11-4-2015

Evaluation of Low-Cost Low Impact Development Practices in Southwest Florida for the Control of Urban Runoff

Laura Kathren Rankin
University of South Florida, samsdrool@gmail.com

Scholar Commons Citation

Rankin, Laura Kathren, "Evaluation of Low-Cost Low Impact Development Practices in Southwest Florida for the Control of Urban Runoff" (2015). *Graduate Theses and Dissertations.*
http://scholarcommons.usf.edu/etd/6019

Evaluation of Low-Cost Low Impact Development Practices in Southwest Florida for the Control of Urban Runoff

by

Laura K. Rankin

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
with a concentration in Water Resources
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Co-Major Professor: Mahmood Nachabe, Ph.D.
Co-Major Professor: Sarina Ergas, Ph.D.
Mark Rains, Ph.D.

Date of Approval:
October 28, 2015

Keywords: stormwater management, LID implementation, hydrology,
NPDES, MS4, watershed management

ACKNOWLEDGMENTS

This thesis would not be possible without my Co-Major Professors, Sarina Ergas, Ph.D. and Mahmood Nachabe, Ph.D., as well as my third committee member, Mark C. Rains, Ph.D., all of whom have provided infinite knowledge, patience, and inspiration. I would like to acknowledge a special thank you to the local and state government agencies that helped me gain a better understanding of the status of Low Impact Development in Southwest Florida. Additionally, I would like to extend my eternal gratitude to my family and fellow graduate students, all of whom have provided encouragement and support while achieving my Master's degree.

This material is based upon work supported by the National Science Foundation under Grant Number DUE-0965743. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Additionally, I would like to thank the Patel Center for Global Sustainability for their source funding.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Stormwater management is required due to development and alteration of the natural environment. It is heavily regulated in Florida and at the national level. Over the last two decades, Low Impact Development (LID) has been promoted as a sustainable and environmentally friendly method of controlling urban runoff. Case studies, provided in Chapter 2, show that LIDs can restore watershed hydrology by balancing the water budget. The difference in runoff between pre-development and post-development appears to increase with soil perviousness. However, the potential for mitigating the impacts of urbanization through runoff reduction is also greater for pervious, sandy soils that dominate central and south Florida. A greater potential for urbanization mitigation in Florida's highly pervious soils initiates more research in quantifying the benefits of LID. Southwest Florida is currently in its infancy when adopting LID on a broad-scale; however, several municipalities are in the process of incorporating LID into their stormwater management programs.

Low Impact Development includes non-structural practices such as minimal site disturbance and maintenance of natural flow patterns as well as structural practices. There are numerous structural LID practices such as rain barrels, bioretention systems, infiltration trenches, green roofs, and pervious pavement. Structural LIDs can be divided into comparison categories such as low capital cost and high capital cost as well as rainwater harvesting and infiltration-based. Low capital cost options include rain gardens, which can range from $4.00 to $10.00 per cubic foot of runoff volume whereas high capital cost options include pervious pavements and

green roofs, which can range from $120.00 and $225.00 - $360.00 per cubic foot of runoff volume, respectively. Given the order of magnitude difference in cost between the low capital cost and the high capital cost LIDs, the focus of this thesis will be on those practices which require a low initial capital investment. Additionally, the low-cost options are further divided into two categories, rainwater harvesting LIDs and infiltration-based LIDs.

Rainwater harvesting (RWH) is a LID practice that attenuates peak flow during wet weather events and reduces potable water demand for uses that would not normally require water of potable quality. The two options for RWH are rain barrels and cisterns. The difference between the two is a matter of scale. Rain barrels are typically implemented in one or more barrels with a volume of approximately 55-gallons, where as cistern volumes start at the hundreds of gallons. Effective RWH design includes long-term supply and demand as well as physical site considerations. Southwest Florida’s climate pattern is not compatible with rain barrels for runoff reduction due to their small volume; however, they still offer modest potable water savings to homeowners. Given the type, duration, and frequency of storm events, cisterns can offer runoff reduction as well as reducing potable water demand. For example, in Tampa, Florida, to achieve approximately 70% catchment efficiency, an average sized home would need approximately fourteen 55-gallon rain barrels or a 750-gallon cistern. Conversely, for a single 50-gallon rain barrel that serves outdoor use only, the water-saving efficiency is about 10% for Tampa.

