AN EVALUATION OF DESIGN: LOW IMPACT DEVELOPMENT VS. TRADITIONAL DESIGN ON A SITE IN LOS ANGELES, CALIFORNIA

By

Morgan Haffey

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ABSTRACT

AN EVALUATION OF DESIGN: LOW IMPACT DEVELOPMENT VS. TRADITIONAL DESIGN ON A SITE IN LOS ANGELES, CALIFORNIA

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Because of the growth in urbanism, professionals in the environmental industry are often tasked with designing strategies to accommodate urban development while minimizing environmental impact (Selbig & Bannerman, 2008). Converting the natural landscape into residential or commercial developments can drastically alter its hydrologic characteristics (Selbig & Bannerman, 2008). This study compares an existing undeveloped site along the Los Angeles River (scenario 1) with two design scenarios. One design is the city's conceptual plan, referred to as a Mia Lehrer and Associates Design (design scenario 3). The second design incorporates low impact design elements, referred to as the Extended LID Design (design scenario 2). Using these three scenarios and the EPA stormwater calculator, runoff, infiltration, and evaporation will be measured to determine which design is most effective along these three parameters. The Friedman's One Way of Variance Test was applied to the treatments in order to determine which design was most successful concerning stormwater management. The results show that the design with LID controls are significantly greater than the existing conditions ($p \leq 0.005$). These results are important because they show that LID controls are beneficial to site design when stormwater management is a concern. These findings also show that it is important to investigate low impact development for future sites and can raise awareness within the engineering community.

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Chapter 1: Introduction

The phrase “low impact development” (LID) indicates systems or practices that emulate natural processes that result in “infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitats” (USEPA, 2016). LID is more closely related to land development and finding a way to manage stormwater as close to its source as possible. LID used in the re-development process is a way of recreating or preserving the natural landscape, and creating effective and aesthetic site drainage that treats stormwater as a valuable resource instead of sending it directly into city/county drains as waste (USEPA, 2016). Managing stormwater on site is extremely important considering that traditional urban areas are primarily impervious surfaces and lead to a more diverse range of pollutants, reduce pollutant removal during overland flow, reduced infiltration, and increased peak flows (Selbig & Bannerman, 2008). LID practices are a way of managing water to reduce the effect and impact of the urban areas.

Stormwater runoff is a major source of pollution in urban areas (USEPA, 2016). Because of urbanization, rainfall cannot naturally seep into the ground. Traditional piping systems are designed to catch rainfall and transport it to bodies of water even though stormwater from urban areas is not naturally filtered and carries trash, bacteria, and other pollutants (USEPA, 2016). These pollutants come from many factors of the urban sprawl such as parking lots, buildings, pavement, and gasoline from cars. In natural areas, rainfall is absorbed and filtered by soil and plants. The goal of LID is to reproduce or emulate this natural process in order to manage stormwater nearest to its source.

Through research it is clear that there are many benefits in using LID for design purposes. Research lacks evidence of the concerns of LID and why people are hesitant to use these design elements. This research focuses low impact development elements, it compares and assesses the ecological benefits and discusses practice of LID designs on new development sites, redevelopment sites, and with urban retrofitting. By comparing specific design variables in each design scenario, calculating the results using the EPA National Stormwater Calculator, and determining LID elements and strategies, this study provides evidential support for adopting LID practices for designers, developers, researchers, and government agencies.

Chapter 2: Literature Review

2.1 Low Impact Development

2.1.1 What is LID?

Low impact development (LID) is a technique that emulates the natural hydraulic cycle by using principles modeled after nature such as infiltration, filtering, storage, evaporation, and detaining runoff close to its source (Southeast Michigan Council of Governments, 2008). With the ever growing rate of population and urban communities, protecting the process of the water cycle is highly important. The use of LID elements is one way to reduce the negative impacts of urbanization on the natural hydraulic systems (USEPA, 2000). The objective for low impact development is to maintain the natural condition that was present before development has occurred. Since the increase in urbanization is critical to the environment, LID seeks to decrease the amount of paving, pipe systems, and stormwater structures by using a more natural approach such as grass swales, constructed wetlands, green roofs, rain gardens, and bioswales.

2.1.2 International Definitions of LID

As previously mentioned, the use of the term low impact development has different meaning around the world. In the United States it is defined as, "a system or practice that mimics the natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat" (USEPA, 2016). In the United States low impact development is more commonly associated with stormwater management practices. In the United Kingdom, LID is defined as "development that through its low impact either enhances or does not significantly diminish environmental quality" (Sylvawood, n.d.). Overtime many people have expanded on the definition of LID. According to Heather Sylvawood, a study by the University of West England defined LID as "integrally connected with land management and as much as describing physical development, LID also describes a form of livelihood" (Sylvawood, n.d.). The study also states that LID is a "multi-featured and intrinsically integrated form of development" (Sylvawood, n.d.). In the United Kingdom, LID encompasses a variation of environmental elements "including visual quality, wildlife habitat protection, air quality, and land consumption as we as stormwater volume and quality" (Wang et al., 2017). Therefore it seems there is no simple definition of low impact development because of how detailed the topic is and how it is implemented in different regions of the world.

2.1.3 The Evolution of LID

Since low impact development was first introduced, it has evolved due to use of different terminology, descriptions, and practices and principles. Because of these differences the evolution of LID has caused an increase in confusion, miscommunication, and misunderstanding (Fletcher et al., 2017). The development and use of terminology in disciplines such as landscape architecture, planning, and engineering is used in more of an informal manner, which is driven by local and regional perspectives and understanding (Fletcher et al., 2017). This results in the use of different terms that in time can be used to define similar concepts in different parts of the world. Over time this will lead to overlaps, contradictions, and confusion (Fletcher et al., 2017). For example, according to Urban Drainage Multilingual Glossary publish in 2004, which includes drainage definitions in English, French, German, and Japanese, there are many terms that have similar definitions between the four languages. But the glossary also demonstrates that some terms and concepts could not be accurately translated from their original language (Fletcher et al., 2017).

A good comparison is the use of terminology and language in the medical field. Medical terminology maintains a common reference point meaning that all terminology is broken down into concepts and relationships (Bronnert, Masarie, Naeymi-Rad, Rose, & Aldin, n.d.). Having this efficiency within the medical field allows for improved communication between medical offices and fields (Fletcher et al., 2017). Medical terminology is based around Nomina Anatomica, or anatomical nomenclature, which removes the obstacle of confusion when assessing new findings (Fletcher et al., 2017). This is along the same reason that plants are classified by their taxonomy. Each type of plant is categorized in a kingdom, subkingdom, super division, division, subdivision, class, subclass, order, family, and genus (USDA & Natural Resources Conservation Service, 2017). Although plants have “common names”, scientific Latin names are used to help describe both the genus and species of plants around the world. This is similar to the use of anatomical nomenclature in the medical field.

The topic of urban drainage dates back to at least 3000 BC and has had a focus on the movement of water away from urban areas (Fletcher et al., 2017). In recent years the topic of sustainability has become very popular and over time has produced new terms (Fletcher et al., 2017). Terms such as low impact development, sustainability, sustainable urban drainage systems, water sensitive urban design, and best management practices are fairly new within the last 20-30 years (Fletcher et al., 2017).

The term low impact development (LID) is most commonly used in North America and New Zealand and was first used in 1977 in a report on land use planning in Vermont, USA (Fletcher et al., 2017). The approach of LID originally was to “minimize the cost of stormwater management by taking a design with nature approach” (Barlow 1977). The original intent of LID was also to complete a “natural” hydrology system by the use of site layout and control measures (Fletcher et al., 2017). This is a balance between pre-development runoff, infiltration, and evapotranspiration volumes, which would be implemented through a “functionally equivalent hydrologic landscape" (Fletcher et al., 2017). After some time, the widespread design community had evolved the interpretation of LID from its original meaning to a broad set of practices and designs that treated stormwater (Fletcher et al., 2017).

Today, since the definition of low impact development has evolved, most states have their own best management practices manual that define what LID is and how it should be used. Most countries have similar definitions, but it is not uncommon that the terminology varies. For example in New Zealand the use of LID implies that the impact of the design is far lower than that of the original practice (Fletcher et al., 2017). Since the definitions and terminology of LID varies with location it is important that researchers and professionals communicate in order to ensure that they are referring to the same concepts.

2.1.4 LID Design Elements

There are many different design elements related to low impact development and it is important to understand the function of each of them in order to incorporate the most appropriate element in site specific design. Different sites have varieties of issues concerning stormwater management. Rain gardens for example are capable of increasing groundwater recharge and are appropriate for sites with contamination as well as excess runoff (Dietz, 2007). Green roofs are another LID design element that research has shown positive results with retention rates between 60% and 70% of precipitation (Dietz, 2007). Permeable paving is a great alternative to concrete and asphalt paving because of its ability to infiltrate stormwater and decrease the rate and amount of runoff in hardscaped areas (Dietz, 2007). Therefore, it is crucial that one understands the different types of design elements associated with LID in order to design with stormwater management in mind.

