approaches are taken to help alleviate the runoff problem: building areas to collect runoff or lowering the amount of impervious surfaces. These methods can certainly be used in conjunction whenever possible. Conventional retention ponds receive water from these runoff areas and allow it to be slowly emptied into existing systems. Conventional retention ponds are also permeable surfaces themselves. Their two basic purposes are to collect runoff and to provide permeable surfaces. Retention ponds reduce peak outflows of stormwater, allowing runoff to be transported to existing bodies of water through smaller pathways. Localized retention efforts slow the release of stormwater runoff, and greatly reduce the need for large civil projects. By implementing localized stormwater regulations, municipalities are putting the burden of stormwater runoff from new developments on to the developers themselves. This approach saves tax dollars by reducing the need for large-scale infrastructure spending by government agencies (Chambers and Tottle, 1980).

Of course, every site is unique and requires various amounts of stormwater retention. For example, in some areas if a site adds no new impervious areas then no additional stormwater retainage that must be added. Projects that do require new retention may require anywhere from 0.05 to 2.10 cubic feet of stormwater retention for every square foot of non-pervious area. The amount of water required various based on several factors: amount of pervious area, frequency of storms, intensity of storms, peak outflow rate, potential pollutants from the site, permeability of the site, and size of watershed site is draining into (Clar et al, 2004).

There are a number of methods that can be used to achieve the goal of stormwater retention. As mentioned previously, the conventional method is to use basins to retain stormwater. However, alternative stormwater BMPs have been developed over the years that accomplish the same goals of a conventional pond. Many of these BMPs require less land, or even no land to be devoted solely to the purpose of retaining stormwater. By taking stormwater retention underground or on rooftops, alternative BMPs allow for greater land use of a given site. Although many unconventional methods are more costly than typical means, the use of the additional land can result in increased income which could add value to a project.

Conventional Ponds

The conventional approach to managing stormwater runoff is to remove the water from the development areas as quickly as possible. Water is diverted from the building to retention ponds or canals and taken away from the site. Channeling water away from buildings lowers the structure's risk of flooding. This is due to the long-standing attitude that water in developed areas is unwanted, unless possessing aesthetic or recreational value (Williams, 2003). This attitude was developed because stormwater is often seen as a destructive force within the construction industry. On the contrary, collected stormwater can serve many useful purposes if handled wisely. For the most part, stormwater should be kept out of the overall building envelope. However, rainwater harvesters can be installed on buildings to collect rainwater and use it for non-potable uses such as flushing toilets and watering plants. Also, stormwater can be retained on the site and used to keep moisture in surrounding landscaping.

In most developments, the site is steeply graded away from buildings to quickly remove water from structures to high-flow storm sewers. However, this approach pays no regard to peak flow during storms, the transfer of pollutants, or total volume reduction (Coffman et al., 1998, 2000). Alternative methods, such as underground retention areas and green roofs, allow for a much slower release of the water into the storm drain system or ground. These methods keep peak volumes down and pollutants filtered at the source. Permeable pavement allows water to naturally permeate to aquifers help to reduce the total volume of stormwater released into stormwater systems. Stormwater control methods, such as conventional retention ponds, also allow for a large percentage of the water retained to be evaporated back into the sky, again reducing total stormwater volume. Local regulations, in areas such as Alachua County, Florida, require developers to make efforts to mitigate peak flows (Alachua County Board of County Commissioners [ACBCC], 2002).

Stormwater retention areas require a large area of land to be effective. The lowest point of a retention pond must be at a greater elevation than the outlet to the conduit used to drain it. This basic principle of retention ponds keeps their overall depth minimal. These shallow depths mean their overall footprint must be large in order to create the volume needed. Conventional retention ponds require large areas of land and are also easy to build and maintain. This ease of use makes the conventional pond a popular choice in areas where land is more abundant. For years, engineers have employed this simple method for water retention. However, this practice cannot be implemented in urban areas, where land is at a premium. Therefore, it is clear that alternative retention methods must be used (Roberts, 1996).

Permeable Pavement

Pavement makes up the largest percentage of impermeable surfaces throughout the United States. A way to help alleviate this problem is a technology that is over 2,000 years old. Permeable pavement was first used by early civilizations in the form of cobblestone roads (Green, 2007). Cobblestone roads are created by fitting stones together to create a hard surface that is easy to travel. The voids between the stones allow water to penetrate the system. While conventional pavements result in runoff, the porous nature of permeable pavements allows stormwater to seep through the pavements and penetrate the earth below (FHWA, undated). This effectively reduces the area for runoff, allowing for the use of other BMPs or smaller wet ponds to detain the remaining runoff created by buildings.

Though the use of permeable paving has continued, the process of creating permeable roadways has changed. Stones are still an acceptable method of permeable pavement but a number of alternatives have been created. Brick pavers can also be used by leaving small gaps between the pavers. The cutting-edge of permeable pavement technology however, lies in pervious concrete paving. Permeable concrete contains a system of interconnected voids running throughout. The voids surround the large aggregate within the concrete mix. Pervious concrete paving is applied much in the way conventional paving is, but with the addition of an aggregate sub-base to allow drainage. Its implementation has been tested during use in recent American highway projects (Hossain and Scofield, 1991). One test determined that average infiltration rates for permeable concrete over one year were 2.5 inches per hour. An acceptable infiltration rate is 1.5 inches per hour. This study was conducted at a rest area for Interstate 4 in central Florida. The site was primarily used by trucks and tractor trailers. Even in an area with heavy traffic, the system showed no visual signs of wear and continued to perform above design requirements (Wanielista and Chopra, 2007).

Although there are obvious benefits to this method, permeable concrete can cost between 15 and 25 percent more than conventional concrete paving. The cost of the aggregate drainage layer also increases the total cost of the system. Higher initial cost can be offset by the removal of curbs and underground storm pipes, which are no longer needed to channel runoff. Even though material costs are higher, by removing curbing on a project, the use of pervious concrete may result in net savings (Field et al., 1982). Another additional cost of permeable pavement is the costs of maintenance. Without proper maintenance, permeable surfaces may become clogged, greatly reducing their drainage capacity (Tan et al, 2003). Small debris from high traffic areas, along with grease and oil, may clog the system and greatly reduce its drainage capacity. These effects can be resolved by vacuuming the area. (Stormwater/Nonpoint Source Management Section, 1988). Sand however, will not clog the system. This is because sand will not be compressed and naturally contains voids allowing continued drainage.

Green Roofing

In addition to paving, the second non-permeable area of a project is usually the building itself. The best way to negate the runoff of these areas is with a green roof. A green roof is a roof which holds vegetation growing in several inches of growing medium. The vegetation naturally collects both sunlight and water. The growing medium needed for vegetated green roofs acts as an excellent insulator as well as an area for stormwater to collect. By retaining moisture within the soil, water is slowly released into the attached stormwater system. The growing medium and vegetation on a green roof act in conjunction to reduce stormwater runoff and lower energy cost (Getter, 2006). As water is retained by the green roof soil or in the plant vegetation, most of the moisture is evaporated back into the atmosphere. Close to half of stormwater that falls on a green roof can be recycled in this manner, cutting down on municipal stormwater holding areas (Kolb, 2004). One study shows that if six percent of the buildings in a town like Toronto, Canada, were to employ green roofing systems, it would be the equivalent of constructing a 60 million dollar (CND) water service pipe (Peck, 2005). Obviously, this option could greatly reduce the infrastructure cost of a new development.

One example of a successful use of a green roofing system is The American Society of Landscape Architects' in Washington, D.C. The facility has installed a green roof, to lower energy cost and set an example for the nation (ENR, 2007). This 3,000 square foot roof reduced runoff by 27,500 gallons of stormwater per hour during peak storms. Along with the added aesthetic and environmental benefits, the green roof can be used as an educational tool.

Some of the obvious costs associated with conventional roofs, such as insulation and shingles can be eliminated. This removal could make a green roof a more viable option. Another benefit is the reduction of the heat island effect, although it may be difficult to quantify by developers and owners. The heat island effect is a phenomenon in which heat is accumulated and retained in urban areas. Therefore, it raises ambient temperatures and increases cooling costs. While many conventional roofing systems increase the heat island effect, green roofs can be used to decrease it. But, no matter how beneficial, the complex nature of a green roof may scare away some potential users. While quite popular in areas of Europe and Canada, green roofs are slow to catch on in the United States (Parrott, 2007).

Although green roofs can be an exceptional method of stormwater retention, there are several drawbacks. Designing a project with a green roof can be complicated. The additional load of soil, vegetation, and retained water must be considered when designing such a building. Another concern in the implementation of a green roof is owner preferences and prejudices. Some owners may welcome the additional green space and stormwater benefits. However, some owners may see a green roof as an area requiring extra maintenance, as well as an area that could be prone to problems such as leaking. The need for additional structural support, along with the costs of green roofing materials, can make the green roof option an expensive one.

Underground Water Vault

Another consideration for water retention in urban areas is the use of an underground water vault. Underground water retention vaults can be built by using creating concrete caverns, specifically designed boxes, perforated polyethylene pipes, or steel pipes. Every method of underground vault has benefits and detriments, which depend on site specific conditions. Underground vaults work in the same way as an above-ground retention pond, by holding the collected stormwater until the surrounding soil can accept it (Metropolitan Council, 2003). Though they use a similar method to conventional ponds, underground vaults allow for courtyards, paving, or light structures to be constructed above them. By enabling construction above, underground vaults can greatly increase the amount of useable land on a project site. Underground vaults are popular in densely populated areas because they allow for nearly full use of the land.

Since they are constructed underground, vaults can be designed to allow for natural filtration through mediums such as sand or peat to remove small particles. Source particulate filtration is a key objective of any stormwater BMP (Roberts, 1996). In addition to reducing peak flows and filtering source pollutants, underground vaults can also help lower the overall volume of potential runoff. Reducing total volume is accomplished by allowing water within the vault to absorb into the surrounding soil, which reduces the total water outflow into municipal systems.

One downfall of underground vaults is their need for regular maintenance. By filtering particles out of the runoff that flows through, the system gradually accumulates sediment and debris. Once they become clogged, underground vaults lose their ability to affectively retain and filter the amount of runoff required. Some extreme cases even require cleaning once a week to maintain efficiency (Northern Virginia District Planning Commission, 1992). Also, initial costs for underground vaults are often higher than conventional methods. Higher costs are incurred because, essentially, a conventional pond must be excavated and fitted with the required drainage connections. The system supporting the ground above must then be installed, drainage pipes must be mounted to direct stormwater to the vault, and access points must be put in place for monitoring and maintenance. The high requirement for maintenance, along with high initial costs, can make underground vaults non-feasible in many applications (Wiegand et al., 1986). Even though underground vaults have their downfalls, their similarity to conventional methods makes them a popular choice.

Industry Trends

There are ever-growing options for developers when considering BMPs. This growth is due to a competitive commercial market that is emerging to meet the demands of urban areas. As the use of alternative BMPs grows, the familiarity and costs of such methods decrease.

Companies that create products used in unconventional BMPs are becoming more and more popular. As the industry grows, there is an increased force pushing for the adoption of new BMPs. These companies are pushing their products by promoting their benefits, and lowering associated material costs (Fassman, 2006).

Some municipalities and developers are looking into the future when considering stormwater BMPs. Land values will continue to increase, driving up the actual cost of conventional ponds. As the parties responsible for implementing alternative BMPs focus more on the future, they increasingly see the benefit of such methods. Another driving factor for using BMPs is the federally mandated National Pollutant Elimination Program, which will require a separate stormwater discharge permit system. Requiring a permit guarantees that the EPA will review every new development. The EPA will review the potential chemicals, sediment and other pollutants that could adversely affect water quality if runoff is untreated and/or released into natural waterways (Urbonas, 1995). This legislation requires more and more developers to adopt unconventional BMPs.

Although many municipalities see the benefit of alternative stormwater BMPs, and push for their use, there are several that do not recognize the benefit. Several Florida counties, including Broward County, will not allow a project’s use of permeable paving to lower the total site retention volume needed. Such counties claim to recognize the benefit of such methods however, since many alternative methods require regular maintenance to remain effective, these districts do not recognize their use and require a more time tested method. Some districts however, will allow the use of alternative stormwater BMPs if the operator of the facility demonstrates the capability to maintain the methods employed (DeWiest and Livingston, 2002).

By requiring an operating permit from two to five years, stormwater authorities are allowed to inspect the site regular to monitor the effectiveness of maintenance, and BMP performance.

The growth of the green building movement, along with increased life-cycle cost analysis will highlight the benefits of many alternative BMPs. The construction industry has been notorious for slowly adopting emerging technologies. New methods will only be accepted is if they are easy-to-use, durable, well-known, and most importantly, economically beneficial. Because some BMPs are scarcely used by American contractors, Virginia Tech University is developing software to help choose the best BMP for a given application (Landers, 2007). This program will promote alternative BMP awareness and educate contractors who are unfamiliar with these techniques. Software like this will promote the adoption of BMPs in urban North America by streamlining the decision-making process.

CHAPTER 3
RESEARCH METHODOLOGY

Introduction

The primary aim of this thesis is to determine the stormwater management method with the greatest economical benefit in specific case studies. Also, this research will determine the reasons specific stormwater practices are used on projects. The methodology of this research was determined by the purpose and hypothesis set out in Chapter 1. The following steps were taken to obtain the necessary information:

- An extensive literature review was conducted on material relating to stormwater BMPs and their use in development projects.
- The data needed for the analysis was identified.
- Projects that may lend themselves to the use of alternative BMPs were selected.
- The information needed from each case study was collected.
- The information collected from the case studies was analyzed to determine life-cycle costs.
- The life-cycle costs were analyzed to select the BMP with the highest economical benefit.
- A sensitivity analysis was conducted to gauge the effect variations on determining factors would have on life-cycle cost.
- The data was analyzed to draw the necessary conclusions on the use of BMPs in these case studies.
- A developer survey was created to obtain opinions and outlooks of developers.
- The survey was administered to the developers selected.
- Surveys were collected and analyzed; conclusions were drawn from the results.