When properly designed, infiltration-based LIDs mitigate groundwater disruptions that result from urbanization such as minimizing receiving water body hydromodifications, such as stream bank erosion, and reducing pollutant discharges to surface waters. Infiltration-based LIDs include systems such as bioretention, level spreaders, drywells, and “pocket” practices i.e.

pocket wetlands. Infiltration-based LIDs may be wet or dry systems and rely on easily attainable construction materials such as gravel, sand, and native vegetation. This combination may have applicability in Florida due to flat slopes, sandy soils, and areas with occasionally high seasonal water table. National standards for LID design should be considered guidelines and adapted accordingly to regional conditions in Southwest Florida. It is possible to utilize any number of LIDs, though one of the key factors to success is proper knowledge of the seasonally high water table, especially along the coast line. Additional factors to ensure infiltration-based LID success include installing a pre-treatment filter strip, standardized infiltration rate testing, standardized materials specifications, proper sequence of construction, and diligent construction inspections during and following construction.

The prospect of increased LID implementation within Southwest Florida appears promising. Municipalities are actively incorporating LID into their stormwater management recommendations. A behavioral study and interviews with staff from local governments regarding LID was conducted. The results indicate that Southwest Florida is facing many of the same barriers to implementation as other communities across the nation. These include lack of knowledge and education, lack of regionally specific design guidelines, and few “real world” pilot projects. Based on the behavioral study, it appears education could be the strongest key to LID acceptance. Over the course of three months in a graduate level urban hydrology course, opinions regarding LID in Southwest Florida went from not possible to positively inquiring how to increase implementation. Since the region faces most of the same barriers to implementation, it may be possible to use other cities’ methods to increase LID acceptance and implementation as a template while modifying them so they are regionally appropriate. A mnemonic device entitled “Let’s Make LIDs RADD” was created to assist engineers in implementing successful

LIDs. Where “R” represents site reconnaissance, “A” stands for choosing the appropriate LID given the site conditions, the first “D” denotes conducting a drainage investigation, and the second “D” corresponds with finalizing the LID design based on the information gathered after conducting all previous acronym activities.

CHAPTER 1: INTRODUCTION

Protection of natural amenities is vital to the economy of Florida. Many tourists escape from the chilling, northern winters and visit Southwest Florida to enjoy the natural beauty of its lakes, springs, estuaries, parks, and beaches while spending billions of dollars annually (FWC, 2014). Southwest Florida's parks and conservation lands provide valuable ecosystem services including food, fiber, flood control, drought protection, water quality, recreational, spiritual, and religious benefits (LMUAC, 2014) (Shi & Brown, 2014). Additionally, the area is under extreme residential and commercial development pressure. These activities cause environmental stressors such as increased imperviousness and surface runoff, decreased groundwater recharge, greater sediment and nutrient loading associated with stormwater runoff, and heightened groundwater withdrawal. This combination of environmental stressors negatively affects the very places that drew tourists and new homeowners to the area in the first place. A major environmental consequence from development and tourism is that many of Florida's water features do not meet national guidelines for acceptable water quality and are subject to Total Maximum Daily Load (TMDL) requirements. Total Maximum Daily Loads are a pollution budget that has been developed to restore impaired waters. For the State of Florida, in general, the leading causes of water body impairments include mercury, oxygen depletion, pathogens, algal growth, and nutrients (EPAd, 2015).

Low Impact Development (LID) is a stormwater management approach that has the potential to mitigate many negative impacts associated with urbanization, such as replenishing groundwater via recharge, utilizing harvested rainwater for non-potable water uses, and providing a level of pollution remediation. Given the amount of money spent in Florida on recreation, an argument for LID implementation can also be made based on economics and environmental services, as LID and/or Green Infrastructure (GI) can increase property values; therefore, creating an inticing financial incentive for developers (EPAf, 2014).

Low Impact Development is defined as stormwater management practices that mimic the pre-development site hydrology by utilizing site design practices that store, infiltrate, evaporate, and detain runoff (PG County, MD, 1999). The EPA (2014) defines LID as an approach to land development, or re-development, that works in conjunction with nature to manage stormwater as close to its source as possible. Low Impact Development extends beyond a structural system and employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional, appealing site drainage that treats stormwater as a resource rather than a nuisance. By implementing LID principles and structural practices, stormwater can be managed in a way that reduces the impact of urbanization and promotes the natural water movement within an ecosystem or watershed. In addition, LID has been characterized as a sustainable stormwater practice by the Water Environment Research Foundation (EPAf, 2014).