2.1.5 Urbanization

In the Unites States there are roughly 400 metropolitan areas, and the top 100 of them occupy 12% of the nation's landmass, generate 68% of our jobs, 75% of our national GDP, and are home to 65% of the population (Katz, 2017). Clean water is an important part of sustaining life, but urbanization is one of the many factors that are threatening our water resources. According to Southeast Michigan Council of Government (2008), problems related to stormwater runoff are most prevalent where urbanization has occurred. Conventional land development alters the land and effects the water cycle (Southeast Michigan Council of Governments, 2008). Altering one part of the water cycle causes changes to the other components of the hydraulic cycle (Southeast Michigan Council of Governments, 2008). Due to a large increase in impervious surfaces such as roads, buildings, and parking lots there is an abundance of rainfall that runs off instead of soaking into the soil (National Asphalt Pavement Association, 2016). The high percentage of impervious surface cover decreases the landscape's ability to absorb water (University of New Hampshire, 1995). According to The National Asphalt Pavement Association or NAPA, the United States has more than 2.7 million miles of paved roads and highways (National Asphalt Pavement Association, 2016). As water flows off of impervious surfaces and runoff increases, the amount of groundwater recharge decreases (Southeast Michigan Council of Governments, 2008). Impacts of stormwater runoff include increased flooding and property damage, degradation of the stream channel, less groundwater recharge and dry weather flow, impaired water quality, increased water temperature, loss of habitat, and decreased recreational opportunities (Southeast Michigan Council of Governments, 2008). Katz (2017), a centennial scholar who focuses on the challenges and opportunities of global urbanization, states that by 2050, 70 percent of the global population will live in an urban area. With this large of an increase in urbanization it is important that we explore the benefits and concerns of low impact design and how it has a positive impact on urban sprawl.

2.1.6 Opportunities/Benefits

Previous studies explore the beneficial uses of LID at many different scales from site specific to entire watersheds. However, there is still a debate concerning the unexplored gaps of low impact development and the effectiveness it has towards stormwater management issues (University of New Hampshire, 1995). Even though LID is a fairly new concept, one benefit is that it can be applied to new developments, urban retrofitting, and redevelopments in order to help communities find a balance between public safety, economic development, and ecological protection (University of New Hampshire, 1995). Since the goal of LID is to emulate the natural landscape, pre-development hydrology measures of runoff rate and run off volume are used in the development of LID elements (University of New Hampshire, 1995). In reality, the amount of water that leaves a site, whether it is a new development or a redevelopment, should match the "same rate, quality, and quantity of water that existed in the predevelopment condition" (University of New Hampshire, 1995).

A project in Ingham County, Michigan concerning Lansing's most polluted pipe outlet is being redesigned to incorporate many LID elements to replace the storm piping system that is currently on site ("Ingham County Drain Commissioner Plans Massive Urban Retrofit," n.d.). This project is a great example of the use of LID elements and their positive impact on the environment. For this "massive urban retrofit" the drain commissioner has resorted to green infrastructure to replace the gray infrastructure because the inclusion of all LID elements is a fraction of the cost of replacing the storm pipes ("Ingham County Drain Commissioner Plans Massive Urban Retrofit," n.d.). The LID features that are incorporated into the future design of this urban retrofit are constructed wetlands, rain gardens, bio-rention areas, ponds and bio-digestive green walls ("Ingham County Drain Commissioner Plans Massive Urban Retrofit," n.d.). Currently the piping system collects runoff for around 800 acres and rushes the contaminated water directly into the Red Cedar River causing it to flood ("Ingham County Drain Commissioner Plans Massive Urban Retrofit," n.d.). According to project planners, it is expected that the "retrofit will reduce pollutant loading by 95%" ("Ingham County Drain Commissioner Plans Massive Urban Retrofit," n.d.).

Another benefit to low impact development is that it does not require large amounts of stormwater piping and infrastructure. Its goal is to reduce the amount of "downstream structural practices" and concentrate on maximizing "soil filtration/infiltration, biological uptake of water and nutrients, and cultivation of useful microbe populations" that are found in natural soils in order to transform compound contaminants found in stromwater (University of New Hampshire, 1995). Integrating low impact development strategies instead of underground piping systems into future designs is an effective way to deal with issues concerning runoff reduction, water quality and quantity treatment, and flood control (University of New Hampshire, 1995). Many studies indicate that it is possible for LID controls to reduce hydraulic impacts of development instead of traditional stormwater systems (Selbig & Bannerman, 2008).

Another advantage of LID is that it addresses stormwater with smaller, cost effective features that are scattered throughout an entire development site, which can ultimately replace the ineffective and costly solution of traditional pipe and pond management (University of New Hampshire, 1995). LID elements that this research will address are rain gardens, constructed wetlands, green roofs, permeable pavement, and infiltration basins. Attempting to identify "sensitive resources" on site is important when distinguishing which LID elements are appropriate on site.

Because low impact development can be applied at many different scales (University of New Hampshire, 1995) it is viewed favorably and shows versatility. This scale spans from watershed level down to individual site design. Resource conservation, pollution prevention, and decentralization of runoff are three factors that can be addressed at a watershed scale. Minimizing cut and fill, reducing impervious surfaces, and strategic timing of runoff are elements that can be dealt with at a site level (University of New Hampshire, 1995). By analyzing the use of LID from large scale to small scale issues, one can see that this is a beneficial factor when considering the use of LID principles.

While there are many benefits of low impact development, there are also concerns that need to be addresses. With a lack of research, it is difficult to determine why people are hesitant to incorporate LID when developing a site design.

2.1.7 Constraints

Communities may be hesitant to incorporate LID into designs because municipal decision making often happens in elective cycles rather than within long term planning (Woolson, 2013). However, while low impact development may show short term stormwater improvement, but is more productive when considering long term effectiveness. Cost concerns are a large issue with low impact development and the materials that are required. People are not willing to pay for a more expensive alternative even though there is research that shows LID is beneficial to the environment and serves a long term purpose when considering stormwater management (Woolson, 2013). Although research has evaluated LID controls individually and has proven that

LID controls are successful in reducing stormwater runoff volumes and improve water quality, there are very few studies that evaluate large scale LID concepts that incorporate multiple LID elements (Selbig & Bannerman, 2008).

Another constraint is the LID is less familiar and therefore communities may be hesitant to adopt. Often communities adopt planning and design approaches, methods, and techniques that are familiar and known. To engage in innovative approaches takes risk, education, and additional energy.

2.2 Design Elements of LID

2.2.1 Rain Gardens

One type of low impact development feature is a rain garden. They provide effective ways to collect and harvest rainwater as well as beautify an area (Grant & Giraud, 2015). Since California has mostly dry seasons with minimal rain, it is important to collect as much rainwater as possible. Although rain gardens are more popular in wetter climates they are efficient for California's Mediterranean climate (Grant & Giraud, 2015). Water from a site is channeled by swales, curb openings, rain gutters, etc., and is diverted into the rain garden area where it soaks into the ground and waters the vegetation (Grant & Giraud, 2015). Rain gardens that are designed correctly hold water for a short period of time in order to retain water long enough for it to percolate into the ground, which over time will maximize the amount of groundwater recharge (Grant & Giraud, 2015). This is one solution to keep water on site instead of diverting it to drains, rivers, and ponds. The goal of rain gardens is to allow water to slowly percolate into the ground acting as a small bioretention pond. "Plants and soil microorganisms break down organic compounds and remove pollutants such as phosphorus, nitrogen, and hydrocarbons" that are collected from surfaces such as parking lots, roofs, driveways, and industrial sites (Grant & Giraud, 2015).

Figure 1 demonstrates the fundamental parts of a constructed rain garden which includes, native moisture tolerant plant materials, native soils, appropriate pond water depth, and a perforated underdrain design (Southeast Michigan Council of Governments, 2008). Rain gardens are suitable for large scale and small scale sites and are beneficial to both residential and commercial design (Southeast Michigan Council of Governments, 2008). While being suitable for large and small scale sites they are also suitable for a variety of soils ranging from sandy loams to clay soils(Jaber, Woodson, LaChance, & Charriss, 2012). Common benefits of rain gardens have been found between researchers and include “less stormwater runoff, slower runoff rates, less pollution in the runoff, more water to replenish groundwater supplies, and improved landscape” (Jaber et al., 2012).