Case Study Analysis

Case Study Criteria

First, the criteria for perspective case studies were determined. The project should be an income-producing property so the benefits could be easily identified with a monetary value. The site must be in an area with a population density of 200 people per square mile or more. Site improvement information, along with the information on the income-producing ability of the project is acquired to perform the necessary analysis.

Project Selection

Case 1 is a retail fresh produce market near downtown Titusville, FL. The project was essentially a new development with little remnants of previous construction. In 1998, a new building and new parking area were constructed on site. The site had been built with a conventional retention pond to the specifications shown in Table 3-1. The total area of the lot, along with the amount of permeable and non-permeable surfaces, is presented in the table. The table also includes the retention pond volume with various ratios of interest about the property.

The case study selected to assist in the analysis of Case 1 in Titusville, FL was the company’s sister store in New Smyrna Beach, FL, entitled Case 1.1. Case 1.1 is approximately 32 miles away from Case 1, in an area with similar population density and population demographics. The project in Case 1.1 consisted of the renovation of two historical buildings, along with the addition of necessary equipment for conducting business as a fresh produce market. Because the site had been previously developed and used for retail purposes, there was already ample room for parking. Since there were no new impervious areas placed, there was no need for new water retention. This project was selected solely to analyze the income-producing potential for Case 1. The project had been built with the specifications shown in Table 3-2.

Another project selected for case study, was a large retail pharmacy chain in Gainesville, FL, referred to as Case 2. The project is a new development in a heavily populated portion of urban Gainesville. The site sits at the intersection of two busy streets, so access from both streets is necessary. The site had previous development that had to be demolished before construction could begin. Since the entire site was completely cleared, the area was considered new development. As a new development, the project could not use the stormwater retention already in place and must abide by all current stormwater regulations. The project utilized a conventional retention pond to meet local stormwater policies. Case 2 was built to the site specifications shown in Table 3-3.

Case 3 is an apartment complex located two blocks from the University of Florida in Gainesville, FL. The proximity to the school makes the land very desirable, and thus very valuable. Most of the surrounding properties are similar rental properties built three to five stories tall. In Case 3, the project is three stories tall and employs an underground vault as its stormwater BMP. There is a central grassy common area constructed on top of the underground vault. City parking available near the location allows tenants to park on the street and free up valuable space on the site. Because there is no parking area, the only pavement areas on site are sidewalks. Case 3 was built to the site specifications shown in Table 3-4.

Information Collected

The necessary information for the analysis of each case study was obtained. For all cases, the information collected included: land area, permeable area, retention pond volume, non-permeable area, amount of concrete curbing, and available parking. This site information was needed to estimate initial and maintenance costs for each alternative stormwater BMP. The use of any BMP not utilized in the original site plan changed the site specifications.

In addition to cost estimates, the site plans for Case 1 were used to calculate the additional parking that could be created by using each stormwater method. Annual income totals for both Case 1 and Case 1.1 were collected dating back to 1999. The income totals were acquired to compare growth between the two sites and determine the benefits of additional parking. The information needed for this analysis was made available by the owner of both projects.

For Case 2 in Gainesville, FL, the plans were acquired and the needed information was calculated. By using this information, estimates could be made for initial and life-cycle costs on the project. As in Case 1, site plans were also needed to determine the amount of additional parking that could be added by using each stormwater method. The annual value of additional parking was obtained from the project owner. Increased income could be generated by the property with the addition of more parking.

The plans for Case 3 were obtained and pertinent figures were also calculated. The effect of the various BMPs included the addition and removal of available rental space. Other areas of the site were impacted by the changing building footprint. These changes were determined so initial cost, LCC, and potential income could be calculated. To generate potential gross income, data on rental rates, vacancy rates, efficiency ratios, and square footage of the building were collected or determined as needed.

To conduct a sensitivity analysis, data was collected to determine a conceivable range of both land value and discount rate. These figures were estimated as accurately as possible, but must be broad enough to draw conclusions. The purpose of the sensitivity analysis is to provide additional information to assist in the decision making process while choosing a stormwater BMP.

Analysis Performed

Initial cost estimates

Once the data was collected, estimates of the initial cost were developed. These estimates were made for the construction of each alternative for each case study. The BMPs selected for this analysis were green roofs, permeable pavement, underground vaults, and conventional retention ponds. “RSMeans building construction cost data 2007” was used to estimate all construction expenses. By using a common source for determining costs, comparisons could be made between the construction methods utilized, and the other methods analyzed in this study.

It was assumed that project costs not associated with the BMP methods selected would remain the same. This assumption allowed only the systems in study to be estimated and compared. The estimated costs were discounted to 1998 for Case 1, and 2008 for Case 2 and Case 3. The location factor given by “RSMeans building construction cost data 2007” for each project location was also used to further modify estimated costs.

For each case study, the use of each BMP affected the site plan differently. Each BMP would change the water retention requirements, thusly changing the size of the retention volume needed. As a result, some BMPs allowed for more parking or more building to be built. Each of these changes had to be calculated to estimate initial costs.

Life-cycle cost estimates

The life-cycle cost software NIST BLCC 5.3 was used to estimate total life-cycle cost. Annually recurring costs, such as maintenance, were included as positive numbers. Annual benefits, such as income generated from additional parking or rental area, were included as negative numbers. Negative numbers in the model indicate a negative cash outflow, or savings. By using the available data, estimates of LCC were determined for each alternative.

Potential income variations of each alternative were projected to support the LCC analysis. The use of actual income data from the different projects were used to project potential income using alternative BMPs. Income projections were developed for Case 1 by comparing the income totals, growth, and available parking of both Case 1 and Case 1.1. The developer of Case 2 gave the annual value of additional parking for projects of this type. By using the values given, the economic benefit of additional parking could be calculated for each BMP. Income projections for Case 3 were determined by calculating the possible rent generated using each alternative.

The economic benefit of each BMP, if any, was determined. If using an alternative BMP would create a cost benefit over the 20 year life of the building, then the null hypothesis set in the introduction is true. If the most economical option over the life of the building is to use a conventional retention pond, then the alternative hypothesis is true.

Sensitivity analysis

To better assist in the decision making process, a sensitivity analysis was conducted to determine the effect factor variation would have on the total LCC of the stormwater methods selected. The discount rate used during the research was altered to a conceivable minimum and maximum to study how the value of money over the life of the project would change the present value of each BMP studied. This research also predicted how the present value of the LCC of each method could vary by studying a range of projected benefits. If land values were to increase or decrease, the value of the benefits would change accordingly. By studying the impact that variation of each factor would have on the selected methods, the sensitivity to each factor could be determined.

Developer Survey

A structured interview of the project developers, along with other local developers, was created and administered to obtain opinions on various areas of BMP application. Developers were selected from a list of the top developers in the central Florida area. The subjects of the study were required to give consent to the survey before the survey could be sent. A total of 40 surveys were sent to the developers from this list, and three sent to the developers of the case studies. Of the 40 surveys distributed, a total of 18 responses were returned and collected for analysis. All responses were given a numerical code to keep the names of respondents confidential.

The survey used a five point Likert scale, ranging from negative two to positive two, to rate responses. Open ended and multiple choice questions were summarized for analysis. The survey included questions designed to gauge developer’s familiarity with each BMP and frequency of use for each BMP. Also, inquiries were aimed at determining the difficulty of drawing permits for each BMP. Questions were used to gain insight on the use of LCC within the industry in the application of stormwater BMPs. Developers were also asked to express their preference between various forms of stormwater management. A copy of the entire survey, as given to the developers in the study, is in Appendix A.

An analysis of the survey was done by calculating the mean of each numerical response. A mean with a positive value represents a positive position on the proposed subject matter. Conversely, a mean with a negative value represents a negative position on the subject. Questions focusing on similar information were placed into groups to assist in developing conclusions. Questions with no numerical value, such as preferences, were analyzed to determine which response was chosen the most and least frequently. Complete results of this analysis are presented in Chapter 4. The study has also drawn conclusions from the data, and this information is presented in Chapter 5.

Limitations

This research was done to gain insight on a specific area of both the construction industry and construction projects in general. By focusing the study, the results of the research cannot be applied to general industry practices. The study was conducted in a specific region; therefore, conclusions can only be applied to developers in the area, not the entire population of developers. If a national or international study had been conducted, then conclusions could be made for a much broader arena. The survey portion of the study only focused on land developers. To gain a full industry perspective on stormwater BMPs, a survey must be administered to members of all disciplines.

Every case study has specific criteria that must be considered during analysis. Because every project is unique, a standardized method cannot be established to account for all variations.

What applies to the projects selected, will not apply to every project. The method of income for projects varies from one to the next requiring various factors to consider in a LCC analysis. For example, a housing development in a suburban area will have different needs and requirements than that of one in an urban environment. An apartment complex will generate income by having long-term residents, as opposed to a retail store that requires a large number of short term customers. Project owners value different things, so certain conditions will appeal to some more than others.

During the development of estimates and projections, certain assumptions had to be made; this is yet another limitation to this study. These were made as accurately as possible to minimize the margin of error. Accurate assumptions keep all estimates and projections as realistic as possible. Assumptions also had to be made to create models designed to predict cost 20 years into the future. The use of "RSMeans building construction cost data 2007" as a source of project costs can also result in variations from actual figures. "RSMeans building construction cost data 2007" determines its cost data by taking averages of generalized work across the country. Though location and time factors were applied to modify costs closer to reality, estimates are never 100 percent accurate.

Table 3-1. Case 1 Site specifications

	Quantity	Units
Total land area:	18924	Sf
Non-permeable Area:	10797	Sf
Permeable area	8127	Sf
Pavement area:	7053	Sf
Permeable % of Total:	43	%
Non-permeable % of Total:	57	%
Pond 1 volume	11608	Cuft
Pond 2 volume	2230	Cuft
Total pond volume:	13838	Cuft
Pond volume/Non-permeable area:	1.28	Cuft/Sf

Table 3-2. Case 1.1 Site specifications

	Quantity	Units
Total land area:	34,907	Sf
Non-permeable area:	21,490	Sf
Permeable area	13,417	Sf
Pavement area:	18,762	Sf
Permeable % of total:	38	%
Non-permeable % of total:	62	%
Total pond volume:	-	Cuft
Pond volume/non-permeable area:	-	Cuft/Sf

Table 3-3. Case 2 Site specifications

	Quantity	Units
Total land area	65557	Sf
Permeable area	45890	Sf
Non-permeable area	19667	Sf
Pavement area	31400	Sf
Pond area	14000	Sf
Permeable % of total	30	%
Non-permeable % of total	70	%
Total pond volume	7012	Cuft
Pond volume/non-permeable area	0.15	Cuft/Sf

Table 3-4. Case 3 Site specifications

	Quantity	Units
Total land area	12,003	Sf
Permeable area	8,029	Sf
Non-permeable area	3,974	Sf
Pavement area	1,706	Sf
Pond area		Sf
Permeable % of total	33	%
Non-permeable % of total	67	%
Total pond volume	3,768	Cuft
Pond volume/non-permeable area	0.47	Cuft/Sf

CHAPTER 4
RESULTS

Case 1 Life-cycle Cost

Using the plans for Case 1 and “RSMeans building construction cost data 2007”, estimates of initial costs were created for each BMP method: conventional, underground vault, permeable pavement, and green roof. The estimates are summarized in Table 4-1 with the available number of parking spots each alternative allows. The values used to determine LCC are presented in Appendix B and detailed estimates for each of the methods are presented in Appendices E-H.

Case 1.1 did not undergo the full analysis as there were no stormwater retention requirements for the project. Case 1.1 was only used as a comparison to generate income projections for its sister store in Titusville. Case 1.1 has 35 parking spots compared to 12 in Case 1. This larger parking area allowed for greater growth. Income totals for each store were obtained and discounted back to 1998 dollar amounts. Annual growth and average growth for each store were determined and presented in Table 4-2 through 4-3 and Figures 4-1 through 4-2. Growth projections were applied to the income totals of Case 1 to estimate the annual benefit that additional parking would provide. These income totals and projections are shown in Table 4-4 through 4-5.

The growth analysis of Case 1 shows that there was little to no actual growth over the study period. Annual income totals were 0.0037 percent lower than if the initial annual income had grown by inflation alone. This stalemate demonstrates that Case 1 had maximized its growth potential with the current parking scenario. If additional parking had been available, growth could have continued on a rate similar to its sister store. Since the parking area in Case 1 would still not be on par with that of Case 1.1, growth could only be assumed for the additional parking alternative BMPs would create. The benefit of the additional parking was estimated to be an additional $28,000 in annual income to the project.

Using the estimated initial cost, projected income benefits, and projected maintenance costs, a life-cycle analysis was conducted for each BMP alternative. The study period chosen for this research was 20 years, beginning in 1998. The study shows that the permeable pavement option had the lowest LCC of ($153,676) over 20 years. The conventional retention pond that was used had a total life-cycle cost of $30,383. The difference in LCC between permeable pavement and conventional concrete is $184,059. This benefit is attained from lower initial and annual cost, along with the added benefit of additional parking. The BMP with the second lowest LCC was the green roof option was ($121,234) over 20 years. Even though initial costs of green roofing were higher than those of conventional methods, the value of the additional parking would overcome the cost differential over the life of the project. The full results of this LCC analysis are shown in Table 4-6.