Often, the terms Low Impact Development (LID) and Green Infrastructure (GI) are used interchangeably. The distinction is subtle and a matter of scale. Green Infrastructure utilizes LID as a means of stormwater management to achieve a much larger, regional planning goal. The EPA’s Office of Water (2011) has defined GI as a comprehensive planning approach toward sustainability. Green Infrastructure provides green spaces, recreational opportunities, enhanced ecosystem services, improved air quality, increased property values, energy savings, economic development, reduced urban heat island effects, and job creation opportunities. Green

Infrastructure benefits are enhanced in urban and suburban areas where green space is limited and environmental degradation may be more extensive (Stoner & Giles, 2011).

Skepticism to large-scale LID implementation has occurred in Southwest Florida despite potential benefits and organizations promoting its use (Coffman, 2002). Although there are a number of real and perceived barriers to LID implementation, both the EPA and the University of Florida have created a series of fact sheets to provide LID education. For example, in a study by Horner et al. (2007) a conventional stormwater design was compared to implementing LID throughout a Pasco County project site. The LID design reduced costs, increased infiltration, and provided an overall balanced water budget for the site. However, the authors noted that LID permitting approval would require additional documentation, which could be a deterrent for some consultants. The authors also reported that maintenance costs for LID systems are slightly higher and, for extremely large storm events, LID would not provide the level of flood protection that would be provided by conventional stormwater systems (Horner, et al., 2007).

Low Impact Development practices can be non-structural or structural in nature. Non-structural LIDs include reduced site disturbance, street sweeping, and pet waste ordinances. Structural LIDs include infiltration-based designs, such as rain gardens, infiltration trenches, and green roofs, as well as rainwater harvesting systems, such as rain barrels and cisterns. In Southwest Florida, some of the most common LID practices that have been actively promoted include rain gardens, pervious pavement, green roofs, and rain barrels. However, a number of these technologies may not be as appropriate to the region as others. For example, green roofs require an irrigation system due to inconsistent rainfall patterns during winter months, pervious pavement requires increased long-term maintenance due to sandy soils, and homeowner rain barrels overflow in summer months due to frequent, intense precipitation. These maintenance issues contribute to the skepticism regarding LID implementation.

The cost of LID installation is an identified barrier to implementation. For example, green roofs and pervious pavement require a substantial initial capital cost increase over options such as rain gardens, which can range in initial cost from $4.00 - $10.00 per cubic foot of runoff volume (CWPa, 2007). According to the Center for Watershed Protection (2007), pervious pavement and green roofs, can range from $120.00 and $225.00 - $360.00 per cubic foot of runoff volume, respectively. Taking into account the order of magnitude difference in cost between the low capital cost and the high capital cost LIDs, this thesis will focus Chapters 3 and 4 on those practices that require minimal initial capital investment.

Numerous studies have found a positive correlation between green or natural environments and citizen's perceived overall general health, mental health, physical health, social health, and longevity (Godfrey, 2013). Additional studies indicate a strong, positive relationship between the experience of natural environments and mental health. Exposure to the natural environment promotes enhanced mood, improved attention, and reduced stress and anxiety. These relationships appear to be stronger among underserved populations in urban settings. In Chicago, those in deprived social housing communities have consistently responded positively to the benefit of space in areas such as cognitive restoration, self discipline, reduced aggression, and reduced crime (Thompson, et al., 2012). Municipal planners and the development community could positively impact neighborhoods when LID/GI use is increased during redevelopment or community revitalization projects (Godfrey, 2013) (Thompson, et al., 2012).

The overarching research question of this thesis is: Why isn't LID implementation more widespread throughout Florida, more specifically in Southwest Florida? To answer this question, research objectives were developed to guide this thesis. The research topics and objectives for each chapter are as follows:

Chapter 2 presents LID in a historical context and provides background information on Florida's stormwater management guidelines related to LID. Specific topics addressed are:

- How LID plays an important role in watershed restoration
- Regulations that apply to LID implementation
- Discussion of Florida's climate, hydrology, and hydrography
- How LID implementation is occurring around the Nation as well as in Southwest Florida

Chapters 3 and 4 provide details on two categories of LID appropriate for Southwest Florida, rainwater harvesting and infiltration-based practices. Specific topics related to these practices are:

- Rainwater harvesting options
- Rainwater harvesting design considerations
- Rainwater harvesting case studies
- Infiltration-based LID options
- Infiltration-based LID desgin considerations
- Infiltration-based LID case studies

Chapter 5 provides information on specific steps that can be taken to increase LID implementation in Southwest Florida:

- Review of known LID implementation in the region
- Review of Sarasota County's LID design manual

- Evaluation of LID perceptions in a graduate level Urban Hydrology class
- Interviews with government entities regarding LID implementation within their communities
- Discussion of recommended steps to increase implementation

CHAPTER 2: LITERATURE REVIEW

2.1 History and Background of Stormwater Management and Low Impact Development

2.1.1 Evolution of the Clean Water Act

The federal government has been attempting to protect citizens against aquatic pollution since the passage of the Federal Water Pollution Control Act of 1948, which mainly focused on state and local efforts. In 1972, the Federal Water Pollution Control Act of 1948 was completely overhauled and re-named the Clean Water Act (CWA), CFR 33 U.S.C. §1251 et seq 1972 (USEPA, 2012; USEPA, 2014). The impetus for change came from a grassroots movement forlorn with the environmental neglect that lead to numerous fires from 1936-1969 on Ohio's Cuyahoga River as a result of nonpoint source pollution (NOAA, 2008).

The CWA incorporated more stringent guidelines for point source and nonpoint source discharges into the nation's water bodies. Subsequently, point source discharges became unlawful without a permit from the Environmental Protection Agency (EPA). Additionally, for increased water quality protection, discharges must now meet pollution control measures. In 1987, Congress updated the CWA to include stormwater discharges, which are typically considered nonpoint sources. Two major water quality monitoring tools came from the 1987 revision of the CWA. First, a list of impaired water bodies must be provided by each state so that a Total Maximum Daily Load (TMDL) pollutant limit or budget can be set for the receiving waters. Second, the National Pollution Discharge Elimination System (NPDES) permit was developed to regulate pollutants, discharges into receiving waters and identify additional mitigation efforts prior to discharge if the receiving water body has a TMDL. The primary enforcement tool for the CWA is the NPDES permit (EPAa, 2014).

2.1.2 Connecting Stormwater Requirements Through Federal Permitting Criteria

Traditionally, stormwater management has been thought of as a necessary evil to deal with the amplified runoff associated with development and increased impervious area. Before the 1987 revision of the CWA, little provisions or regulations existed to contain stormwater runoff, which causes streambank erosion and contains pollutants such as nitrogen, phosphorus, fecal matter, sediment, heavy metals, and oils. Even with the construction of conventional detention/retention ponds, erosive velocities of discharges and pollutants were still being released to the receiving water body causing various ecological disruptions. Once the CWA recognized stormwater discharges as a nonpoint sources of pollution, pre-treating its discharge became an important tool in improving the nation's water quality through the use of stormwater Best Management Practices (BMPs) or in conjuction with Low Impact Development (LID).

Low Impact Development's goal is to mimic the pre-development site hydrology by utilizing site design practices that store, infiltrate, evaporate, and detain runoff (PG County, MD, 1999). Employing LID practices can lead to runoff being managed in a way that reduces the impact of development, or re-development, and promotes the movement of water within an ecosystem or watershed along its natural path (EPAb, 2014). The terms Green Infrastructure (GI) and LID are frequently used interchangably. Green Infrastructure typically refers to a broader coverage area such as community or watershed level. At the community level, GI incorporates sustainable development practices such as compact development, reduction of impervious areas, creation of walkable communities, and increases or retains open space as well as the inclusion of LID practices at the site level. On the watershed level, GI is an interconnected network of preserved or restored natural lands and water bodies that provide essential environmental functions (EPA, 2010).

The NPDES permitting requirements came in two phases; Phase I was implemented in 1990 and Phase II was implemented in 1999. In between these two phases, the EPA contracted with Prince George's County, Maryland Department of Environmental Resources to develop, what is now the Nation's Low Impact Development Manual, *Low Impact Development Design Strategies: An Integrated Design Approach*. This is the seminal document that continues to lead LID implementation. The opening pages of the National LID Manual repeatedly mention how, in 1999, LID was considered a radically different approach to stormwater management. One could argue this is still true today, some 16 years later, as LID has not been widely adopted as a form of stormwater management to protect water quality despite being advocated through NDPES and Municipal Separate Storm Sewer Systems (MS4) permitting.