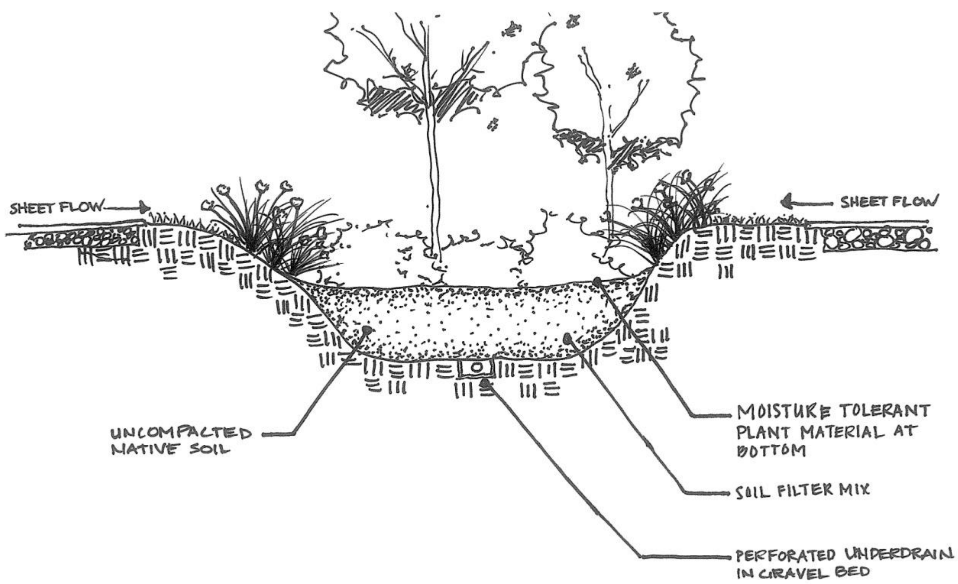

Figure 1. Schematic Design of a Rain Garden

2.2.2 Green Roofs

Vegetated roofs, otherwise known as green roofs, are thin layers of vegetative materials that allow for the rooftop to serve as a green space (Southeast Michigan Council of Governments, 2008). There are three types of vegetated roofs that all contain different layers and thickness of materials. The three types of variations are intensive, semi-intensive, and extensive (Southeast Michigan Council of Governments, 2008). An intensive green roof “utilizes a large variety of plants that include trees and shrubs”, which requires four inches or greater of layers (Southeast Michigan Council of Governments, 2008). This type of green roofs requires a lot of maintenance and are often found in park like settings (Southeast Michigan Council of Governments, 2008). Extensive vegetated roofs have a limited variety of plant selection because the substrate layer is shallow (Southeast Michigan Council of Governments, 2008). Unlike the intensive variation, extensive green roofs require little maintenance once the are established. This specific type is commonly used for an environmental benefit, such as storm runoff (Southeast Michigan Council of Governments, 2008). All of these variations have layers that contain “waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, synthetic components, and foliage” (Southeast Michigan Council of Governments, 2008). Green roofs can be applied to many different scales of design including commercial, urban areas, industrial, residential, and recreational (Southeast Michigan Council of Governments, 2008).

Figure 2 demonstrates the different layers that are associated with a vegetated roof. These layers can be different thicknesses depending on the type of green roof. Each layer has a different purpose. The root structure protects the roof construction from damaging any roots (Southeast Michigan Council of Governments, 2008). The waterproof membrane protects the structure from extra moisture(Southeast Michigan Council of Governments, 2008). Next is the protective layer, which is a “specially designed perforation resistant protection mat” that stops mechanical damage of the root barrier and roof construction during installations (Southeast Michigan Council of Governments, 2008). The purpose of the drainage layer is to allow excess run off into water outlets. Depending on the design of the green roof many drainage layers also serve as a means of “water storage, enlargement of the root zone, space for aeration of the system and protection for the layers below it” (Southeast Michigan Council of Governments, 2008). The filter layer separates the plant and substrate layers from the drainage layers in order to collect “small particles, humic and organic materials” for the availability of the plants (Southeast Michigan Council of Governments, 2008).

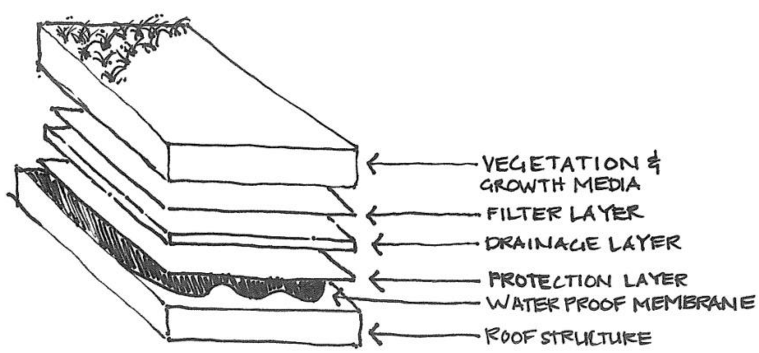

Figure 2. Schematic Design of a Green Roof

2.2.3 Permeable Paving

One type of infiltration technique is permeable paving, also known as pervious pavement. Pervious pavement is a technique that uses stormwater infiltration, storage, and structural pavement that has a permeable surface (Southeast Michigan Council of Governments, 2008) and dates back to the 1960’s (EPA, Woodlands, Thelen, Howe, & Associates, 2017). The idea of porous pavement was introduced in order to “promote percolation, reduce storm sewer loads, reduce floods, raise water tables, and replenish aquifers” (EPA, Woodlands et al., 2017). Many porous pavement sites have been constructed since then and have both succeeded and failed in various climate situations (EPA, Woodlands et al., 2017). Most of the failures are due to the fact that silt and other materials entered the site and clogged the pavement seams (EPA, Woodlands et al., 2017). As time has passed many variations of pavers and pavement have been created. According to Cahill Associates, who have implemented more than 200 porous asphalt pavement sites since the 1980's, have reported no failures because of proper design and construction methods (EPA, Woodlands et al., 2017). Therefore it is important that when implementing low impact development elements on a site, intense research must be performed in order to design for successful site specific performance. Underneath these layers is a storage reservoir that collects the run off from the above layers. Pervious pavement can be used for all variations of scale including "parking lots, entire streets, walking paths, sidewalks, playgrounds, plazas, and recreation courts" (Southeast Michigan Council of Governments, 2008). Different variations of pervious paving are porous asphalt, pervious concrete, permeable paver blocks, and reinforced turf/gravel (Southeast Michigan Council of Governments, 2008).

Figure 3 is an illustration of the layers that make up pervious pavement. The top layer, pervious pavement, allows water to pass through and slowly infiltrates through the next couple layers of large aggregate, coarse aggregate, and uncompacted subgrade (Southeast Michigan Council of Governments, 2008). Depending on the site and scale different designs will call for varying amounts of layers. As the water passes through these layers is it cleansed of some pollutants and larger particles that cannot pass through the small openings in the pervious pavement. Pervious pavement can be used for more than a best management practice (BMP), it can also be used for safety reasons. Because pervious pavements allow water to pass through, it decreases the chances of hydroplaning (Southeast Michigan Council of Governments, 2008).

Porous asphalt is a “standard bituminous asphalt where the fines have been screened and reduces, allowing water to pass through small voids” (Southeast Michigan Council of Governments, 2008). Porous asphalt can be used in any location that is appropriate to use standard asphalt. It is typically poured directly on the gravel subbase with a thickness of 2.5 inches (Southeast Michigan Council of Governments, 2008). Pervious concrete is another variation of pervious pavement. It is very similar to porous asphalt in that fact that it is also created by reducing the number of fines in a mix in order to establish voids (Southeast Michigan Council of Governments, 2008). Porous concrete is much more ridged in appearance compared to traditional concrete due to the larger fines which makes this easy for water to pass through (Southeast Michigan Council of Governments, 2008). According to the LID Manual for Michigan, porous concrete has proven to be an effective stormwater management technique if it is installed correctly. Permeable paver blocks are made up of “interlocking units that provide some portion of surface area that may be filled with a pervious material such as gravel” (Southeast Michigan Council of Governments, 2008). Most permeable paver blocks are often concrete and serve as an aesthetic element. They can be used in many different type of designs, but they are most popular in “plazas, patios, parking areas, and low-speed streets” (Southeast Michigan Council of Governments, 2008). Reinforced gravel/turf is another variation of pervious pavement types and also consists of an interlocking structural unit that has voids for turf grass to grow (Southeast Michigan Council of Governments, 2008). This makes it suitable for traffic and parking (Southeast Michigan Council of Governments, 2008). The reinforced turf includes concrete or plastic underlain by a gravel layer serving as a drainage system (Southeast Michigan Council of Governments, 2008). These different types of permeable pavings are great options when considering stormwater management solutions, but there are common concerns within the previous research. These concerns include clogging and failure, cost prohibitive, maintenance costs are high, functionality in cold climates, and adequate stability and structure for truck traffic and heavy loading (“Eisenberg, Bethany, Lindow, Kelly Collins, and Smith, David R.,” 2017).

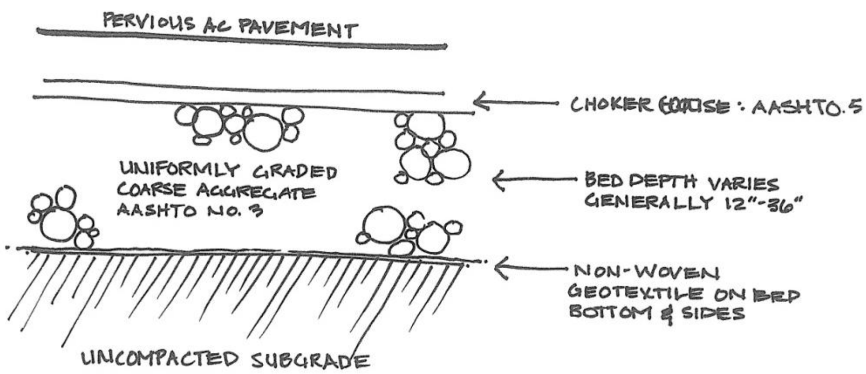

Figure 3. Schematic Design of Permeable Paving

2.2.4 Infiltration Basin

An infiltration basin is a vegetated depression where stormwater runoff is stored until it slowly infiltrated into the soil (RWRA, n.d.). The purpose of an infiltration basin is primarily to enhance water quality by removing pollutants, but it can also serve as a means for managing flooding and channel erosion control (RWRA, n.d.). This specific LID element applies mostly to sites that contain soils with a reasonable infiltration rate and the water table is fairly low in order to prevent pollution of groundwater (RWRA, n.d.). Unlike a conventional piping system that requires an outflow, LID infiltration basins do not require this component due to the fact that outflow is through the surrounding soil (New Jersey Stormwater Manual, 2004). Ideal sites to incorporate the use of infiltration basins are usually medium-density residential or commercial sites that contain an impervious cover of 36%-66% (RWRA, n.d.).