Case 2 Life-cycle Cost

The next case study, Case 2, was the pharmacy in Gainesville, FL. Site plans and "RSMeans building construction cost data 2007" were used to estimate the total initial cost for all BMP options. Initial cost and the number of available parking spaces are presented by BMP type in Table 4-7. The option with the lowest initial costs is the option employed in the current site plan. The initial cost of this option is $79,138. After the initial option, the second least expensive option is the underground vault method with a total cost of $170,469. The most influential factor in the price of these two options is the use of asphalt paving. Asphalt paving has very low initial cost for paving of large areas. The other options of permeable pavement and green roofs result in initial cost of $182,690 and $214,274, respectfully. LCC used in the analysis are in Appendix C and the full initial cost of these estimates is presented in Appendices I-J.

The pharmacy chain's real estate department gave the following description for choosing a potential new location:

> "A new… location with the highest probability for approval by the Real Estate Committee will have the following characteristics:
>
> - **Site criteria:**
> - "A new Walgreen Drug Store location with the highest probability for approval by the Real Estate Committee will have the following characteristics:
> - Freestanding location at signalized intersection of two main streets with significant traffic counts.
> - Direct access to service the site.
> - 75,000 square feet +/- of land to accommodate parking for **70+ cars** and a pharmacy drive thru.
>
> **Building criteria:**
>
> - 112' x 130' = 14,560 square feet.
> - Trade area population of 20,000."
>
> (Walgreens, 2009)

The current site plan has met all of the criteria except for one; parking for 70+ cars. Use of a conventional pond only allowed for 53 spaces on site. By employing either permeable pavement or an underground vault the total number of parking spaces could be increased to 73. The use of a green roof also increased the available parking to a total of 63, a gain of 18.87 percent, but it would still not meet the recommended number.

The results of the life-cycle analysis for the BMP methods in this case are presented in Table 4-8. It was determined by the project developer that the benefit of additional parking would be $380 annually (Spock, personal communication). A conventional retention pond with normal asphalt paving has the lowest life-cycle cost of $91,351. The lowest alternative method was the installation of an underground vault and the life-cycle cost of the vault option is $127,660. Green roofing was the most expensive option because the total LCC was $204,982.

The initial cost of a green roof was higher than the other options, and offered less than 50 percent of the additional parking other alternatives allowed.

Case 3 Life-cycle Cost

Case 3 is a three story apartment complex consisting of two separate buildings connected with a covered walkway. Land usage and water retention specifications such as retention volume needed, permeable area, and non-permeable area, are shown in Table 4-9 for each alternative. This table displays how the land would be utilized for each situation. Needing a relatively small retention volume of 800 cuft, the green roof option creates the most permeable area on site. This is compared to the volume of 3,768 cuft needed for an underground vault, creating a difference in volume of 2,967 cuft. With an average depth of five feet, the green roof option could add an additional 594 sqft of constructible space.

Table 4-10 show how each alternative would affect retention volume needed, building area, and total rentable area. By using these numbers, along with rent rates and vacancy rates, the gross annual income each option could produce was determined. The annual income figures for the various alternatives were compared to the method used, which is an underground vault. BMPs that resulted in a larger rentable space allowed for more income to be produced, while those that required additional land lowered the total rentable space. Annual income varied from $352,430 for the green roof option to $278,440 with the conventional method.

Using the areas defined in Tables 4-8 and 4-9, initial costs of each method were estimated. The figures determined for the LCC are in Appendix D and detailed initial cost estimates are presented in Appendices M-P. An LCC analysis was performed with the initial cost, annual cost, and life-cycle costs shown in Table 4-11. This analysis determined that the most cost efficient method would be the underground vault method, with a total 20 year LCC of $52,763. The green roof option would allow for additional building area, thus more rent, however this option has the highest initial cost. The high initial cost makes the green roof option the least economical. The conventional method is less economical compared with the underground method, though initial costs would be the lowest. The area needed for the pond would remove 2,069 sf of building space, resulting in an annual loss of $34,079 in annual income.

Sensitivity Analysis

The factors of discount rate and BMP benefit were chosen to study how the LCC for each method would be affected if these factors were to change. A discount rate of 4.7 percent was used for the baseline study. The baseline rate was determined by the U.S. Department of Energy in the NIST BLCC 5.3 software. It was determined that the rate could conceivably drop as low as 1.0 percent, or could rise as high as 7.0 percent. The present value of LCC cost was determined for each stormwater control method with these high and low rates. Benefits of the BMPs were calculated at 25.0 percent above and below the baseline case to gauge how changes in potential benefits would impact LCC. The benefits of the additional land made available by the use of alternative BMPs would vary according to the value of the land.

The sensitivity analysis showed that the change in discount rate would have the greatest impact over the 20 year life of the study. The average variation for each method from the low to high discount rate, was $139,000 for Case 1, $27,000 for Case 2, and $180,000 for Case 3. Compare these to the difference that variations in benefit would cause of $67,000, $16,000, and $86,000 respectively. For both factors studied, the projects where alternative BMPs had the greatest economical impact were affected the most dramatically by changes in the sensitivity factors.

Figure 4-3 illustrates a direct correlation of land value and the economic benefit of alternative BMPs. As the value of parking spaces increases, the life-cycle cost of alternative BMPs decreases as well, showing at what point alternative methods would become more economical than the conventional method used. The full results from the sensitivity analysis are in Table 4-12 through 4-19 and Figures 4-4 through 4-16. This analysis shows that as the discount rate decreases, and future money becomes more valuable today, alternatives with high potential benefits were given a great advantage. In both Case 2 and Case 3, options that were originally less economical than others became the most beneficial as the interest rate decreased. These methods had a high initial cost, but their benefit over time would overcome the cost if the future value of money was relatively high. As the value of future money decreased, Case 3 saw the conventional method become the most economical. This method had the lowest income producing potential, but also had the lowest initial cost. The low initial cost was more preferred in this scenario where future money has little value.

Developer Survey

The purpose of the survey is to obtain opinions on alternative stormwater retention methods, along with the use of LCC analysis in the implementation of stormwater BMPs. In the scored portion of the developer survey, there is a range of (2) to 2 points. A positive number represents a positive perception of alternative BMP use, and a negative number represents the opposite. There was also a multiple choice section of the survey. To analyze the multiple choice questions, the responses for each choice were counted and summed to draw conclusions. The responses of the survey are presented in Appendices Q and R.

After gathering and evaluating developer responses, conclusions could be developed by following a particular method of analysis. By grouping together questions on general alternative BMP use, LCC use, and permitting, the study could focus on these certain points of interest. Additionally, questions regarding a specific BMP were put into their respective BMP’s group. The full results of this group analysis are in Table 4-12 and Figure 4-17. The questions were grouped as follows:

- General alternative BMPs - 1, 8, and 14
- LCC – 13 and 18
- Permitting – 15, 16, and 17
- Permeable pavement – 2, 10, and 19
- Green roof – 3, 11, and 20
- Underground vault – 4, 12, and 21

Once the questions were grouped, a mean score for each group was determined. The mean score for general alternative BMP use was 0.11. This score showed a positive perception on the use of alternative stormwater retention methods. Although developers viewed alternative methods favorably, there are still benefits to using conventional methods. The survey showed that the biggest reason for choosing conventional BMPs over others was first cost, and not lack of awareness of the alternatives. Developers surveyed rarely used life-cycle costing to determine what method of stormwater retention to employ. Questions regarding LCC analysis received a mean score of (0.08), representing a lack of LCC in the industry today. The survey also exemplified that permitting can be a problem with the implementation of alternative BMPs. Every permitting question received a negative mean score with the entire group receiving a mean of (0.11).

There were several questions designed to evaluate the developer's attitudes on the alternative stormwater retention methods studied in this research. Arithmetic means of the responses for the alternative BMP groups are as follows: permeable pavement 0.21, underground vault 0.19, and green roof with (0.33). The data from the numerical portion of the survey is supported by the information acquired in the multiple choice portions. By calculating the number of multiple choice responses regarding the most preferred method, the permeable pavement option was determined to be the most popular. The multiple choice section of the survey showed that the permeable pavement was selected by 10 out of the total 18 respondents. The option chosen second most was the use of underground vaults, which was selected 7 times.

Green roofing proved to be the least preferred method, with one respondent who chose it as their preference. In regards to which methods the respondents would be least likely to use, green roofing was selected 16 times. Permeable pavement and underground vaults were each chosen once as the least preferred method.

Table 4-1. Case 1 BMP initial costs

Conventional	
Total initial cost	$ 24,277
Parking spots	12
$/Parking spot	2,023
Permeable pavement	
Total initial cost	$ 26,016
Parking spots	17
$/Parking spot	1,530
Underground vault	
Total initial cost	$ 97,736
Parking spots	17
$/Parking spot	5,749
Green roof	
Total initial cost	$ 56,547
Parking spots	17
$/Parking spot	3,326

Table 4-2. Case 1 Income

Year	Annual income	Annual growth	Growth by inflation only	Annual inflation rate
1999	$ 764,584	-	$764,584	2.19%
2000	$ 764,863	0.04%	$790,427	3.38%
2001	$ 735,543	-3.83%	$812,796	2.83%
2002	$ 799,998	8.76%	$825,719	1.59%
2003	$ 935,537	16.94%	$844,463	2.27%
2004	$ 963,634	3.00%	$867,095	2.68%
2005	$ 847,888	-12.01%	$896,489	3.39%
2006	$ 873,922	3.07%	$925,536	3.24%
2007	$ 924,863	5.83%	$951,913	2.85%
2008	$1,046,399	13.14%	$988,562	3.85%
Avg	$ 865,723	3.88%	$866,759	2.83%

Table 4-3. Case 1.1 Income

Year	Annual income	Annual growth	Growth by inflation only	Annual inflation rate
1999	$544,631	-	$544,631	2.19%
2000	$604,409	10.98%	$563,040	3.38%
2001	$602,962	-0.24%	$578,974	2.83%
2002	$758,706	25.83%	$588,179	1.59%
2003	$886,947	16.90%	$601,531	2.27%
2004	$831,533	-6.25%	$617,652	2.68%
2005	$806,978	-2.95%	$638,590	3.39%
2006	$837,986	3.84%	$659,281	3.24%
2007	$870,607	3.89%	$678,070	2.85%
2008	$1,078,357	23.86%	$704,176	3.85%
Avg	$782,312	8.43%	$617,412	2.83%

Table 4-4. Case 1 Income growth

Year	Titusville	Titusville in 1998 $	Titusville growth	Titusville growth discounted
1999	$ 764,584	$ 747,840	-	-
2000	$ 764,863	$ 717,365	0.04%	-4.25%
2001	$ 735,543	$ 678,171	-3.83%	-5.78%
2002	$ 799,998	$ 719,438	8.76%	5.74%
2003	$ 935,537	$ 816,256	16.94%	11.86%
2004	$ 963,634	$ 808,103	3.00%	-1.01%
2005	$ 847,888	$ 683,567	-12.01%	-18.22%
2006	$ 873,922	$ 679,649	3.07%	-0.58%
2007	$ 924,863	$ 683,659	5.83%	0.59%
2008	$ 1,046,399	$ 773,498	13.14%	11.61%
Avg	$ 865,723	$ 730,755	3.88%	0.0037%

Table 4-5. Case 1 Income potential

Year	Case 1 in 1998 $	Case 1 potential in 1998 $	Case 1 capacity with alt. BMPs	BMP benefit
1999	$ 747,840	$ 731,462	$ 1,036,238	$ (16,378)
2000	$ 717,365	$ 732,847	$ 1,038,200	$ 15,482
2001	$ 678,171	$ 738,265	$ 1,045,876	$ 60,095
2002	$ 719,438	$ 752,878	$ 1,066,577	$ 33,440
2003	$ 816,256	$ 762,661	$ 1,080,436	$ (53,595)
2004	$ 808,103	$ 769,444	$ 1,090,045	$ (38,660)
2005	$ 683,567	$ 770,824	$ 1,092,000	$ 87,256
2006	$ 679,649	$ 773,362	$ 1,095,597	$ 93,713
2007	$ 683,659	$ 778,925	$ 1,103,478	$ 95,267
2008	$ 773,498	$ 776,739	$ 1,100,381	$ 3,241
Avg	$ 730,755	$ 758,741	$ 1,074,883	$ 27,986
Sum	$ 7,307,546	$ 7,587,407	$ 10,748,827	$ 279,861

Table 4-6. Case 1 Life-cycle costs analysis

	Present value	Annual value
Conventional		
Initial capital costs	$ 24,277	
Annually recurring costs	$ 6,106	$ 478
Total life-cycle cost	$ 30,383	
Underground vault		
Initial capital costs	$ 97,736	
Annually recurring costs	$ (12,147)	$ (951)
Total life-cycle cost	$ (81,585)	
Permeable pavement		
Initial capital costs	$ 26,016	
Annually recurring costs	$ (179,692)	$ (14,071)
Total life-cycle cost	$ (153,676)	
Green roof		
Initial capital costs	$ 56,547	
Annually recurring costs	$ (177,781)	$ (13,922)
Total life-cycle cost	$ (121,234)	

Table 4-7. Case 2 Available parking with BMP options

Conventional	
Total initial cost:	$ 79,139
Parking spots	53
$/Parking spot	1,493
Underground vault	
Total initial cost:	$ 170,469
Parking spots	74
$/Parking spot	2,304
Permeable pavement	
Total initial cost:	$ 182,690
Parking spots	74
$/Parking spot	2,469
Green roof	
Total initial cost:	$ 214,274
Parking spots	63
$/parking spot	3,401

Table 4-8. Case 2 Life-cycle costs analysis

	Present value	Annual value
Conventional		
Initial capital costs	$ 79,139	
Annually recurring costs	$ 12,212	$ 955
Total life-cycle cost	$ 91,351	
Underground vault		
Initial capital costs	$ 170,469	
Annually recurring costs	$ (42,810)	$ (3,349)
Total life-cycle cost	$ 127,660	
Permeable pavement		
Initial capital costs	$ 182,690	
Annually recurring costs	$ (40,898)	$ (3,200)
Total life-cycle cost	$ 141,793	
Green roof		
Initial capital costs	$ 214,274	
Annually recurring costs	$ (9,292)	$ (727)
Total life-cycle cost	$ 204,982.	