By obtaining a NPDES permit, the EPA can track pollutant loading in waterbodies either with or without an imposed TMDL allocation. Stormwater is typically transported through MS4s. Municipal Separate Storm Sewer System permits are required for municipalities and small urban areas. Each MS4 permit is associated with a NPDES permit and the owner of the MS4 permit must develop a stormwater management program (EPAc, 2014). Section 402(p) of the CWA establishes the regulation of stormwater discharges from three potential sources: MS4s, construction activities, and industrial activities. Through the enforcement of this permitting mechanism, local surface waters such as streams, rivers, lakes or coastal waters will have a reduction in the impact of stormwater runoff. According to the Florida Department of Environmental Protection (FDEP), surface water quality standards are set forth in Florida Administrative Code 62-302 and the associated table of water quality standards of section 62-

302.503, while sections 62-303 and 62-304 establish the regulatory authority to regulate surface water quality and impose a TMDL on a water body (FDEP, 2015; PG County, MD, 1999).

For water bodies with a TMDL, LID technologies are recommended as a tool for current and future pollutant load allocations and/or reductions. Using LID can reduce pollutants associated with stormwater and help restore the natural hydrology of the site or watershed (EPA, 2008). TMDLs are one of the driving forces behind the promotion of utilizing LID for pollutant removal. There is a secondary, and equally important, driver in the implementation of LID: restoring the natural hydrology of the watershed. This thesis will focus on restoring the natural hydrology, water conservation and implementation of LID within the context of Southwest Florida. Though LID has largely been associated and promoted regarding its pollutant removal, the underlying idea of LID is decentralized stormwater management and promotion of groundwater infiltration. Before discussing the status of LID in Florida, it is important to review the current status of stormwater management in Florida and within the Southwest Florida Water Management District (SWFWMD).

The *NPDES Phase I Municipal Separate Storm Sewer System (MS4) Permitting Resource Manual* (2013) by FDEP is the living document guiding MS4 permittees toward stormwater compliance. The legal authority is established in Section 403.0885, Florida Statutes, and in Section 402(p) of the Federal Clean Water Act and the regulatory requirements for NPDES MS4 permits are set forth in Chapter 62-624, F.A.C. Permittees have the option to impose a stormwater utility fee as a dedicated funding source for stormwater management programs through Section 403.0893, F.S. Over 150 communities have implemented a stormwater utility or other stormwater dedicated funding source (FDEP, 2013).

As part of the MS4 permit, municipalities are required to periodically review their land development codes to ensure they are promoting sustainable development with adequate infrastructure to protect public health, safety, and welfare. By reviewing land development codes, municipalities have the ability to remove any impediments toward building a more sustainable development process that is crucial to protecting Florida's water resources. The *NPDES Phase I Municipal Separate Storm Sewer System (MS4) Permitting Resource Manual* (2013) acknowledges LID as one way of promoting newer, more sustainable stormwater management. Although municipalities are responsible developing their own implementation and adherence of the MS4 permit, the State of Florida and SWFWMD dictate the minimum stormwater regulations. Local governments have the option of creating more stringent requirements above and beyond the requirements of the State or the Water Management District.

2.1.3 Current Status of Florida Stormwater Management

The State of Florida has been regulating stormwater discharges since the early 1980s to prevent pollution of Waters of the State and to protect the designated beneficial uses of surface waters. Stormwater management is regulated at the State level by the FDEP, at the regional level by water management districts, and at the local level by municipalities. Chapter 62-40 of the Florida Administrative Code (FAC), titled "Water Resource Implementation Rule", sets the goals for stormwater management within the State of Florida. This rule establishes that stormwater design criteria shall achieve at least 80% reduction of the average annual load of pollutants that cause or contribute to violations of State Water Quality Standards. The design and performance criterion increases to 95% reduction when the stormwater system discharges to an Outstanding Florida Water (OFW) (FDEP, 2007).