A study done by the Wisconsin Department of Natural Resources (WDNR) and the U.S. Geological Survey (USGS) compared two infiltration basins to determine whether using LID techniques or conventional stormwater systems was more productive when aiming to reduce runoff volumes and improve water quality (Selbig & Bannerman, 2008). Comparisons of pollutant loads was analyzed between both infiltration basin designs in order to evaluate the benefits of low impact design (Selbig & Bannerman, 2008). This study along with many others indicated that developments adopting the low impact development approach produce less runoff than conventional sites (Brander, Owen, & Potter, 2004).

Figure 4 demonstrates a typical design for an LID infiltration basin. When designing an infiltration basin consideration should be given to the soil characteristics, depth to the groundwater table, sensitivity to the region, and runoff water quality (New Jersey Stormwater Manual, 2004). It is important that the soils are permeable and not compacted during the design phase because this will alter the infiltration rate and cause contamination, clogging, or flooding (New Jersey Stormwater Manual, 2004). Basins should only occur where the surrounding slopes are less than ten percent, and the basin floor needs to be as level as possible for "uniform spreading" of stormwater runoff (New Jersey Stormwater Manual, 2004).

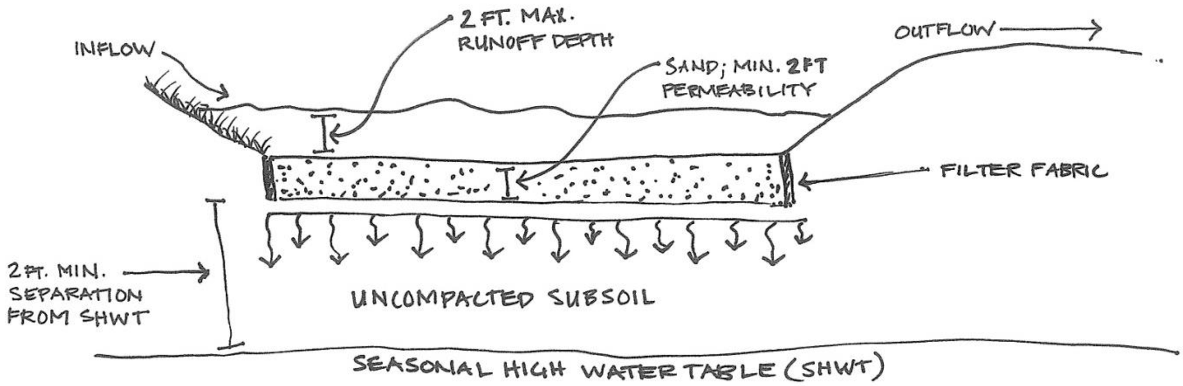

Figure 4. Schematic Design of an Infiltration Basin

2.2.5 Constructed Wetlands

Constructed wetlands are manmade wetlands that simulate the natural processes in order to properly treat stormwater, wastewater, agricultural waste water, and improve water quality of point and non-point sources of water pollution (Davis, n.d.). Much like the other LID elements, constructed wetlands have layers. The layers consist of wetland vegetation, soils, and "microbial assemblages" that improve water quality (USEPA, 2000). Wetlands are most commonly used in the process of revitalizing ecosystems and as water treatment systems (Davis, n.d.). Although constructed wetlands can be used at a variety of scales, they are most successful when designed for a larger site. A benefit of this element of LID development is that constructed wetlands can have an infinite lifetime (Davis, n.d.). Depending on the wastewater loadings and the capacity of the wetland to remove waste, a wetland can operate for over 20 years with little to no loss in effectiveness (Davis, n.d.).

Figure 5 demonstrates how a wetland is constructed and its different layers. Typically a constructed wetland requires an inlet device and an outlet device. The use of marsh plants and water tolerant vegetation is required so that they can use the nutrients and minerals that are cleansed from the water that is collected resulting in higher water quality (Davis, n.d.).

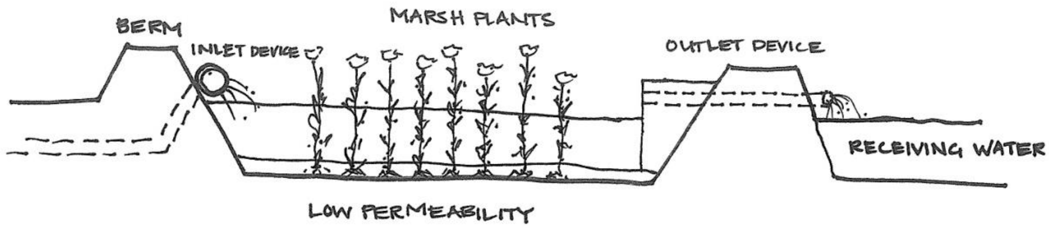

Figure 5. Schematic Design of a Constructed Wetland

2.3 Recent LID Studies

A recent study conducted in May 2007 in Waterford, CT analyzed the stormwater runoff and pollutants of a traditional subdivision design compared to a low impact subdivision design. The traditional design includes 17 lots that were built using current codes, regulations, and construction practices (Dietz & Clausen, 2008). The traditional design included a curb and gutter system with a 8.5 meter asphalt road, landscaping, and turf that were similar to new subdivisions in the area (Dietz & Clausen, 2008). The roof runoff was directed toward lawn areas and driveways, and the total impervious surface of the subdivision after construction was 32% (Dietz & Clausen, 2008). The low impact subdivision included 12 lots and incorporated several "pollution prevention measures" (Dietz & Clausen, 2008). This site replaced the 8.5 meter asphalt road and curb and gutter with a 6.1 meter Ecostone paver road and grassed swales (Dietz & Clausen, 2008). Other LID controls that were integrated into the design include bioretention, rain gardens, permeable pavers for driveways, and houses were constructed in clusters which reduced lawn size and maintenance (Dietz & Clausen, 2008). The total impervious surface after construction was completed was 21%, significantly lower then in the traditional design. The results of this study show that a large increase in runoff volume was due to the increase in impervious surfaces in the traditional subdivision design (Dietz & Clausen, 2008). It also demonstrated that in the LID subdivision the annual stormwater runoff volume did not change as the impervious surfaces increased (Dietz & Clausen, 2008). There is not a change in stormwater runoff volumes due to the low impact controls used throughout the subdivision design.

An additional case study on a project in Houston, Texas resulted in the development of an apartment complex that would have been canceled if it were not for the use of low impact development strategies. Queenston Manor Apartments sit on a 7.2 acre site in Houston,Texas. The developer originally planned the apartment complex on this site, but the economic model required that nine apartment buildings be constructed in order to generate the appropriate revenue (Convergent Water Technologies, 2014). Originally all of the sites detention was accounted for offsite in surrounding developments, but the county determined that it was no longer available for use and the project came to a halt. Engineers at EHRA saved the project by incorporating LID as well as a FocalPoint High Performance Modular Biofiltration System (HPMBS) (Convergent Water Technologies, 2014). A HPMBS is a “combination of a high performance, open cell underdrain, a clog-proof bridging mesh, bridging stone, and a high performance biofiltration media that flows at a rate of over 100” per hour” (Convergent Water Technologies, 2014). This system allowed for all of the complex’s common areas and courtyards to serve as drainage areas. The objective of the LID design was to decrease peak flow, which in time would decrease the total detention volume (Convergent Water Technologies, 2014). By introducing the LID approach to design, the developer was able to proceed with the project due to the fact that the area dedicated to the detention facility in the traditional design was eliminated. This allowed for an increase in area for more apartment buildings, which permitted the developer to meet the revenue requirements (Convergent Water Technologies, 2014). Designers at EHRA redesigned the project to include "porous pavers in parking stalls, a directly infiltrated underground detention system, vegetated swales and vegetated depressions which drain through a series of small FocalPoint HPMBS" (Convergent Water Technologies, 2014). This resulted in a decrease in surface storage, which allowed space for two additional apartment buildings. This was equivalent to 48 apartment units (Convergent Water Technologies, 2014). The success of a combination of LID controls allowed for this project to be implemented.

The Ipswich River Watershed developed three low impact development case studies as part of a demonstration project "designed to showcase practices that can help improve low-flow and water quality conditions" (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). The case studies asses, quantify, and demonstrate the benefits of LID controls.

The first case study was the Partridgeberry Place, a residential development in Ipswich, Massachusetts. Twenty houses were clustered together on 0.2 acre lots surrounded by woodland areas. The LID controls that were included in the design were significantly smaller setbacks to property lines, a common septic tank, minimal pavement due to clustering, narrow roadways, short driveways, rooftop stormwater drains which infiltrate directly into the ground, rain gardens, grass pavers, grass swales, and native vegetation (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). A computer program was developed in order to process site measurements such as runoff patterns, rate of runoff, and average rainfall (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). The computer program also produced results that were compared to four design conditions. The four design conditions were the pre-developed condition, the LID subdivision, a cluster only subdivision, and a traditional subdivision design (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). By producing runoff patterns for each site and comparing them, the study "characterized how effective the LID features" were at reducing runoff compared to traditional design. The results showed that for the pre-developed site the peak runoff rates were the lowest for all storm sizes (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). The LID subdivision and the cluster only design yielded similar results in that the peak flow runoff rates were slightly higher than the pre-developed site. The results also showed that the traditional subdivision design produced significantly more runoff and higher peak flow rates compared to all other design scenarios (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009).