Table 4-9. Case 3 site specifications for each BMP

	Conventional	Underground	Permeable	Green roof	
	Quantity	Quantity	Quantity	Quantity	Units
Total land area:	12,003	12,003	12,003	12,003	Sf
Non-permeable area:	7,346	8,029	6,323	1,706	Sf
Permeable area	4,657	3,974	5,680	10,297	Sf
Pavement area:	1,706	1,706	1,706	1,706	Sf
Permeable % of total:	39	33	47	86	%
Non-permeable % of total:	61	67	53	14	%
Total pond volume:	3,448	3,768	2,967	801	Cuft
Pond volume/ non-permeable area:	0.47	0.47	0.47	0.47	Cuft/Sf

Table 4-10. Case 3 income projections

	Conventional	Underground	Permeable	Green roof	
	Quantity	Quantity	Quantity	Quantity	Units
Building	5,633	6,323	5,730	7,131	Sf
Pond area	690	754	593	160	Sf
Pond gallons	25,789	28,187	22,198	5,989	gallons
Total building area	16,900	18,969	17,189	21,392	sf
Efficiency factor	0.82	0.82	0.82	0.82	
Rentable area	13,858	15,555	14,095	17,541	sf
Rent $/sf/yr	$ 22	$ 22	$ 22	$ 22	
Vacancy rate	0.93	0.93	0.93	0.93	
Gross annual income	$ 278,440	$ 312,518	$ 283,186	$ 352,430	
Rent difference	$ (34,079)	-	$ (29,333)	$ 39,911	

Table 4-11. Case 3 life-cycle cost analysis

	Present value	Annual value
Conventional		
Initial capital costs	$ (168,259)	
Annually recurring costs	$ 239,361	$ 18,727
Total life-cycle cost	$ 71,102	
Underground vault		
Initial capital costs	$ 38,088	
Annually recurring costs	$ 14,675	$ 1148
Total life-cycle cost	$ 52,763	
Permeable pavement		
Initial capital costs	$ (142,747)	
Annually recurring costs	$ 206,790	$ 16,178
Total life-cycle cost	$ 64,043	
Green roof		
Initial capital costs	$ 294,686	
Annually recurring costs	$ (170,154)	$ (13,312)
Total life-cycle cost	$ 124,532	

Table 4-12. Case 1 discount rate sensitivity analysis

Low - 1%	Present Value	High - 7%	Present Value
Conventional		Conventional	
Initial Capital Costs	$ 24,277	Initial Capital Costs	$ 4,277
Annually Recurring Costs	$ 10,640	Annually Recurring Costs	$ 4,391
Total Life-Cycle Cost	$34,917	Total Life-Cycle Cost	$ 28,668
Underground vault		Underground vault	
Initial Capital Costs	$ 97,736	Initial Capital Costs	$ 97,736
Annually Recurring Costs	$ (312,476)	Annually Recurring Costs	$ (128,965)
Total Life-Cycle Cost	$ (214,740)	Total Life-Cycle Cost	$ (31,229)
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ 26,016	Initial Capital Costs	$ 26,016
Annually Recurring Costs	$ (313,124)	Annually Recurring Costs	$ (129,232)
Total Life-Cycle Cost	$ (287,108)	Total Life-Cycle Cost	$ (103,216)
Green roof		Green roof	
Initial Capital Costs	$ 56,547	Initial Capital Costs	$ 56,547
Annually Recurring Costs	$ (309,793)	Annually Recurring Costs	$ (127,858)
Total Life-Cycle Cost	$ (253,246)	Total Life-Cycle Cost	$ (71,311)

Table 4-13. Case 1 BMP benefit sensitivity analysis

Low -25%		High +25%	
	Present Value		Present Value
Conventional		Conventional	
Initial Capital Costs	$ 24,277	Initial Capital Costs	$ 24,277
Annually Recurring Costs	$ 6,106	Annually Recurring Costs	$ 6,106
Total Life-Cycle Cost	$ 30,383	Total Life-Cycle Cost	$ 30,383
Underground vault		Underground vault	
Initial Capital Costs	$ 97,736	Initial Capital Costs	$ 97,736
Annually Recurring Costs	$ (132,887)	Annually Recurring Costs	$ (225,759)
Total Life-Cycle Cost	$ (35,151)	Total Life-Cycle Cost	$ (128,023)
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ 26,016	Initial Capital Costs	$ 26,016
Annually Recurring Costs	$ (133,259)	Annually Recurring Costs	$ (226,131)
Total Life-Cycle Cost	$ (107,243)	Total Life-Cycle Cost	$ (200,115)
Green roof		Green roof	
Initial Capital Costs	$ 56,547	Initial Capital Costs	$ 53,262
Annually Recurring Costs	$ (131,347)	Annually Recurring Costs	$ (224,220)
Total Life-Cycle Cost	$ (74,800)	Total Life-Cycle Cost	$ (167,673)

Table 4-14. Case 2 discount rate sensitivity analysis

Low	Present Value	High	Present Value
Conventional		Conventional	
Initial Capital Costs	$ 79,139	Initial Capital Costs	$ 79,139
Annually Recurring Costs	$ 21,280	Annually Recurring Costs	$ 8,783
Total Life-Cycle Cost	$ 100,419	Total Life-Cycle Cost	$ 87,922
Underground vault		Underground vault	
Initial Capital Costs	$ 170,469	Initial Capital Costs	$ 170,469
Annually Recurring Costs	$ (74,597)	Annually Recurring Costs	$ (30,788)
Total Life-Cycle Cost	$ 95,872	Total Life-Cycle Cost	$ 139,681
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ 182,690	Initial Capital Costs	$ 182,690
Annually Recurring Costs	$ (71,266)	Annually Recurring Costs	$ (29,413)
Total Life-Cycle Cost	$ 111,424	Total Life-Cycle Cost	$ 153,277
Green roof		Green roof	
Initial Capital Costs	$ 214,274	Initial Capital Costs	$ 214,274
Annually Recurring Costs	$ (16,192)	Annually Recurring Costs	$ (6,683)
Total Life-Cycle Cost	$ 198,082	Total Life-Cycle Cost	$ 207,591

Table 4-15. Case 2 BMP benefit sensitivity analysis

Low	Present Value	High	Present Value
Conventional		Conventional	
Initial Capital Costs	$ 79,139	Initial Capital Costs	$ 79,139
Annually Recurring Costs	$ 12,212	Annually Recurring Costs	$ 12,212
Total Life-Cycle Cost	$ 91,351	Total Life-Cycle Cost	$ 91,351
Underground vault		Underground vault	
Initial Capital Costs	$ 170,469	Initial Capital Costs	$ 170,469
Annually Recurring Costs	$ (29,561)	Annually Recurring Costs	$ (56,063)
Total Life-Cycle Cost	$ 140,908	Total Life-Cycle Cost	$ 114,406
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ 182,690	Initial Capital Costs	$ 182,690
Annually Recurring Costs	$ (27,650)	Annually Recurring Costs	$ (54,152)
Total Life-Cycle Cost	$ 155,040	Total Life-Cycle Cost	$ 128,538
Green roof		Green roof	
Initial Capital Costs	$ 214,274	Initial Capital Costs	$ 214,274
Annually Recurring Costs	$ (2,987)	Annually Recurring Costs	$ (15,597)
Total Life-Cycle Cost	$ 211,287	Total Life-Cycle Cost	$ 198,677

Table 4-16. Case 3 discount rate sensitivity analysis

Low		High	
	Present Value		Present Value
Conventional		Conventional	
Initial Capital Costs	$ (168,259)	Initial Capital Costs	$ (168,259)
Annually Recurring Costs	$ 417,099	Annually Recurring Costs	$ 172,145
Total Life-Cycle Cost	$ 248,840	Total Life-Cycle Cost	$ 3,886
Underground vault		Underground vault	
Initial Capital Costs	$ 38,088	Initial Capital Costs	$ 38,088
Annually Recurring Costs	$ 25,571	Annually Recurring Costs	$ 10,554
Total Life-Cycle Cost	$ 63,659	Total Life-Cycle Cost	$ 48,642
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ (142,747)	Initial Capital Costs	$ (142,747)
Annually Recurring Costs	$ 360,343	Annually Recurring Costs	$ 148,721
Total Life-Cycle Cost	$ 217,596	Total Life-Cycle Cost	$ 5,974
Green roof		Green roof	
Initial Capital Costs	$ 294,686	Initial Capital Costs	$ 294,686
Annually Recurring Costs	$ (418,845)	Annually Recurring Costs	$ (172,866)
Total Life-Cycle Cost	$ (124,159)	Total Life-Cycle Cost	$ 121,820

Table 4-17. Case 3 BMP benefit sensitivity analysis

Low		High	
	Present Value		Present Value
Conventional		Conventional	
Initial Capital Costs	$ (168,259)	Initial Capital Costs	$ (168,259)
Annually Recurring Costs	$ 211,841	Annually Recurring Costs	$ 344,291
Total Life-Cycle Cost	$ 43,582	Total Life-Cycle Cost	$ 176,032
Underground vault		Underground vault	
Initial Capital Costs	$ 38,088	Initial Capital Costs	$ 38,088
Annually Recurring Costs	$ 14,675	Annually Recurring Costs	$ 14,675
Total Life-Cycle Cost	$ 52,763	Total Life-Cycle Cost	$ 52,763
Permeable Pavment		Permeable Pavment	
Initial Capital Costs	$ (142,747)	Initial Capital Costs	$ (142,747)
Annually Recurring Costs	$ 181,749	Annually Recurring Costs	$ 294,838
Total Life-Cycle Cost	$ 39,002	Total Life-Cycle Cost	$ 152,091
Green roof		Green roof	
Initial Capital Costs	$ 294,686	Initial Capital Costs	$ 294,686
Annually Recurring Costs	$ (121,485)	Annually Recurring Costs	$ (218,824)
Total Life-Cycle Cost	$ 173,201	Total Life-Cycle Cost	$ 75,862

Table 4-18. Discount rate sensitivity analysis summary

Case 1	Low - 1%	Base - 4.7%	High - 7%	Difference
Conventional	$ 34,917	$ 30,383	$ 28,668	$ 6,249
Underground vault	$ (214,740)	$ (81,585)	$ (31,229)	$ 183,511
Permeable Pavment	$ (287,108)	$ (153,676)	$ (103,216)	$ 183,892
Green Roof	$ (253,246)	$ (121,234)	$ (71,311)	$ 181,935
			Average	$ 138,897

Case 2	Low - 1%	Base - 4.7%	High - 7%	Difference
Conventional	$ 100,419	$ 91,351	$ 87,922	$ 12,497
Underground vault	$ 95,872	$ 127,660	$ 139,681	$ 43,809
Permeable Pavment	$ 111,424	$ 141,793	$ 153,277	$ 41,853
Green Roof	$ 198,082	$ 204,982	$ 207,591	$ 9,509
			Average	$ 26,917

Case 3	Low - 1%	Base - 4.7%	High - 7%	Difference
Conventional	$ 248,840	$ 71,102	$ 3,886	$ 244,954
Underground vault	$ 63,659	$ 52,763	$ 48,642	$ 15,017
Permeable Pavment	$ 217,596	$ 64,043	$ 5,974	$ 211,622
Green Roof	$ (124,159)	$ 116,806	$ 121,820	$ 245,979
			Average	$ 179,393

Table 4-19. BMP benefit sensitivity analysis summary

Case 1	Low -25%	Base	High +25%	Difference
Conventional	$ 30,383	$ 30,383	$ 30,383	$ -
Underground vault	$ (35,151)	$ (81,585)	$ (128,023)	$ 92,872
Permeable Pavment	$ (107,243)	$ (153,676)	$ (200,115)	$ 92,872
Green Roof	$ (74,800)	$ (121,234)	$ (167,673)	$ 92,873
			Average	$ 69,654
Case 2	Low -25%	Base	High +25%	
Conventional	$ 91,351	$ 91,351	$ 91,351	$ -
Underground vault	$ 140,908	$ 127,660	$ 114,406	$ 26,502
Permeable Pavment	$ 155,040	$ 141,793	$ 128,538	$ 26,502
Green Roof	$ 211,287	$ 204,982	$ 198,677	$ 12,610
			Average	$ 16,404
Case 3	Low -25%	Base	High +25%	
Conventional	$ 43,582	$ 71,102	$ 176,032	$ 132,450
Underground vault	$ 52,763	$ 52,763	$ 52,763	$ -
Permeable Pavment	$ 39,002	$ 64,043	$ 152,091	$ 113,089
Green Roof	$ 173,201	$ 116,806	$ 75,862	$ 97,339
			Average	$ 85,720

Table 4-20. Survey group analysis summary

Question category	Mean score	Frequency most preferred	Frequency least preferred
General alternative BMPs	0.11		
LCC	(0.08)		
Permitting	(0.11)		
Permeable pavement	0.21	10	1
Green roof	(0.33)	1	16
Underground vault	0.19	7	1