Evaluation of Current Stormwater Design Criteria within the State of Florida (2007) is the current design manual provided by FDEP. It details stormwater design guidelines by water management district. This thesis will focus on the Southwest Florida Water Management District's jurisdiction; however, some aspects of stormwater management are the same across the state, with the St. John's and South Florida Water Management Districts having the most stringent stormwater management guidelines. The Southwest Florida Water Management District provides their stormwater management requirements in *Environmental Resource Permit Applicant's Handbook Volume II* (2013). The handbook specifically addresses traditional stormwater management systems; their requirements are outlined in Table 2.1. Both the State and SWFWMD stormwater guidance manuals address traditional stormwater management techniques such as wet detention, retention, and detention with filtration. After reviewing both the State and the District guidelines, it was revealed neither specifically addresses LID or other emerging technologies as a possible solution for water quality or water quantity issues associated with stormwater management (SWFWMD, 2013; FDEP, 2007).

The only State or District level guidance document found that addresses LID is the MS4 permit, which is implemented at the municipality level. Within the SWFWMD boundaries, some municipalities are implementing some aspects of LID such as Sarasota County, the City of Winter Haven, and the City of Dunedin (City of Dunedin, nd; City of Winter Haven, 2010; Sarasota County Government, nd). Pinellas and Hillsborough counties are in the process of implementing more LID use in their stormwater management codes. In 2014, Hillsborough County reviewed the codes and barriers to LID implementation in the publication *Summary of Green Infrastructure Inconsistencies and Barriers in Codes and Guidance with Action Items for Hillsborough County* (Hillsborough County Government, 2014). Pinellas County outlines their goals to implement more LIDs in their surface water management program requirements and review any code barriers to LID implementation in their comprehensive plan document titled *The Compendium of the Pinellas County Comprehensive Plan* (Pinellas County Planning Department, 2012).

Table 2.1 Standard Stormwater Practices and Criteria for Southwest Florida
(adapted from Evaluation of Current Stormwater Design Criteria within the State of Florida, 2007; Environmental Resource Permit Applicant's Handbook Volume II, 2013)

Type of System	Design Parameter	Criteria
Retention	Treatment Volume	On-line retention of runoff from 1" of rainfall
		If less than 100 acres, on-line retention of 0.5" of runoff
		Off-line retention of runoff from 1" of rainfall
		If less than 100 acres, off-line retention of 0.5" of runoff
	Volume Recovery	Total volume available in less than 72 hours
	Vegetation	Not Referenced
Underdrain System	Treatment Volume	Not referenced
	Volume Recovery	Not referenced
	Vegetation	Not referenced
Underground Exfiltration	Treatment Volume	Storage of runoff from 1" of rainfall
		If less than 100 acres, on-line retention of 0.5" of runoff
	Volume Recovery	Total volume available within 72 hours
		Designed with a safety factor of 2
		Seasonal HGWT ≥ 1' below bottom of perforated pipe
	Additional Design Requirements	Pipe diameter must be a minimum of 12 inches
		Trench width must be a minimum of 3 feet
		Rock material in trenches must be enclosed in filter material
		Maintenance sumps must be provided in inlets
	Vegetation	Not referenced
Wet Detention	Treatment Volume	First 1" from watershed
	Volume Recovery	No more than 50% within 60 hours, no more than 100% within 120 hours
	Residence time	Not referenced
	Littoral Zone	Minimum of 35% littoral zone, concentrated at the outfall littoral zone shall be no deeper than 3.5 feet below the design overflow elevation
	Pond Depth	Not referenced
	Configuration	Not referenced
	Vegetation	Mulching and/or planting is desirable but not required, unless the soils in the proposed littoral zone are not capable of supporting wetland vegetation; in this case, mulching will be required. Native vegetation that becomes established in the littoral zone must be maintained as part of the operation permit
	Pre-treatment	Provisions to remove sediment, oils and greases from runoff entering the wetland. This can be accomplished through incorporation of sediment sumps, baffles and dry grassed swales or a combination thereof. A dry grassed swale system designed for detention of the first one-fourth inch of runoff with an overall depth of no more than 4 inches will satisfy the requirement for prior removal of sediment, oils and greases.

Table 2.1 (Continued)