Another case study related to theIpswich Watershed is the Silver Lake Beach LID Retrofit. It is a 28 acre pond in Wilmington, MA, but is frequently closed due to high amounts of E.Coli bacteria from polluted stormwater runoff (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). LID controls that were implemented in this case study include planted swales, permeable pavement, and bioretention cells. Sampling wells were placed in the parking lot to evaluate the concentrations of chemicals in the water that is collected from asphalt runoff (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). Samples were collected for five months prior to the start of construction and for one year after construction was completed. The results show that overall the combination of "LID retrofits" helped to reduce the number of beach closures in the swimming area (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). The study also concluded that the four different types of permeable paving allowed for infiltration at a rate ranging from 49 inches per hour to 10,000 inches per hour (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). By testing different permeable pavers the case study proved that permeability is a successful element of LID design, but also is successful in reducing the amount of pollutants in stormwater runoff.

The third case study that is affiliated with the Ipswich Watershed is the Silver Lake Neighborhood LID Retrofit. This case study entails a three acre residential neighborhood that borders the lake. The goal was to determine successful LID elements that can decrease the amount of runoff from rooftops, driveways, and streets within the neighborhood (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). Twelve rain gardens and two areas of permeable pavers were used in the front of homes in the public right of way along both sides of the street. Runoff from rooftops, driveways, and roads was redirected into the rain gardens and permeable pavers to allow for infiltration (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). An important aspect of this case study is the importance of educating the homeowners about LID, the rain gardens, and the permeable pavers. Community members were informed of the study and educated on how to maintain and protect the low impact development features. Rain gauges were installed to measure and monitor the runoff volumes from the neighborhood to the lake (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). In order to measure concentrations of pollutants such as phosphorus, nitrogen, metals, petroleum hydrocarbons, and bacteria, additional equipment was used to capture samples from storm drains (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009). The results concluded that the combination of rain gardens, permeable pavers, and vegetated swales reduced the volume of stormwater runoff that flows directly into the lake. The results also state that the sample size was too small in order to determine if the use of rain gardens and permeable pavers reduces the amount of pollutants in stormwater runoff. It is suggested that the conclusion is based on a limited data set and needs to be further investigated (The Massachusetts Department of Conservation and Recreation & Ipswich River Watershed Association, 2009).

It is clear that recent research and case studies prove that low impact development is a successful way to decrease runoff rates and increase infiltration volumes. It is unclear if LID is a good alternative for reducing the amount of pollutants in stormwater runoff. Whether or not a combination of LID elements is more successful than the use of a single LID control is unclear and will require further research.

2.3.1 MSU Low Impact Investigations

In recent years graduates at Michigan State University (MSU) have been highly interested in the topic of low impact development. Their studies have inspired me to further investigate the topic of LID and its positive effects on the environment. In 2016 a similar study was completed by Hongwei Tian on a site in Grand Rapids, Michigan. The study investigates the "LID performance by examining four different design scenarios", two designs include LID controls and two designs lack LID controls (Tian, 2016). The four different sites include the existing site, LID with Cloud Design, LID Design, and a traditional design. The design scenarios were evaluated using eleven variables that were selected in the areas of energy use, climate change, stormwater management and ecosystems (Tian, 2016). The eleven variables include impervious surfaces, permeable pavement, green space, average tree water consumption, total shadow area, number of trees, runoff, soil infiltration, evaporation, field sparrow habitat sustainability index, and fox squirrel habitat sustainability index (Tian, 2016). These eleven parameters were analyzed using the Friedman's One Way of Variance Test in order to compare the design scenarios using rankings. After analyzing these parameters, the results show that the designs with LID elements are statistically better than the existing design, but it cannot be determined that the design scenarios with LID elements are better nor worse than a traditional design.

Students at MSU also completed a related study, Metrics in Master Planning Low Impact Development for Grand Rapids, Michigan, that investigates the metrics that demonstrate the effects that low impact development has on urban sustainability issues (Burley, Li, Ying, Tian, & Troost, n.d.). The metrics include "reduction in stormwater volume, increase in stormwater quality, increase in songbird habitat sustainability, increase in vegetation biodiversity, reduction in water requirements by woody vegetation, increase in latent soil productivity, increase in vegetation adaptation to climate change, increase in visual quality, improvement in microclimate diversity, reduction in landscape maintenance and energy inputs, and walkability" (Burley et al., n.d.). LID controls that are incorporated into the design include green roofs, rain tanks and cisterns, permeable pavement, bioretention and rain gardens, dry and wet swales, and constructed wetlands (Burley et al., n.d.). The goal of the proposed design was to improve stormwater management treatments. A team of students, professors, and varying professionals designed a combination of LID controls and assessed the stormwater runoff, infiltration, and evapotranspiration rates using the U.S. EPA National Stormwater Calculator to document the change volumes (Burley et al., n.d.). For this study, climate change was also examined by measuring variables such as trees, shade, and land use changes. In order to evaluate tree water consumption the Simplified Landscape Irrigation Demand Estimation (SLIDE) was used (Burley et al., n.d.). This method calculates the water demand for water-conserving irrigation plans based on plant species (Burley et al., n.d.). After analyzing all of the parameters, stormwater, tree water consumption, change in land cover, habitat sustainability, visual quality, and soil productivity, the results show that the master plan developed by the MSU team members is significantly better than traditional approaches and significantly better than the existing site (Burley et al., n.d.).

Another study completed by a student at MSU concerns low impact housing in River Rouge, Michigan. This research investigates the positive and negative effects of using a landscape based approach to design versus an architectural based design approach. The landscape based design incorporates mixed-use areas, residential areas, commercial areas, stormwater treatment strategies, open spaces, closed wetlands, and open wetlands (Wang et al., 2017). This approach “orchestrates the structure of the environment based upon the composition of the landscape and then the needs of the greater environment” (Wang et al., 2017). The buildings and circulation are then laid over in “designated zones determined by the organization of the landscape plan/design” (Wang et al., 2017). This means that the design of the sites comes first, where as in architectural based design, the landscape comes last in the design process. An architectural design includes the placement of structures, and then incorporating circulation patterns and landscape in “leftover spots” (Wang et al., 2017). In this study a visual quality test is used to examine and compare treatments to measure environmental visual quality and stormwater runoff quality. Different LID controls and combinations of LID controls were assessed for each scenario and include bioswales, bioretention, open wetlands, and a combination of bioretention and constructed wetlands. After evaluating the parameters the results “indicate that the landscape based housing development has significantly better visual/environmental quality and that a bioretention water treatment area combined with a constructed wetland” has a positive effect on water quality by removing approximately 96.3% of phosphorus in the onsite runoff (Wang et al., 2017).

2.4 LID Summary

Although communities, developers, and designers are considering the use of LID elements, there is limited research concerning the effectiveness of low impact development versus traditional design, including research on the effects of integrated LID techniques. This research evaluates designs with LID elements to determine if there is a slower rate of stormwater runoff and lower energy use compared to a traditional design. Furthermore, this research assesses the combined use of a series of low impact development elements throughout an entire site. Previous researchers have focused on the evaluation of one specific LID technique such as just green roofs, or just rain gardens. Although previous studies have evaluated a single LID element at different scales, research on the cumulative benefits of multiple LID elements for a single site is needed. More research is needed on the evaluation of a combination of LID techniques on revitalized environments.

In summation this research seeks to explore the positive effects of low impact development techniques on stormwater runoff rates for a specific site using EPA measures and NCRS (Natural Resources Conservation Service) soil data to compare three design scenarios.

Chapter 3: Methods

This research will analyze the use of a combination of low impact development elements for three different design scenarios. Each design will incorporate a different combination and size of LID elements. After calculating the six different variables (average annual runoff, days per year with runoff, percent of wet days retained, smallest rainfall with runoff, largest rainfall without runoff, and maximum rainfall retained) and comparing the scenarios against different LID combinations, the Friedman One-Way Analysis of Variance Test will be applied in order to compare the design scenarios, and determine if their differences are statistically significant.

3.1 Study Site

The study site is approximately 44 acres and is adjacent to the Los Angeles River (See Figure 6). The site's soil type is D, which represents high runoff potential. This soil type is classified as urban land or commercial land (NRCS, 2017). The hydraulic conductivity of the soil is approximately 0.01 inches per hour, which implies that the soil has a high amount of runoff. Soils with lower conductivity produce more runoff (USEPA, 2014). The site's topography is particularly flat and has an average slope of approximately 5%. The site's precipitation and evaporations data are collected by the Downtown Los Angeles and the University of Southern California rain gage and weather station. The climate change scenario is classified as "no change". The land cover and LID controls vary based on the design scenario being analyzed. The wet dry event threshold is 0.10 inches on site. "The Center for Watershed Protection recommends using a runoff threshold of 0.10 inches because impervious areas of the watershed are assumed to generate runoff beginning at approximately 0.10 inches of rainfall" (MDEQ, 2006).

Figure 6. Aerial Image of Existing Site (adapted from Google Earth)

3.2 Design Scenarios Description

This research will analyze and estimate the stormwater management runoff of three design scenarios for the study site including the existing site (design scenario 1), extended LID design (design scenario 2), and the preliminary design in the LA River Master Plan (August 2014) developed by Mia Lehrer and Associates (design scenario 3). Design scenario 1 is an abandoned rail yard along the Los Angeles River and is in the process of being revitalized. Design scenario 2 is a master plan design created at Michigan State University (MSU) in a graduate level course that integrates extensive LID elements specific to this research. Design scenario 3 was completed by Mia Lehrer and Associates, a firm hired by the city of Los Angeles to design parcel G2 of the Taylor Yard Site. Each site is thoroughly described below.