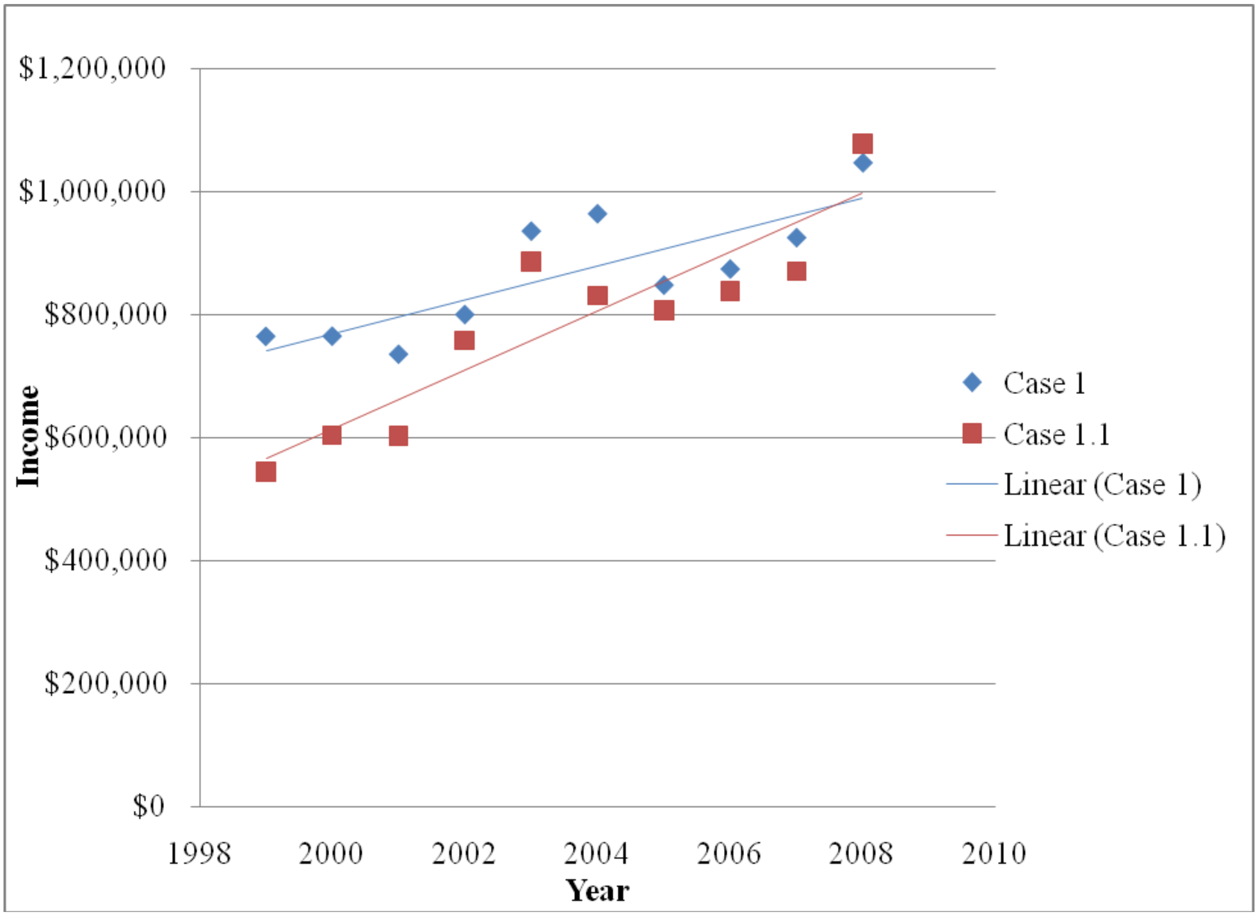


Figure 4-1. Case 1 and Case 1.1 comparitive growth

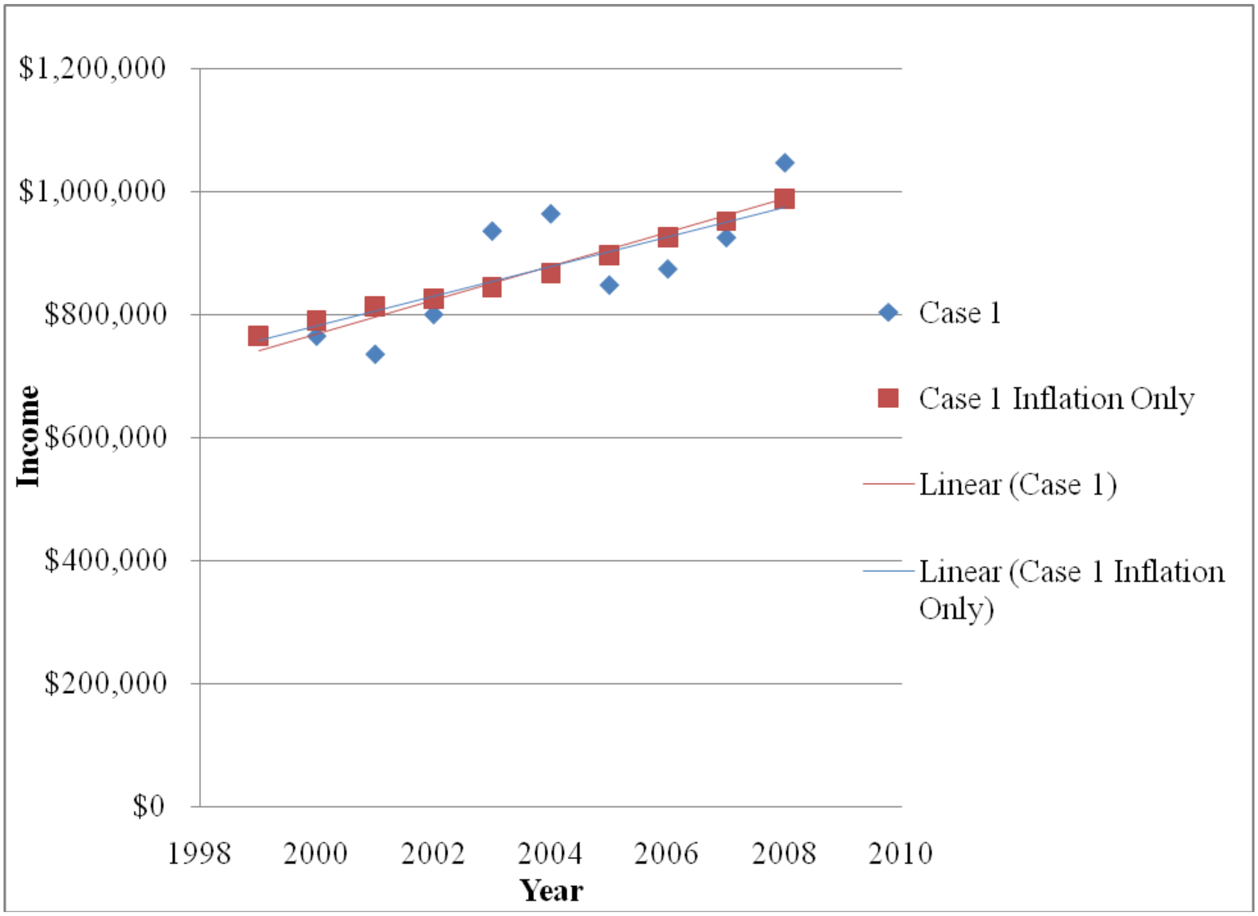


Figure 4-2. Case 1 growth vs. inflation

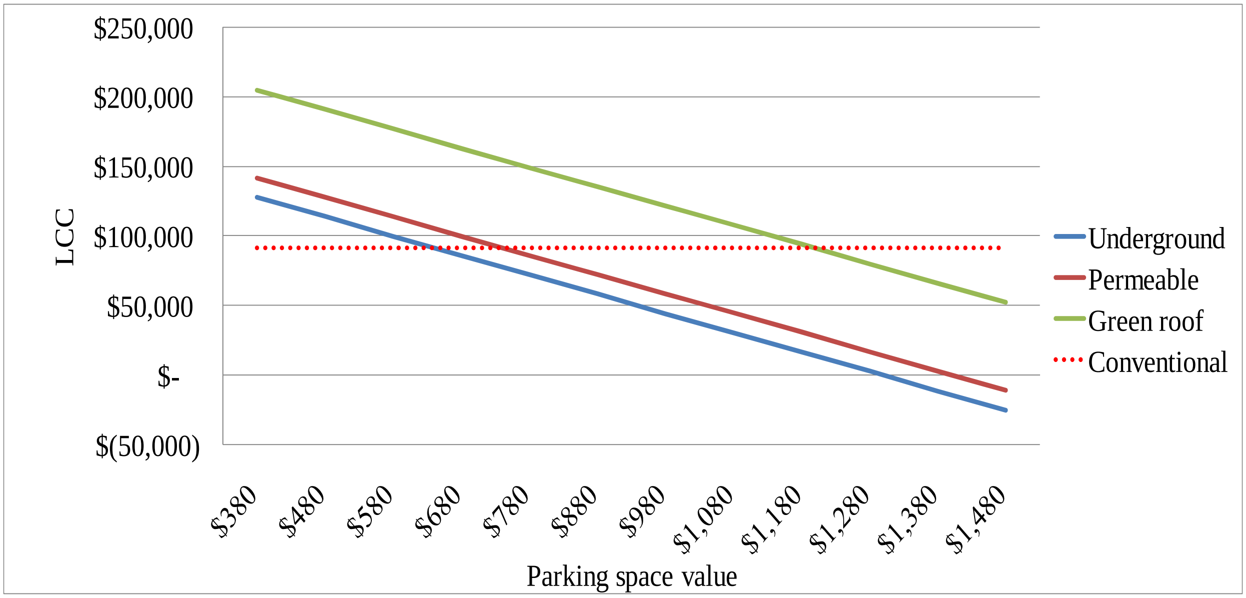


Figure 4-3. BMP life-cycle cost vs. parking space value in Case 2

Figure 4-4. Case 1 Conventional pond sensitivity analysis

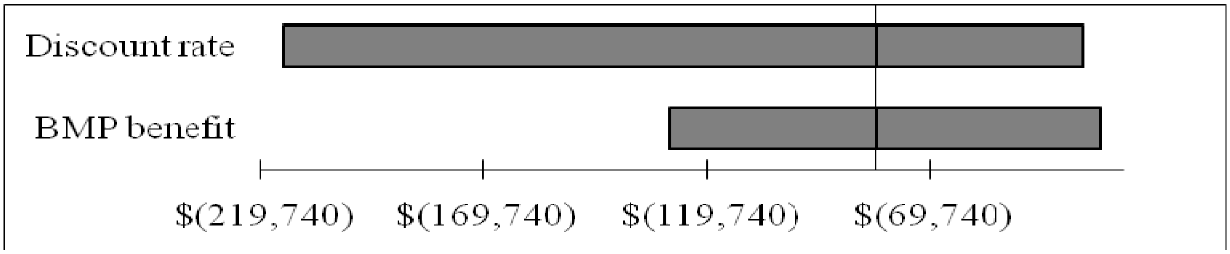


Figure 4-5. Case 1 Underground vault sensitivity analysis

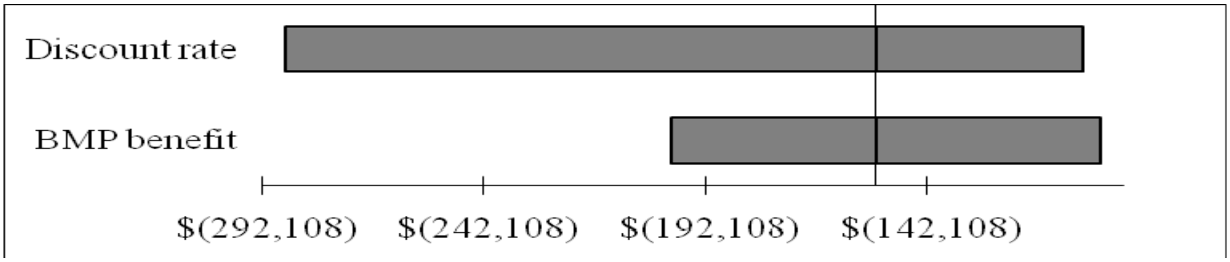


Figure 4-6. Case 1 Permeable pavement sensitivity analysis

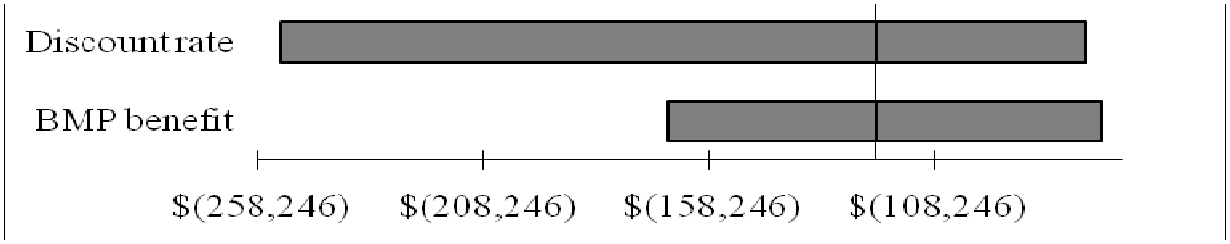


Figure 4-7. Case 1 Green roof sensitivity analysis

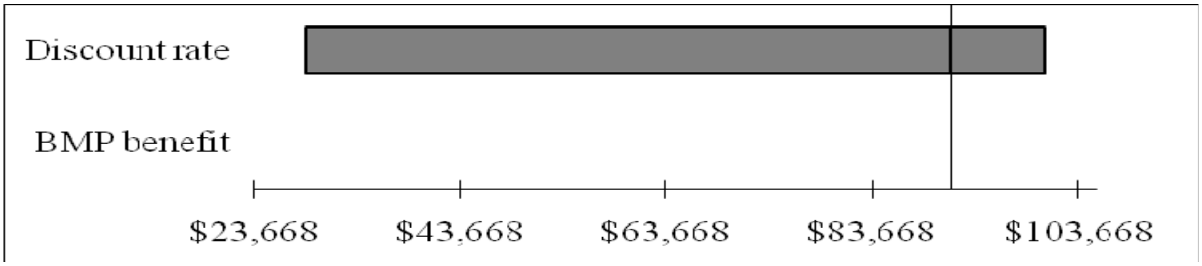


Figure 4-8. Case 2 Conventional pond sensitivity analysis

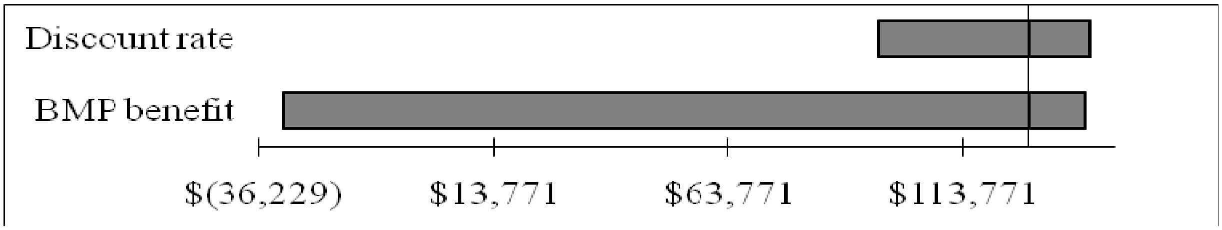


Figure 4-9. Case 2 Underground vault sensitivity analysis

Figure 4-10. Case 2 Permeable pavement sensitivity analysis

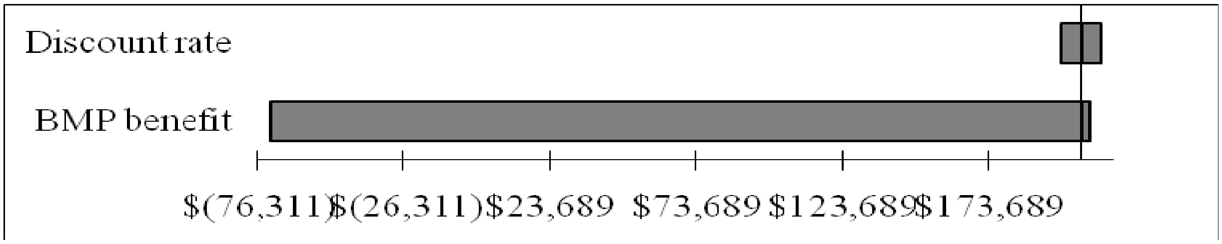


Figure 4-11. Case 2 Green roof sensitivity analysis

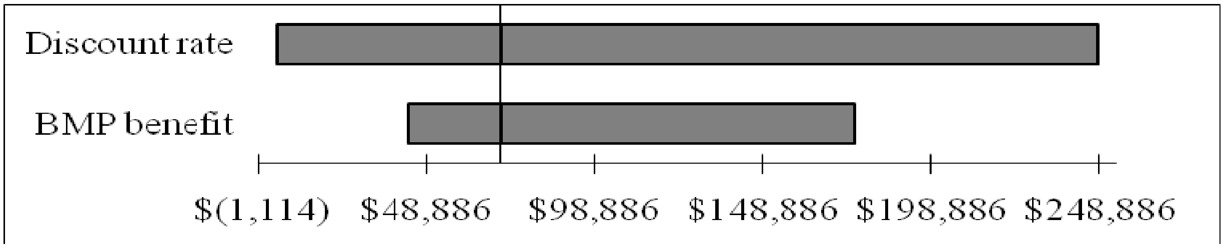


Figure 4-12. Case 3 Conventional pond sensitivity analysis

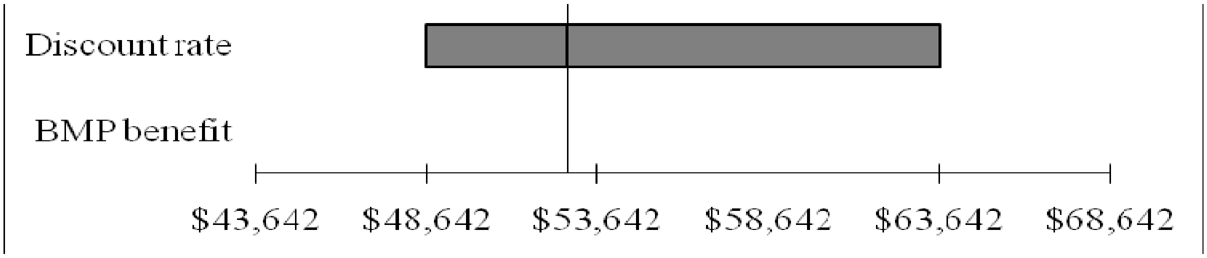


Figure 4-13. Case 3 Underground vault sensitivity analysis

Figure 4-14. Case 3 Permeable pavement sensitivity analysis

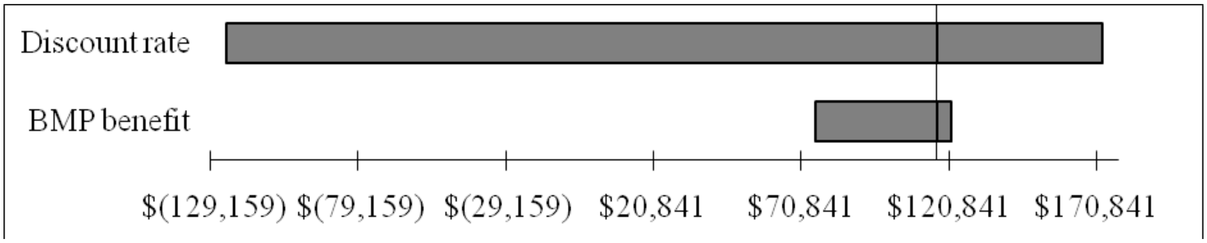


Figure 4-15. Case 3 Green roof sensitivity analysis

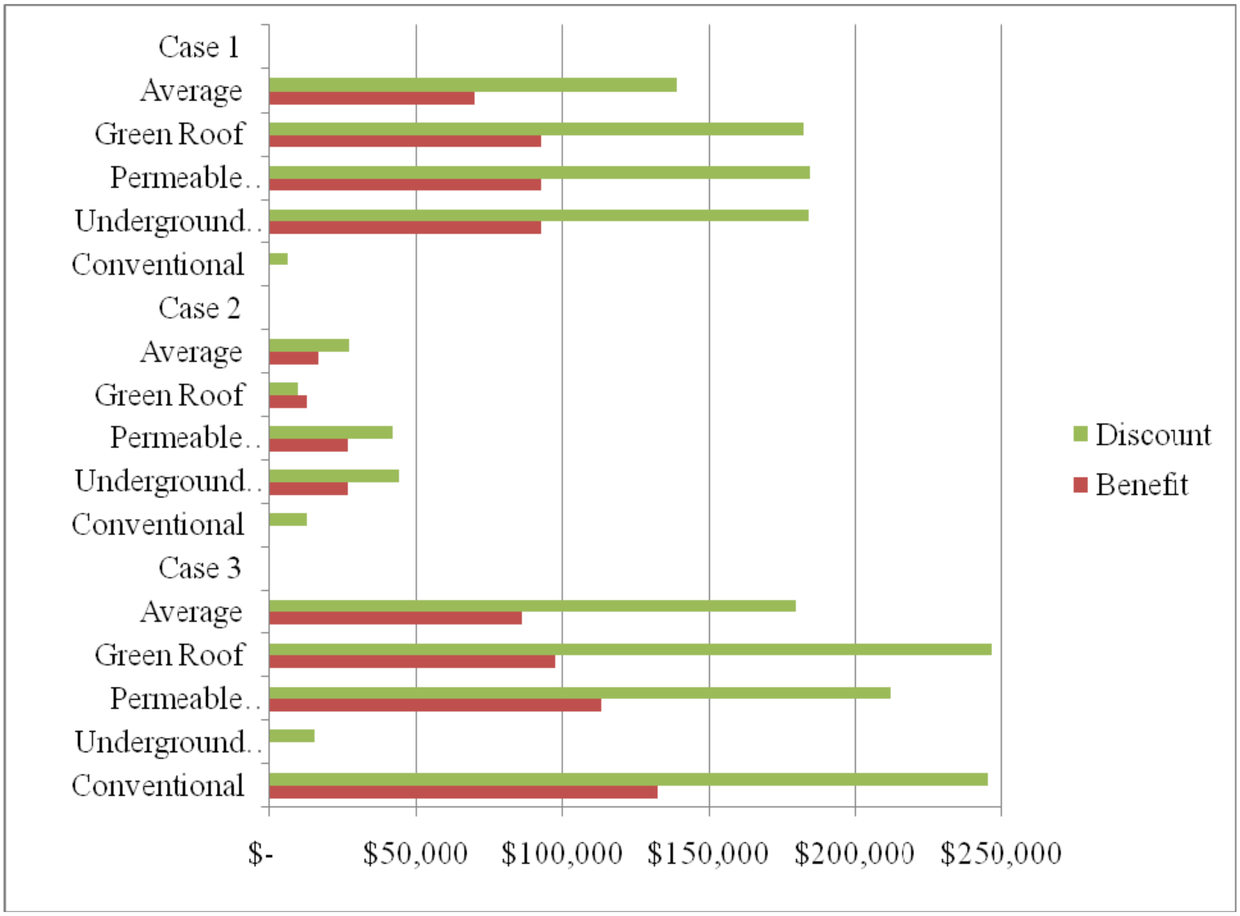


Figure 4-16. LCC factor sensitivity

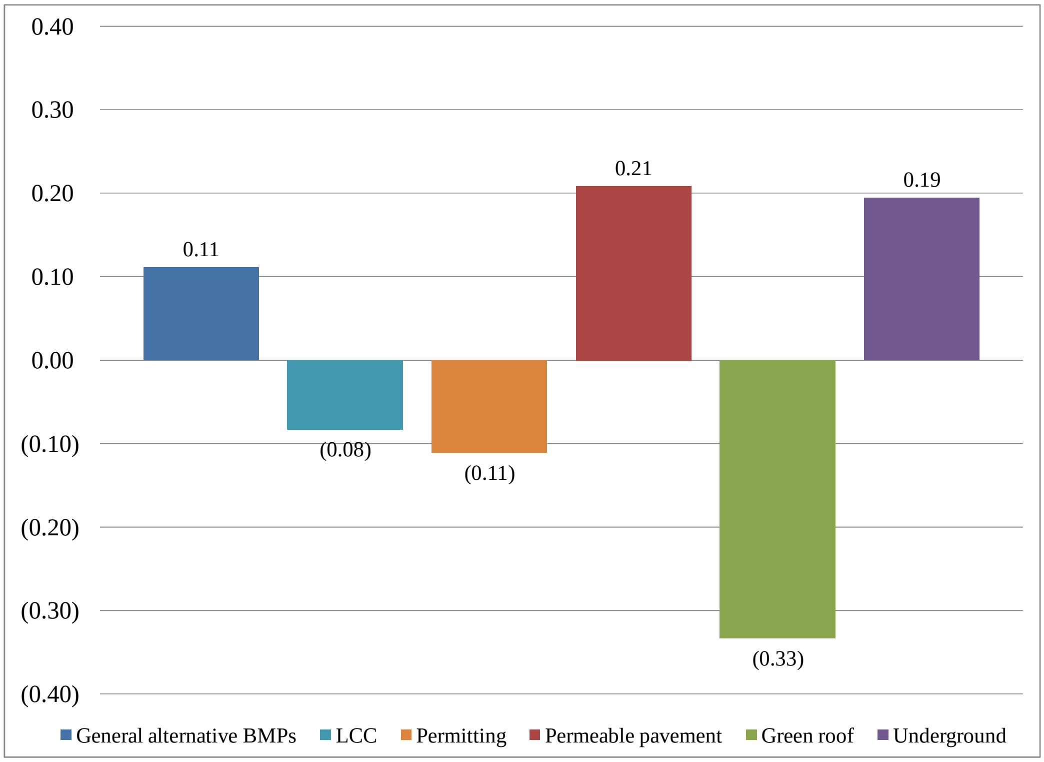


Figure 4-17. Mean survey responses for each question group

CHAPTER 5
CONCLUSIONS

In Case 1, the most economical choice would have been to employ the use of permeable pavement. Permeable pavement allowed for a 43 percent increase in available parking with little additional maintenance cost over the life of the project. The initial costs were $26,016 compared to $24,277 for conventional concrete paving, creating an initial cost burden of $1,739. Similar costs were realized by having less of a retention pond to dig and sod, even though material cost of permeable pavement is considerably more than regular concrete. The 43 percent increase in parking would allow for store income to grow by allowing more customers at one time, along with easier ingress and egress for customer vehicles. Because the store relies on a high volume of customers spending relatively small amounts of money, additional parking is very beneficial.

Though each alternate BMP allows for the same increase in available parking area, the green roof and underground vault option have higher initial and LCC than permeable pavement. The BMP options rated by lowest LCC are permeable pavement, green roof, underground vault, and lastly, a conventional pond.