3.2.1 Existing Site (Design Scenario 1)

The existing site (Figure 6 and Figure 7) is an abandoned rail yard located in Los Angeles, California alongside the Los Angeles River and occupies approximately 247 acres.

According to “The River Project”, it is the largest undeveloped parcel along the river, which presents “extraordinary opportunities” for river revitalization plans (The River Project, 2011). Within the existing site there are seven different parcels. This study will focus on parcel G2.

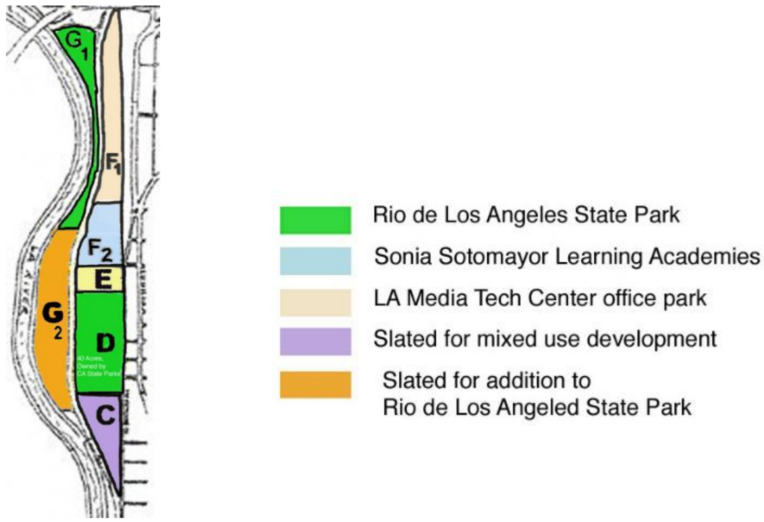

Figure 7. Map of Taylor Yard Parcels (adapted from The River Project, 2011.)

“Parcel G2 is currently owned by Union Pacific and is the operating facility for the existing but abandoned rail lines. It is a contaminated site due to the industrial uses. Parcel G2 contains the majority of the rail lines along the Los Angeles River. This parcel is under a feasibility study in order to incorporate future habitat restoration, water quality remediation, flood mitigation, wetlands restoration, and recreation uses. This parcel is approximately 44 acres” (The River Project, 2011. pg 1).

The existing site has been used for various maintenance, fueling, and industrial operations which began in the 1930’s and continued until 2006 (Environmental Management Group, 2014). These operations include diesel shops, machine shops, a roundhouse, two turntables, underground and above ground storage tanks, a service track, and miscellaneous buildings (Environmental Management Group, 2014). Once the site was permanently closed in

2006, all above ground structures that remained on the site except for various concrete slabs, footings, and foundations were demolished (Environmental Management Group, 2014). In previous years many soil and groundwater investigations have taken place on site and identified many chemicals in the soil including petroleum hydrocarbon, arsenic and lead (Environmental Management Group, 2014). Since this site has been identified as a "crown jewel" of Los Angeles, it is in the process of being rezoned for uses other than industrial, and the site continues to undergo remediation and evaluation (Environmental Management Group, 2014).

3.2.2 Extended LID Design (Design Scenario 2)

Design scenario 2 (Figure 8) focuses on the revitalization of the Los Angeles river front in parcel G2. In parcel G2 the design includes many LID elements including rain gardens, bioswales, constructed wetlands, infiltration basins, and permeable paving. The city of Los Angeles is eager to develop parcel G2 in Taylor Yard because of its placement on the river. Design Scenario 2 studies the option of narrowing the river due to the low average amount of water that is usually in the river. Because of the existing concrete ditch that was originally designed to handle flooding, it is nearly impossible for the river to help clean and filter stormwater runoff. The U.S. Army Corps of Engineers has performed an Integrated Feasibility Report (IFR) for the Los Angeles River Ecosystem Restoration Study, which aims to restore natural riparian ecosystem values amongst an 11 mile portion of the river (Environmental Management Group, 2014). The purpose of the IFR is to transform the space into a "20^{th} century single purpose river channel into a 21^{st} century multi-purpose infrastructure that incorporates the natural environment, public use, recreation, and flood control" solutions (Environmental Management Group, 2014). This design incorporates significant green space for activities, connections to the nearby state park, walkable systems for the surrounding communities, and connections across the river. All of these elements contribute to the concept of a "21st century multi-purpose" public space with a focus on environmental quality.

Figure 8. Conceptual Rendering of Extended LID Design

3.2.3 Mia Lehrer and Associates Design (Design Scenario 3)

Design scenario 3 (Figure 9) was designed by Mia Lehrer and Associates after being hired by the City of Los Angeles. Their design is strictly conceptual and includes site remediation, water quality improvements, abundant parkland and open space, river amenities, community gateways, and integration of habitat elements (Environmental Management Group, 2014).

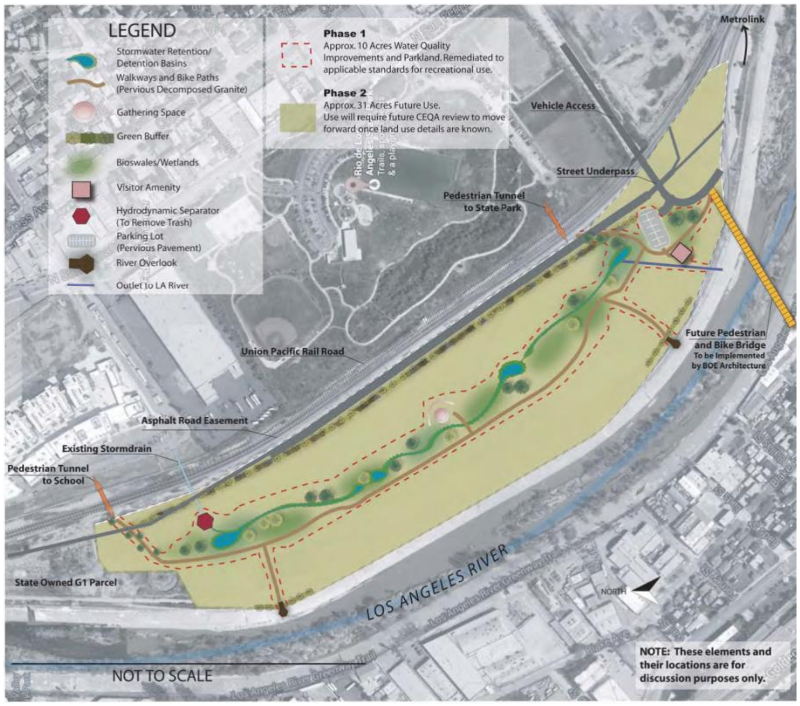

Figure 9. Conceptual Plan Designed by Mia Lehrer and Associates

3.3 Measurement Elements- Stormwater Management

For these three scenarios stormwater runoff, infiltration, and evaporation rates will be analyzed by using the National Stormwater Calculator (SWC). The SWC is a software tool that evaluates runoff, infiltration, and evaporation for small scale sites in the United States (USEPA, 2014). The goal of SWC is to estimate the amount of stormwater runoff generated from a specific location under different development and control scenarios (USEPA, 2014). The calculations are based on historical findings of average rainfall, soil conditions, soil drainage rates, topography, different types of land cover, and different LID controls (USEPA, 2014). Part of the calculation process allows you to incorporate different LID elements into each design and see how they affect the outcome of the sites stormwater runoff rates. The SWC's "computational engine" is run by the EPA Stormwater Management Model (SWMM), which is highly recommended for hydrology modeling and analysis (USEPA, 2014)The SWC focuses on informing professionals in the development industry on how they can meet preferred stormwater targets and can be used to assist in answering the following questions (USEPA, 2014):

1. What is the largest daily rainfall amount that can be captured by a site in either its pre-development, current, or post-development condition?
2. To what degree will storms of different magnitudes be captured on site?
3. What mix of LID controls can be deployed to meet a given stormwater retention target?
4. How well will LID controls perform under future meteorological projections made by global climate change models?

Data on 1) site location, 2) the site's soil type, 3) the site's soil drainage rate, 4) the site's topography characteristics, 5) hourly rainfall data from a nearby rain gage, 6) evaporation rate from a nearby weather station, 7) climate change scenario selection, 8) the site's land cover for each design scenario, and 9) LID control measures for each design scenario is input into the SWC model to predict accurate runoff rates, infiltration rates, and evaporation rates. The calculator results include average annual rainfall, average annual runoff, days per year with rainfall, days per year with runoff, percent of wet days retained, smallest rainfall with runoff, largest rainfall without runoff, maximum rainfall retained, and a pie chart representing percentage of runoff, infiltration, and evaporation rates for each design scenario.

3.4 Statistical Method to Test the Hypotheses

The null hypothesis for this research states that if the SWC is applied to each design scenario, then there will not be a significant difference is the amount of runoff for each design scenario. Therefore LID elements have no positive effect on stormwater management practices. The research/alternative hypothesis states that if the SWC is applied to each design scenario, then at least one scenario will show that LID elements have a positive effect on stormwater management practices because the runoff amount will be lower than at least one other scenario.

For this research, the Friedman One Way of Variance Test will be applied in order to determine which design is most successful when considering LID elements as a feature to control stormwater management on site. The Friedman One Way of Variance Test is a non-parametric statistical test used to evaluate the treatments' values based on ranks (Daniel, 1978.). Friedman's Test is used "between groups when the dependent variable being measure is ordinal" (Statistics, 2013).