Case 2 was considerably larger than Case 1, and the relative volume of water retention needed was considerably lower. These factors dissipated the cost effectiveness of alternative BMPs. The area had less than optimal parking available but, the added cost of alternatives over the life of the project proved detrimental to their implementation. Though the parking area was less than the recommended amount, there is not a great financial benefit of additional parking. The parking area was still quite large at 53 spots, along with a drive thru area for the pharmacy. The only times the parking capacity is predicted to be inadequate would be during peak shopping periods throughout the year.

Case 2 used asphalt paving instead of concrete paving due to the large parking area. Asphalt is much cheaper than concrete for large areas throughout the life of the project. Permeable concrete had an initial cost that was much too great to overcome, even with additional parking made available. An underground vault allowed for greater parking, but again a high initial cost was detrimental. The use of a green roof had the highest initial cost and with little economic benefit, the option was unsatisfactory.

Case 3 is in a highly developed area, very close to the University of Florida. The value of land in this area is high, with rental properties drawing very expensive rates. For this reason, the need to maximize land use is essential. A conventional water retention pond was not used on this project, instead an underground vault was used to maximize available land. The green roof option would allow for a greater rental area to be built. However, higher initial and maintenance costs erase any benefit of additional income. Even though the green roof option would allowed for increased income, the added design complexity and possible complications make the option less attractive compared to simpler alternatives.

Since there was no on-site parking required, the use of permeable pavement would add little benefit to stormwater management on the site. The only paved areas of the project were the sidewalks. If a conventional pond would have been used, the area needed for the pond would remove available land currently used for construction of a large portion of the apartments. This land is too valuable to be used as a retention pond and not as income producing property.

The selection of an underground water storage vault was the correct selection because it allows for the lowest LCC. It also has relatively easy maintenance and greatly increases available land compared to the conventional method. Many apartment complexes immediately surrounding the area also use underground vaults. This further strengthens the assumption that areas of high population density and land value are better candidates for alternative stormwater BMPs.

The sensitivity analysis exhibits that as the price of land increases, alternative methods become more viable. The results of the sensitivity analysis show that in Case 3 the most economical option would change from an underground vault, as in the base case, to permeable paving as the value of benefits decrease. Benefit value in Case 3 would decrease if the value of the land were to decrease. This is why developers are much more likely to employ unconventional BMPs in areas of high land value as hypothesized. As the discount rate changes from high to low and the value of future money increases, options with higher future financial benefits become the most economical. In Case 3 the most economical option with a discount rate of 1.0 percent was the green roof. The green roof would have the lowest present value LCC because future money would be most valued and the increased income would make a greater impact. Conversely, the conventional pond method would have the lowest present value LCC if the discount rate was as high as 7.0 percent. This scenario favors immediate cost savings over increased income over the life of the project.

The survey helped to conclude that many project owners have a limited construction budget and must use the least costly method. Most alternate practices are more expensive initially, though the long term benefit of the additional useable land can make up for high initial cost. The developers surveyed rarely use LCC to determine what method of stormwater retention to employ. This exemplifies that alternative BMPs face the same problem many emerging construction technologies face. There is little to no LCC analysis employed while choosing the subsystems of a project. Without LCC analysis, many systems are incorrectly written off as impractical due to high first costs. Most emerging technologies only see a financial payoff after years of service. The lack of LCC analysis by developers suggests there is much room for improvement in the area.

Green roofs are the least popular option among the developers surveyed due to their highly unconventional nature. The effect of a green roofing system on the total site can be hard to qualify within the entire stormwater management system of a particular project. Another deterrent of green roofing adoption is the interdisciplinary effort that must be taken between the architect, landscape architect, and civil engineer. A truly diverse team must be utilized to fully integrate a green roof into a stormwater retention system. High initial costs are also a major drawback to widespread use of green roofing.

Permeable paving, on the other hand, requires little to no maintenance over the life of the project compared to green roofing. For this reason, permeable paving was the most preferred choice among those surveyed. The application of pervious concrete is very similar to that of conventional concrete. With its long life and high durability, the only major drawbacks to permeable pavement are high upfront and maintenance costs. Permeable paving is not a viable choice for application in very densely populated areas. This is because many developments in highly urbanized areas do not have parking lots, but rather parking structures or basements. Permeable concrete is most useful when it is applied on grade with no cover.

Underground vaults were preferred second after permeable pavement. Underground vaults, like permeable pavements, are more similar to the conventional method than green roofs. Municipal stormwater systems are connected to underground vaults much in the way regular retention ponds are connected. This makes them popular within the developer community. To reduce the size needed for an underground retention vault, this method can be used in conjunction with other traditional and non-traditional practices. Reducing the size of the vault needed would also reduce the associated cost. Not only can an underground vault be used with permeable pavement, but any of these methods can be used together to increase effectiveness. A project site utilizing a green roof and permeable pavement would have little to no post development runoff. The little runoff that may be created could be controlled by a small retention pond or underground vault.

The survey shows that permits for alternative methods are reasonably easy to obtain, with those for green roofs being the most difficult. Responses also expressed that permits for permeable pavements have become increasingly easier to obtain over the last decade. This is due to a push from state and local municipalities for the adoption of more BMP alternatives. This study determined that alternative stormwater BMPs should be pressed to be used more frequently in urban development. Benefits of additional land use outweigh the extra initial and maintenance cost. Central Florida has seen some of the most rapid growth in the nation over the last several years. As a result, the area must learn to successfully control development and its consequences.

CHAPTER 6
SUGGESTIONS FOR FUTURE RESEARCH

The potential to expand on this study is virtually infinite. One area that may be particularly beneficial would be the investigation of the industry, outside of developers, on their opinions of alternative stormwater BMPs. Research could also be conducted to study how particular methods are being pushed for increased use. Another area of interest would be investigating the use of LCC analysis regarding areas of construction besides stormwater management. A study determining trends of use for various areas of the nation would also be highly beneficial. By studying what types of BMPs are used in certain areas, one could determine trends for BMP use. These tendencies could be based on geological areas, geographical areas, population density, and the age of the city developments are built in.

The primary aim of this study was focused on economical benefits, but another important issue is the ecological and environmental benefits of various stormwater BMPs. Ecological and environmental aspects are more important now than ever, especially in conjunction with the current green building movement. An aspect beyond the scope of this study would be investigating a green roof's benefit of lowering cooling loads in warm climates. Another area of study would be the investigation of cutting-edge BMP applications that are either in developmental or early-use stages. By researching new technologies, studies could help determine what the future of stormwater management will be.

APPENDIX A
DEVELOPER SURVEY

The following is a survey designed to assess your opinions on various forms of stormwater best management practices in urban developments. The conventional method of stormwater management is with a wet/dry storm basin or retention pond. Permeable pavements are paving materials with voids that allow water to penetrate freely. Underground vaults store stormwater in underground cavities allowing slow release, which is similar to a conventional pond. Green roofs consist of soil and vegetation on a building's rooftop. These roofs are designed to accept rainwater and slowly release it, minimizing peak flows from rooftops.

1. Do you consider any alternative water retention methods during the design of your projects?	No Yes ☐ ☐ ☐ ☐ ☐
2. How interested would you be in using permeable pavement?	Little Some Great ☐ ☐ ☐ ☐ ☐
3. How interested would you be in using green roofs?	Little Some Great ☐ ☐ ☐ ☐ ☐
4. How interested would you be in using underground vaults?	Little Some Great ☐ ☐ ☐ ☐ ☐
5. Are there any other methods you would consider using?	
6. Which alternative method are you MOST likely to use?	1. Permeable 2. Underground 3. Green Roof 4. Other ______________________

7. Which alternative method are you LEAST likely to use?	1. Permeable 2. Underground 3. Green Roof 4. Other ________________________
8. How many projects have you used alternative methods?	None Some Many ☐ ☐ ☐ ☐ ☐
9. What is the biggest reason you choose the conventional method?	1. Familiarity 2. Code 3. First Cost 4. Life-cycle Cost 5. Other ____________________
10. How likely would it be for you use to permeable pavement in an urban development project?	Very Unlikely Very Likely ☐ ☐ ☐ ☐ ☐
11. How likely would it be for you use to green roofing in an urban development project?	Very Unlikely Very Likely ☐ ☐ ☐ ☐ ☐
12. How likely would it be for you to use underground vaults in an urban development project?	Very Unlikely Very Likely ☐ ☐ ☐ ☐ ☐
13. On how many projects do you perform a life-cycle analysis for stormwater best management practices?	None Some All ☐ ☐ ☐ ☐ ☐
14. Why are alternative methods not employed?	Unknown Not Possible ☐ ☐ ☐ ☐ ☐

15. How difficult is permitting for permeable paving?	Very Difficult Very Easy ☐ ☐ ☐ ☐ ☐
16. How difficult is permitting for underground vaults?	Very Difficult Very Easy ☐ ☐ ☐ ☐ ☐
17. How difficult is permitting for green roofs?	Very Difficult Very Easy ☐ ☐ ☐ ☐ ☐
18. How often would you use the method with the lowest life-cycle cost?	None Some All ☐ ☐ ☐ ☐ ☐
19. How familiar are you in using permeable pavement?	None Some Very ☐ ☐ ☐ ☐ ☐
20. How familiar are you in using green roofs?	None Some Very ☐ ☐ ☐ ☐ ☐
21. How familiar are you in using underground vaults?	None Some Very ☐ ☐ ☐ ☐ ☐

APPENDIX B
LIFE-CYCLE COSTS USED IN CASE 1

Conventional pond	Initial costs	Construction	$ 24,277
	Annual costs	Maintenance	$ 120
		Clean filter	$ 240
		Cut grass	$ 560
		Net annual	$ (920)
Permeable pavement	Initial costs	Construction	$ 26,016
	Annual costs	Maintenance	$ 144
		Clean filter	$ 288
		Cut grass	$ 480
	Annual benefits	Additional parking	$ 27,986
		Net annual	$ 27,074
Green roof	Initial costs	Construction	$ 56,547
	Annual costs	Plant maintenance	$ 520
		Clean filter	$ 200
		Cut grass	$ 480
	Annual benefits	Additional parking	$ 27,986
		Net annual	$ 26,786
Underground vault	Initial costs	Construction	$ 97,736
	Annual costs	Maintenance	$ 288
		Cut grass	$ 480
	Annual benefits	Additional parking	$ 27,986
		Net annual	$ 27,218

APPENDIX C
LIFE-CYCLE COSTS USED IN CASE 2

Pond	Initial costs	Construction	$ 79,135
	Annual costs	Maintenance	$ 240
		Clean filter	$ 480
		Cut grass	$ 1,120
		Net annual	$ (1,840)
Permeable pavement	Initial costs	Construction	$ 182,690
	Annual costs	Maintenance	$ 288
		Clean filter	$ 576
		Cut grass	$ 960
	Annual benefits	Additional parking	$7,986.12
		Net annual	$ 6,162
Green roof	Initial costs	Construction	$ 214,274
	Annual costs	Plant maintenance	$ 39,833
		Clean filter	$ 420
		Cut grass	$ 960
	Annual benefits	Additional parking	$ 3,800
		Net annual	$ (36,993)
Underground vault	Initial costs	Construction	$ 170,469
	Annual costs	Maintenance	$ 351
		Clean filter	$ 370
		Cut grass	$ 815
	Annual benefits	Additional parking	$7,986.12
		Net annual	$ 6,820

APPENDIX D
LIFE-CYCLE COSTS USED IN CASE 3

Pond	Initial Costs	Construction	$ (168,259)
	Annual Costs	Maintenance	$ 265
		Clean Filter	$ 490
		Cut Grass	$ 1,230
		Lost Rent	$ 34,079
		Net annual	$ (1,985)
Permeable Pavement	Initial Costs	Construction	$ (142,747)
	Annual Costs	Maintenance	$ 288
		Clean Filter	$ 576
		Cut Grass	$ 960
		Lost Rent	$ 29,333
		Net annual	$ (31,157)
Green Roof	Initial Costs	Construction	$ 282,483
	Annual Costs	Plant maintenance	$ 2,160
		Clean Filters	$ 576
		Cut grass	$ 960
	Annual Benefits	Additional Rent	$ 39,911
		Net annual	$ 36,215
Underground Vault	Initial Costs	Construction	$ 38,088
	Annual Costs	Maintenance	$ 576
		Cut Grass	$ 960
		Clean Filter	$ 675
		Net annual	$ (2,211)

APPENDIX E
CASE 1 CONVENTIONAL POND ESTIMATE

Sub System	Quantity	Units	$/unit	Total
Sod	8,127	Sf	0.47	$ 3,779
Excavate Pond:	513	Cy	9.70	$ 4,971
Haul excavated soil:	615	Lcy	11.00	$ 6,765
Total pond				$ 15,516
Paving	522	Sy	38.00	$ 19,853
Strait curbs	246	Lf	22.50	$ 5,541
Curved curbs	62	Curved	25.00	$ 1,544
Stripes	12	Stalls	10.30	$ 124
Total lot				$ 27,061
Total site costs w/ conventional:				$ 42,576
Location factor				82.40%
Time factor				30.80%
				$ 24,277

APPENDIX F
CASE 1 UNDERGROUND VAULT ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	7,339	Sf	0.47	$ 3,413
Excavate pond:	82	Cy	9.70	$ 795
Haul excavated soil:	177	Lcy	1.00	$ 1,952
Vault tank	1	Ea		$ 131,500
Total vault				$ 137,661
Paving	581	Sy	45.60	$ 26,484
Strait curbs	246	Lf	22.50	$ 5,541
Curved curbs	62	Curved	25.00	$ 1,544
Stripes	17	Stalls	10.30	$ 175
Total lot				$ 33,743
Total site costs w/ underground vault:				$ 171,404
Location factor				82.40%
Time factor				30.80%
				$ 97,736

APPENDIX G
CASE 1 PERMEABLE PAVEMENT ESTIMATE

Sub System	Quantity	Units	$/unit	Total
Sod	7,339	Sf	0.47	$ 3,413
Excavate Pond:	82	Cy	9.70	$ 795
Haul excavated soil:	98	Lcy	11.00	$ 1,083
Total pond				$ 5,291
Paving	581	Sy	45.60	$ 26,484
Aggregate drainage	581	Sy	11.35	$ 6,592
Strait curbs	246	Lf	22.50	$ 5,541
Curved curbs	62	Curved	25.00	$ 1,544
Stripes	17	Stalls	10.30	$ 175
Total lot				$ 40,335
Total site costs w/ permeable:				$ 45,626
Location factor				82.40%
Time factor				30.80%
				$ 26,016

APPENDIX H
CASE 1 GREEN ROOF ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	7,339	Sf	0.47	$ 3,413
Excavate pond:	372	cy	9.70	$ 3,610
Haul excavated soil:	447	Lcy	11.00	$ 4,913
Total pond				$ 11,936
Green roof	3744	Sf	17.00	$ 63,648
Shingles	4980	Sf	2.04	$ 10,158
Total green roof				$ 53,490
Paving	581	Sy	45.60	$ 26,484
Strait curbs	246	Lf	22.50	$ 5,541
Curved curbs	62	Curved	25.00	$ 1,544
Stripes	17	Stalls	10.30	$ 175
Total lot				$ 33,743
Total site costs w/ permeable:				$ 99,168
Location factor				82.40%
Time factor				30.80%
				$ 56,547

APPENDIX I
CASE 2 CONVENTIONAL POND ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	19,667	sf	0.47	$ 9,145
Excavate pond:	260	cy	9.70	$ 2,519
Haul excavated soil:	312	lcy	11.00	$ 3,428
Total pond				$ 15,093
Paving				
1 1/2"binder course	2,326	sy	5.20	$ 12,095
2" wearing course	2,326	sy	7.00	$ 16,281
10" limestone base	307	sy	12.15	$ 3,731
6" limestone base	2,019	sy	7.85	$ 15,848
Strait curbs	995	lf	22.50	$ 22,388
Curved curbs	260	lf	25.00	$ 6,500
Stripes	53	stalls	10.30	$ 546
Total lot				$ 77,389
Total site costs w/ conventional:				$ 92,481
Location factor				82.40%
Time factor				3.85%
				$ 79,139

APPENDIX J
CASE 2 UNDERGROUND VAULT ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	10,317	sf	0.47	$ 4,797
Excavate pond:	313	cy	9.70	$ 3,033
Haul excavated soil:	375	lcy	11.00	$ 4,127
Water vault	1	ea	90,500.00	$ 90,500
Total vault				$ 102,457
Paving				
1 1/2"binder course	3,019	sy	5.20	$ 15,696
2" wearing course	3,019	sy	7.00	$ 21,130
10" limestone base	307	sy	12.15	$ 3,731
6" limestone base	2,711	sy	7.85	$ 21,285
Strait curbs	1,140	lf	22.50	$ 25,650
Curved curbs	340	lf	25.00	$ 8,500
Stripes	74	stalls	10.30	$ 762
Total lot				$ 96,754
Total site costs w/ underground:				$ 199,211
Location factor				82.40%
Time factor				3.85%
				$ 170,469

APPENDIX K
CASE 2 PERMEABLE PAVEMENT ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	10,317	sf	0.47	$ 4,797
Excavate pond:	82	cy	9.70	$ 795
Haul excavated soil:	98	lcy	11.00	$ 1,083
Total pond				$ 6,675
Paving	3,019	sy	45.60	$ 137,644
Aggregate drainage	3,019	sy	11.35	$ 34,260
Strait curbs	1,140	lf	22.50	$ 25,650
Curved curbs	340	lf	25.00	$ 8,500
Stripes	74	stalls	10.30	$ 762
Total lot				$ 206,816
Total site costs w/ permeable:				$ 213,492
Location factor				82.40%
Time factor				3.85%
				$ 182,690

APPENDIX L
CASE 2 GREEN ROOF ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	21,331	sf	0.47	$ 9,919
Excavate pond:	187	cy	9.70	$ 1,815
Haul excavated soil:	225	lcy	11.00	$ 2,470
Total vault				$ 14,204
Paving				
1 1/2"binder course	2,449	sy	5.20	$ 12,736
2" wearing course	2,449	sy	7.00	$ 17,144
10" limestone base	307	sy	12.15	$ 3,731
6" limestone base	2,142	sy	7.85	$ 16,815
Strait curbs	1,045	lf	22.50	$ 23,513
Curved curbs	280	lf	25.00	$ 7,000
Stripes	63	stalls	10.30	$ 649
Total lot				$ 81,588
Green roof	14,490	sf	14.00	$ 202,860
3 ply roofing	14,490	sf	2.33	$ 33,762
Insulation	14,490	sf	1.00	$ 14,490
Total green roof				$ 154,608
Total site costs w/ green roof:				$ 250,401
Location factor				82.40%
Time factor				3.85%
				$ 214,274

APPENDIX M
CASE 3 CONVENTIONAL POND ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	4,657	sf	0.47	$ 2,165
Excavate pond:	128	cy	9.70	$ 1,239
Haul excavated soil:	153	lcy	11.00	$ 1,685
Total pond				$ 5,089
Concrete				
Paving	190	sy	38.00	$ 7,203
Total paving				$ 7,203
Less building	(2,069)	sf	101.00	$ (208,920)
Total site costs w/ conventional:				$ (196,628)
Location factor				82.40%
Time factor				3.85%
				$ (168,259)

APPENDIX N
CASE 3 UNDERGROUND VAULT ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	3,974	sf	0.47	$ 1,848
Excavate pond:	140	cy	9.70	$ 1,354
Haul excavated soil:	167	lcy	11.00	$ 1,842
Water vault	1	ea	32,265.00	$ 32,265
Total vault				$ 37,309
Concrete				
Paving	190	sy	38.00	$ 7,203
Total lot				$ 7,203
Total site costs w/ underground:				
Location factor				82.40%
Time factor				3.85%
				$ 38,088

APPENDIX O
CASE 3 PERMEABLE PAVEMENT ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	3,974	sf	0.47	$ 1,848
Excavate pond:	110	cy	9.70	$ 1,066
Haul excavated soil:	132	lcy	11.00	$ 1,451
Total pond				$ 4,365
Concrete				
Paving	190	sy	45.60	$ 8,644
Total lot				$ 8,644
Less building	-1,780	sf	101.00	$ (179,823)
Total site costs w/ permeable:				$ (166,814)
Location factor				82.40%
Time factor				3.85%
				$ (142,747)

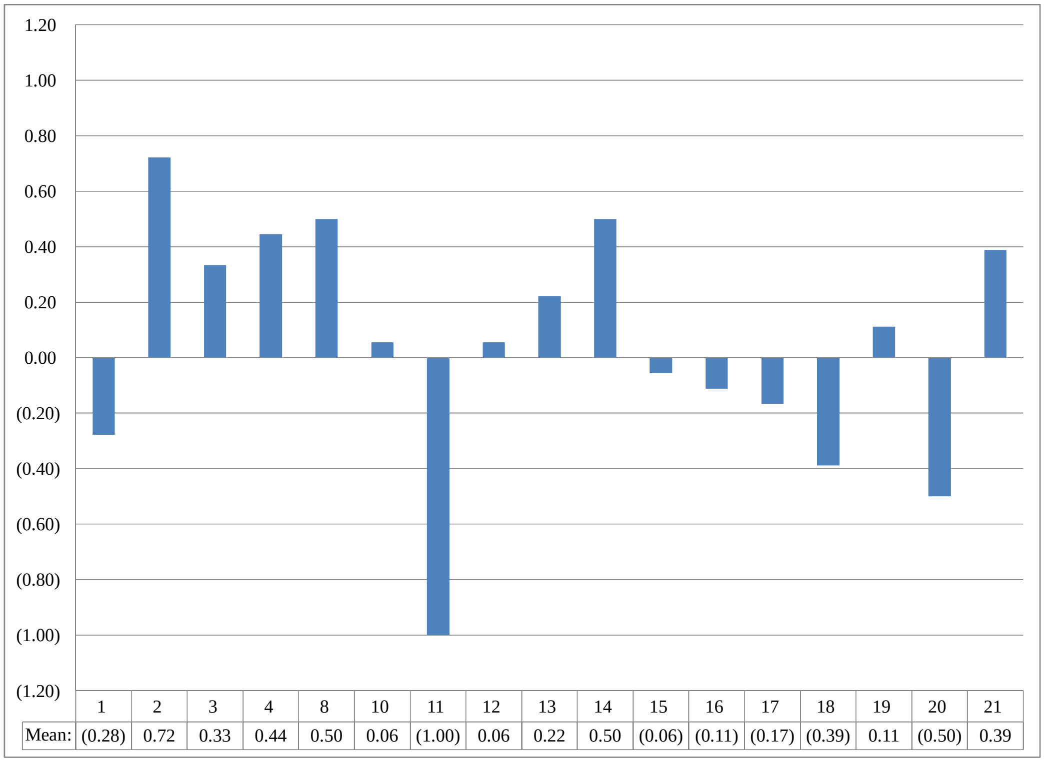
APPENDIX P
CASE 3 GREEN ROOF ESTIMATE

Sub system	Quantity	Units	$/unit	Total
Sod	3,167	sf	0.47	$ 1,472
Excavate pond:	30	cy	9.70	$ 288
Haul excavated soil:	36	lcy	11.00	$ 391
Total vault				$ 2,151
Concrete Paving	190	sy	38.00	$ 7,203
Total lot				$ 7,203
Green roof	7,131	sf	16.00	$ 114,088.
3 ply roofing	7,131	sf	2.33	$ 16,614
Insulation	7,131	sf	1.00	$ 7,131
Total green roof				$ 90,343
Additional building	2,423	sf	101.00	$ 244,673
Total site costs w/ green roof:				$ 344,371
Location factor				82.40%
Time factor				3.85%
				$ 294,686

APPENDIX Q
SURVEY DATA

		Respondent Code:																	
Question:	Mean:	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	(0.28)	2	(1)	1	(1)	(2)	0	(2)	1	(1)	(2)	1	(1)	(2)	1	0	1	0	0
2	0.72	0	0	1	1	2	1	2	0	1	2	2	0	2	0	(1)	(1)	(1)	2
3	0.33	1	(1)	(1)	0	2	2	0	0	2	(1)	2	1	2	(2)	(2)	0	(1)	2
4	0.44	0	(1)	1	1	1	(1)	1	0	1	0	1	2	1	0	2	0	0	(1)
5	N/A	N/A																	
6	N/A	2	1	2	1	2	2	1	1	2	1	2	1	2	1	1	3	1	1
7	N/A	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	1	3	3
8	0.50	2	0	1	1	2	1	2	1	1	(1)	(1)	1	0	(2)	(1)	0	2	0
9	N/A	4	3	2	3	2	3	3	3	1	4	3	5	2	3	3	2	5	4
10	0.06	(1)	0	2	0	0	(2)	(2)	0	2	2	0	2	1	0	1	(1)	(1)	(2)
11	(1.00)	(1)	(1)	(2)	(2)	(2)	0	(1)	1	(1)	(1)	(2)	(1)	0	(2)	(2)	(2)	(1)	2
12	0.06	1	(1)	(1)	0	(1)	(1)	(1)	2	1	0	(1)	1	(1)	(1)	2	(2)	2	2
13	0.22	(2)	1	0	0	(1)	(2)	1	1	2	2	2	(2)	1	(1)	(1)	1	2	0
14	0.50	2	1	1	1	(1)	0	(1)	2	1	(1)	1	1	1	0	1	0	(1)	1
15	(0.06)	(1)	0	0	0	2	(2)	0	(2)	(1)	2	1	1	2	2	(2)	(1)	(1)	(1)
16	(0.11)	1	0	1	1	(1)	1	1	0	0	(2)	(2)	1	0	(2)	(1)	1	(1)	0
17	(0.17)	(2)	0	(1)	(1)	0	1	(1)	1	0	1	(2)	(1)	1	(2)	1	(1)	2	1
18	(0.39)	(1)	(2)	(1)	(1)	(2)	(1)	(2)	(2)	2	(2)	2	2	1	(1)	1	(1)	(1)	2
19	0.11	2	2	1	1	(1)	2	(1)	1	(2)	1	(1)	1	(2)	2	(1)	(1)	(2)	0
20	(0.50)	0	(2)	(2)	(2)	0	(1)	0	(2)	(1)	(1)	1	1	(2)	1	0	(2)	2	1
21	0.39	2	0	1	1	1	0	(2)	2	(2)	0	0	2	1	1	0	0	2	(2)

APPENDIX R
MEAN RESPONSES FOR NUMERICAL SURVEY QUESTIONS



	1	2	3	4	8	10	11	12	13	14	15	16	17	18	19	20	21
Mean:	(0.28)	0.72	0.33	0.44	0.50	0.06	(1.00)	0.06	0.22	0.50	(0.06)	(0.11)	(0.17)	(0.39)	0.11	(0.50)	0.39

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BIOGRAPHICAL SKETCH

Kenny Perrine was born in Cape Canaveral, FL, and was the youngest of four children. He grew up in Titusville, Florida, where he acquired his high school education at Astronaut High School. Afterwards, he enrolled in the University of Florida and entered the M.E. Rinker Senior School of Building Construction two years later. After four years of college, he graduated with a Bachelor of Science in Building Construction. He completed his Masters of Science in Building Construction the following year. After school, he married his college sweetheart and moved to Houston, Texas, to begin his career.