The first step in completing the Friedman's Test is to convert the results into rankings. To do this, the observations in each block (b) are ranked separately so that each block contains a separate set of ranks (k). A block is one of the eight statistical results adapted from the SWC. These are the eight computational components that the SWC computes once the data is inserted. Each design was ranked by six blocks and three different treatments.

The second step is to determine the null hypothesis and the research hypothesis. For this research, the null hypothesis (H_0) is that all of the design scenarios have identical effects, and the research hypothesis (H_1) is at least one design scenario has a larger value than at least one other design scenario.

The third step is to obtain the sums of the ranks (R) in each column. If all treatments have identical effects, than we would expect the sums to be fairly similar in size. When there is one sum that is sufficiently different from the others the null hypothesis can be rejected.

The fourth step is to find the computational chi-squared value.

Equation 1: Computational Chi-squared Value

$$x_r^2 = \frac{12}{bk(k+1)} \sum_{j=1}^{k} R_j^2 - 3b(k+1)$$

Where:

- b is the number of blocks
- k is the number of treatments
- R is the sum of ranks for reach treatment

The fifth step is to determine the level of risk, or alpha (α). In this research α is equal to 0.005. Alpha is the percent chance that the null hypothesis is correct. Since alpha is equal to 0.005, this means that there is a 99.5% chance that the research hypothesis is true. Using the book, Applied Nonparametric Statistics, Daniel provides a table (Daniel, 1978, p.452) that contains the chi-square values of $x_{(1-\alpha)}^2$ with k-1 degrees of freedom (Daniel, 1978). If x_r^2 is greater than or equal to the tabulated value of $x_{(1-\alpha)}^2$ with 2 degrees of freedom, then the null hypothesis will be rejected (Daniel, 1978).

The sixth step is to determine which design scenarios are better than others using the multiple comparison test that is associated with Friedman's test. When the Friedman's test is applied to research and leads us to reject the null hypothesis, we are curious as to where the differences are relevant (Daniel, 1978). The multiple comparison procedure will determine where the differences in the research are apparent.

Equation 2: Multiple Comparison Test

$$|R_j - R_{j'}| \geq z\sqrt{\frac{bk(k+1)}{6}}$$

Where:

- R_j and $R_{j'}$ are two sums of the different treatments' ranks
- z is the tabulated value provided by a specific table in Daniel's book (Daniel, 1978, p.397) and corresponding to $\alpha/k(k-1)$

Chapter 4: Results

In order to test the research hypothesis, that is the SWC is applied to each design scenario, then at least one scenario will show that LID elements have a positive effect on stormwater management practices by decreasing the amount of runoff on site, measurements on site parameters were recorded. Table 1 shows all of the data input for the stormwater calculator for each design scenario.

Parameter	Design Scenario 1	Design Scenario 2	Design Scenario 3
Site Area (acres)	44	44	44
Hydrologic Soil Group	D - High Runoff Potential	D - High Runoff Potential	D - High Runoff Potential
Hydraulic Conductivity (inches/hour)	0.01	0.01	0.01
Surface Slope (%)	5% - Moderatly Flat	5% - Moderatly Flat	5% - Moderatly Flat
Precipitation Data Source	Los Angeles Downtown/USC	Los Angeles Downtown/USC	Los Angeles Downtown/USC
Evaporation Data Source	Los Angeles Downtown/USC	Los Angeles Downtown/USC	Los Angeles Downtown/USC
Climate Change Scenario	No Change	No Change	No Change
% Forest	0	18	28.3
% Meadow	0	16	13
% Lawn	14.3	21	30.2
% Desert	0	0	0
% Impervious	85.7	46	28.5
Years Analyzed	25	25	25
Ignore Consecutive Wet Days	FALSE	FALSE	FALSE
Wet Day Threshold (inches)	0.1	0.1	0.1
% Disconnection	0	0	0
% Rain Harvesting	0	10/4	0
% Rain Gardens	0	30.4/50	0
% Green Roofs	0	5/100	0
% Street Planters	0	10/6	0
% Infiltration Basins	0	25/10	0
% Porous Pavement	0	19.6/100	0

Table 1. The National Stormwater Calculator (SWC) Parameters

Table 2 indicates the results of eight different variables for the three design scenarios, where average annual rainfall and days per year with rainfall are constant. The sites will be compared based on the six remaining variables. According to Table 2 and the statistical results computed by the SWC, the average annual runoff for the three design scenarios is 12.86, 7.07, and 8.92 inches. The days per year with runoff for each design are 18.43, 3.92, and 5.64 days.

The percent of wet days retained is 14.89, 69.66, and 56.48 days. The smallest rainfall with runoff for each design is .1, .49, and .4 inches. The largest rainfall without runoff is .22, .88, and.44 inches. And the maximum rainfall retained is .4, 1.49, and .87 inches.

SWC Statistical Results	Design Scenario 1	Design Scenario 2	Design Scenario 3
Average Annual Rainfall (in.)	15.31	15.31	15.31
Average Annual Runoff (in.)	12.86	7.07	8.92
Days per Year With Rainfall	22.82	22.82	22.82
Days per Year With Runoff	19.43	3.92	5.64
Percent of Wet Days Retained	14.89	69.66	56.48
Smallest Rainfall w/ Runoff (in.)	0.1	0.49	0.4
Largest rainfall w/o Runoff (in.)	0.22	0.88	0.44
Max Rainfall Retained (in.)	0.4	1.49	0.87

Table 2. SWC Statistic Results

Table 2 is a representation of each design scenarios results and their percent of runoff, infiltration, and evaporation for an annual average rainfall.

When comparing the existing site to design scenario 2 and 3, one can see in Figure 10 that the percent of runoff was reduced by 38% and 26%, while infiltration increased by 33% and 25%.

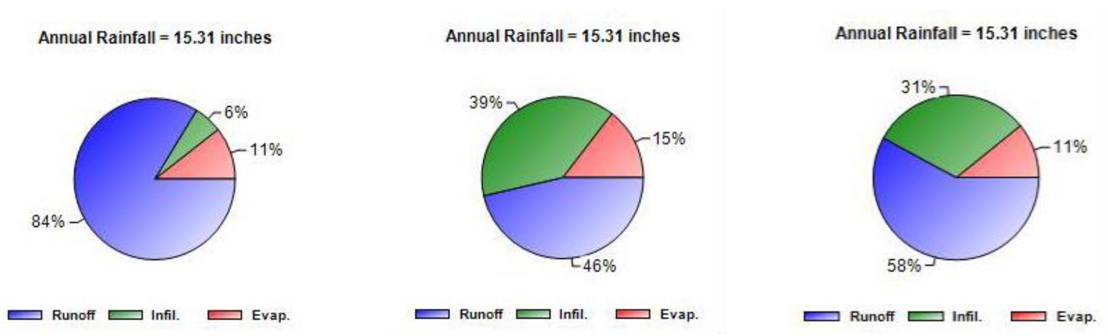

Figure 10. SWC Runoff, Infiltration, and Evaporation Analysis Results (adapted from SWC)

In Table 3, the design scenarios have been ranked from 1-3 where 1 means the most effective stormwater management design and 3 meaning the least effective stormwater management design.

SWC Statistical Results	Design Secnario 1 (Rank)	Design Scenario 2 (Rank)	Design Scenario 3 (Rank)
Average Annual Rainfall (in.)			
Average Annual Runoff (in.)	3	1	2
Days per Year With Rainfall			
Days per Year With Runoff	3	1	2
Percent of Wet Days Retained	3	1	2
Smallest Rainfall w/ Runoff (in.)	3	1	2
Largest rainfall w/o Runoff (in.)	3	1	2
Max Rainfall Retained (in.)	3	1	2

Table 3. Friedman's Test Results

The sum for design scenario 1 is R=18, design scenario 2 where R=6, and design scenario 3 where R=12. We then need to find r^2. For design scenario 1 where R^2=324, for design scenario 2 where R^2=36, and for design scenario 3 where R^2=144.

Given the ranks calculated, the number of blocks being 6 and the three design treatments, the chi-squared value was determined to be 12.

Therefore:

Equation 3: Results of Computational Chi-squared Value

$$x_r^2 = \frac{12}{(6(3)(3+1)}(18^2 * 6^2 * 12^2) - 3(6)(3+1) = 12$$

The computational chi-squared is 12.

The value of $x_{0.995}^2$ with 2 degrees of freedom is 10.597, which is smaller than the computational chi-square of 12. Therefore, in this research, there is at least one design that is statistically better than at least one other design scenario.

Using the table from Daniel's book (Daniel, 1978, p397), and knowing that α is equal to 0.005 and k is equal to 3, we can calculate that z is equal to 2.4.

Therefore:

Equation 4: Results of Multiple Comparison Test

$$2.4\sqrt{\frac{18(3+1)}{6}} = 8.313$$

The rank totals were R_a (Design scenario 1-Design scenario 2) = 12, R_b (Design scenario 2 – design scenario 3) = 6, R_c (Design scenario 3 – Design scenario 1) = 6. Thus we can conclude that design scenario 2 is better than design scenario 1, but neither better nor worse than design scenario 3. We can also conclude that design scenario 3 is better than design scenario 1, but neither better nor worse than design scenario 2.

Chapter 5: Discussion

Before I began my research involving low impact development, I was unsure of its benefits, but always believed there was an environmentally friendly opportunity for designers to incorporate stormwater management techniques into urban development. Although this research investigates and analyzes the use of LID elements, it opens up a platform for further research. This thesis also inspires designers, planners, and environmentalists to pose questions about the rules and regulations of design in the 21st century. Should professionals be required to use tools such as the National EPA Stormwater Calculator in order to prove that a plan is designed to the best of their ability while keeping the health of the people and the environment in mind? After completing this research I believe that this is one of the most important questions to pose.

The calculations indicate that design scenario 2, which includes green space and a combination of LID controls, can successfully reduce runoff volume by retaining rainfall on site. Design scenario 3 is similar because of its large amount of green space, but lacks LID variables. Although you can see the positive impact of LID elements in the quantifiable research, it is important to keep other aspects of design in mind that were not measured using statistical analysis. Aspects such as the value of aesthetics and educational components are more difficult to measure, but are extremely important to successful developments that encourage and teach people about the environment. They are important because there is a lack of knowledge of environmental issues. Using educational components is a way to inform people of LID benefits and constraints. By using simple diagrams, such as the diagrams previously shown in the literature review, people can be educated on the process of each LID element and how each one works. Once people understand the process, benefits, and constraints, they can use these elements in an aesthetic manner. Therefore, the LID elements are beneficial, as well as providing aesthetic appeal for visitors. On site educational components are a great way for landscape architects, planners, engineers, and designers to influence visitors and share their knowledge of ways to be environmentally friendly. Given the rate of urbanization along with increase in impervious surfaces sharing this knowledge from community to community is important. It is also a way for visitors to inform themselves of the history of a site. This history is important to professional designers because it influences the way that they approach their designs. For example, a designer would approach a site that was previously a forested area differently than they would approach a site that was once an industrial park. Investigating all parameters of a site will ensure that the design resolves the sites existing issues. The history of the site is also important to the community. It is a way for community members to learn about the past and to incorporate history into future designs through education. Education can be taught on site in many different ways. Some ways include educational signage, historical landmarks, sculptures, and interactive educational components. All of these factors are just as important as the quantifiable research and raises many questions as to what factors designers should be focus on.

This research analyzes the average rainfall on site as well as the average amount of runoff. Even though the average of these parameters shows that Design Scenario 2 and Design Scenario 3 are similar when considering stormwater runoff, infiltration, and evaporation amounts, the research does not show what would happen in a large storm event. In a large rain storm it may be more obvious that LID elements are required to design for successful on site stormwater management, but further research is required in order to determine those results. There are many factors that need to be analyzed in order to determine if LID is an appropriate solution for site specific developments. These factors include soil conditions, slopes, elevations, and climate. These factors are important to consider because they influence the approach that designers have in solving the sites issues. These factors are also important because they can impact a designer’s decision of which LID elements, if any, are appropriate on site and how they should be implemented. It is possible that future research may show that LID controls are site specific solutions and they are not a good alternative to stormwater management for every single design.

As previously mentioned there are many benefits and constraints to the use of LID elements. Throughout this research I have documented what I think the most important barriers in the research of LID are and that need to be further explored. This includes government limitations, code limitations/regulations, cost, preconceived notions, interaction between disciplines, and most important unfamiliarity. Code regulations are one reason that it is difficult to require use of LID elements in site design. This is because the process of submitting permits can be tedious for professionals, so professionals tend to avoid this process. Cost and preconceived notions are a reason that communities and clients have a hard time accepting the use of LID elements. As previously mentioned, LID elements can be expensive, but it is difficult to show or convince people that the expense in the beginning will benefit over a longer period of time. People have difficulty seeing the benefits when there is a lack of results from the beginning. Interaction between disciplines is critical in order to design properly. Different disciplines needs to work together to influence communities and government agencies that LID is in fact a productive feature for the environment. Unfamiliarity is a lack of education within communities and government agencies. It is possible that some professionals also lack the knowledge of LID results and influences. By requiring professionals to attend conferences and performing continuing educational practices, professionals will be more knowledgeable of LID and their benefits and constraints. When engineers, landscape architects, and planners work together the result is often more efficient. Rethinking the standards of stormwater management includes cooperation from all participating disciplines and an understanding of each disciplines roll. It also includes an investigation of regulatory standards of stormwater management systems and designs. The use of LID elements and proof of their success is going to require people to look past the traditional standards and be open to alternative options such as LID. Successful design requires a mixture of many different approaches, not just the approach that only meets the require standard. That is failure to design with the health, safety, and welfare of the community in mind.

It is obvious that the sites with larger amounts of green space reduce the amount of runoff and increases infiltration rates. One can also see that the site with LID controls reduces the amount of runoff even more, as well as increasing the amount of infiltration. The difference between the results of design scenario 2 and design scenario 3 indicates that a combination of LID controls and an abundance of green space are crucial to reducing runoff rates, increasing infiltration rates, and positively managing evaporation rates. However, research is still needed on how different levels of LID technique integration effects model outputs and more importantly how different levels of LID techniques effect urbanizing communities and their residents including their perceptions of sustainability and the value of natural habitat particularly in urban spaces. Additionally, the practice of LID and its potential to be implemented would benefit from studies that compare stormwater model outputs, costs associated with stormwater management, and the cost of these lid practices.

5.1 Limitations

With any research come limitations. Unfortunately the main limitation for this research is the site that was selected. Taylor Yard was originally selected due to the intense drought that southern California was experiencing. While the site offered a great way to model the importance of collecting, filtering, and reusing water. However, due to the phasing process the design for the site was not fully developed. This resulted in the use of a conceptual design. The EPA calculator was more difficult to determine areas with a conceptual design. For this current thesis, the solution was to provide estimates for all three sites in order to compare them equally. It is obvious that design scenario 1 is mostly made up of impervious surfaces, but design scenario 2 and 3 were more difficult to determine areas such as paving, green space, buildings, LID elements, meadow, and forest.

A significant limitation of this research is using only the SWC, to improve understanding and to better compare design alternatives further research should incorporate more variables and models that would include other parameters such as energy use, habitat analysis, and possibly even climate change. Although the EPA calculator relayed important information about low impact development, these parameters could all be compared against each other using multiple tests including Friedman's Test. That would provide a better understanding of their benefits, concerns, and how they impact design.

If future research were to compare additional parameters such as energy use, it would make this research more viable. Energy use is an important parameter and can be determined by analyzing the sites canopy coverage. In urban areas canopy coverage is extremely important because it affects environmental elements such as shade, cooling, improve air quality, and reduce stormwater runoff (Bartens, Day, Harris, Wynn, & Dove, 2009). The American Forests recommend that a city should target 40% canopy coverage.

Another parameter that would further develop this research is the evaluation of current and future climate change. In order to determine climate change the shadow casting and areas on site will need to be determined. Because urban areas are the main generation of greenhouse gases, it is determined that they have an increasing impact on climate change (Tian, 2016). Climate change includes more intense weather such as frequent storming and intense changes in temperature (Tian, 2016). By determining increasing the shadow area climate change can be slowed down. LID applications can reduce and control stormwater runoff, as well as absorb heat by providing shade area (Tian, 2016).

A final parameter that would further develop this research is to perform an ecosystem analysis. By finding critical or important species on site, their habitat suitability can be calculated for each design scenario. In order to do this the Habitat Suitability Index Model will need to be applied. This model provides information regarding impact assessment and habitat management (Sousa, 1983). This will determine which types are cover and site amenities are appropriate for increase in reproduction. Ultimately one design will be more ideal than the others depending on what type of cover each species requires.

5.2 Policy and Practice Recommendations

This research is an example of an application, The EPA National Stormwater Calculator, and how it has a positive effect on design intentions. From this research it is recommended that landscape architects, planners, engineers, and designers should be required to use such applications in order to provide parameters that can be compared and contrasted. It is important that the design phase includes measurable attributes that can show why different design decisions were implemented. For example, in a new site development designers may implement different concepts that affect stormwater management, ecosystems, climate change, or even energy use and these applications can help determine what design decisions are best from an environmental standpoint.

Regardless of how much, it is obvious that the use of LID elements effects stormwater management. If designers were required to use the SWC application, they could further prove why their design is more appropriate than the existing site. The research determines that it is important that landscape architects, engineers, planners, and designers encourage each other to go one step further in the design process and incorporate the use of these available applications in order to raise more questions in the design field. Opening more questions within the design field will give the design process more recognition and credibility.

5.3 Conclusion

In summation one can conclude that LID controls have the most positive affect on the environment when combined with green space. It also investigates the use of LID controls and their positive and negative effects on stormwater management practices. The purpose of this research was not only to show the difference in use on sites with and without LID controls, but to help pose questions for future research regarding the use of technology programs such as the EPA National Stormwater Calculator. By posing other questions regarding LID controls, it is possible that this can influence the standards and regulations of design requirements. Not only does this research show that a combination of LID controls and green space have the most positive influence on stormwater management, it also challenges landscape architects, engineers, and designers to incorporate quantitative and qualitative research into each design in order to prove that each site was designed to the best of their ability. As previously mentioned, some of these variables include aesthetics, educations, and history. These qualitative variables are important for communities to understand the comprehensive reasoning behind designs and helps community members to better understand the site itself. By also providing clients with an abundance of information regarding quantitative results such as average runoff rates before and after the implementation of LID controls, one can see how low impact development can positively affect urbanized areas.

Although this research provides initial results regarding LID controls, it sets a platform for future research and how LID controls are site specific. Future research will help people to understand the importance of stormwater management and its effect on the environment.

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