Type of System	Design Parameter	Criteria
Off-line Treatment Systems	Treatment Volume	On-line retention of runoff from 1" of rainfall
		If less than 100 acres, on-line retention of 0.5" of runoff
	Volume Recovery	Total treatment volume shall again be available within 72 hours, however, only that volume which can again be available within 36 hours may be counted as part of the volume required for water quantity storage under Chapter 3
Swales	Treatment Volume	Not referenced
	Volume Recovery	Not referenced
Dry Detention	Use Restrictions	Not referenced (generally discouraged)
	Treatment Volume	Not referenced (generally discouraged)
	Volume Recovery	Not referenced (generally discouraged)
Detention with Filtration	Treatment Volume	On-line retention of runoff from 1" of rainfall
		If less than 100 acres, on-line retention of 0.5" of runoff
		Off-line retention of runoff from 1" of rainfall
		If less than 100 acres, off-line retention of 0.5" of runoff
		The treatment volume can be counted as part of the storage required for water quantity storage under AH II Chapter 3
	Filter System	Permeability ≥ surrounding soil
		Stormwater must pass through a minimum of two feet of the filter material before entering the perforated pipe
		FDOT requirement for media - washed with <1% silt, clay, and organic matter
		Media uniformity coefficient > 1.5
		Effective grain size: 0.20-0.55mm
		Designed with a safety factor of 2
		Seasonal HGWT ≥ 1' below perforated pipe centerline
	Volume Recovery	Storage capacity restored in < 36 hours
Discharges to Outstanding Florida Waters, Class I or II Waters	Treatment Volume	In general, an additional 50% of volume over and above standard design criteria (wet detention, detention with effluent filtration, on-line retention or off-line retention)

2.2 Florida's Topography, Climate, Hydrography, and Hydrology

Florida's penninsula region is remarkably flat, with little longitudanal topographic relief. It is covered in sandy soils and porous substrates; therefore, there is a short residence time for stormwater within the soils. Florida's ecosystems rely on annual rains for replinishment. These distinquishing characteristics mold the iconic scrub lands, pine lands, high and low hummocks, river and cypress swamps, savannas, as well as fresh and salt marshes. The Tampa Bay region lies within the Gulf Coastal Plain physiographic subdivision and exhibits consistent physiography. Relatively flat bedrock yields the flat, low-lying terrain. Within the Gulf Coastal Plain, the Tampa Bay region lies in the Gulf Coastal Lowlands and extends westward to the Central Highlands. The Gulf Coastal Lowlands are depicted by numerous lakes, very swampy areas, and marine features such as bars and barrier islands. In *Ecosystems of Florida,* the Tampa Bay region is characterized by two physiographic districts, Eastern Flat Woods and Ocala Uplift Districts. The Eastern Flat Woods District contains mostly flat wood pines, prairies, cypress domes, dunes, and mangroves, with surface materials being primarily sandy with areas of peat deposits. The landscape is varied in the Ocala Uplift District containing distinctive low, rolling karst in addition to stream-sculptured hills, flats and swamps, and sandhills (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001; see also Bureau of Geology, Florida Department of Natural Resources, 1974; Florida State University, Institue of Science and Public Affairs, 1998).

Florida has a humid, sub-tropical climate with a strong, distinctive climatic cycle. The Bermuda high pressure cell regulates rainfall within the State. During the fall and winter months, the high pressure cell hinders convective clouds from turning into thunderstorms. Fall and winter storms are characterized by their long duration, low to moderate rainfall intensities, and coverage of large land areas. During late spring and summer, the high pressure cell weakens creating convective storms late afternoon and evenings on the Gulf of Mexico. The convective storms associated with Florida summers are induced by the diurnal heating of the land surface along with the sea breeze. Summer, convective storms have notably high rainfall intensity, short duration, and cover small areas whereas the winter, frontal storms have a longer duration, a more broad land coverage, and traditionally less intensity than the summer storms (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001).

Climate conditions may be one of Florida's most important resources; although it lies along the same latitude as most of the world's deserts it is one of the wettest states in the country, with an annual average of 53 inches of rainfall. Nationally, it is one of the highest ranking states for rainfall characteristics in the following categories: proportion of summer rainfall versus winter rainfall, number of summer months exceeding 4 inches of rainfall, amount of rainfall in the wettest month; difference in rainfall amounts between the average wettest and driest months, and the maximum expected 30 minute rainfall. The Tampa Bay region is located within the South Central Climatological Division, a term which was utilized by the former United States Department of Agriculture crop reporting districts (Florida State University, Institute of Science and Public Affairs, 1998).

Florida ranks third in the nation for the amount of inland water among the 50 states, with inland water bodies totaling 3,383 square miles. Streams, springs, lakes, wetlands, and rivers make up the state's inland water bodies. The total number and miles of perennial streams and rivers is more than 1,700 and covers 22,993 miles. The total number of lakes, ponds, and reserviors, which are greater than 10 acres by state definition, is 7,748 and have a combined coverage of 2,390 square miles. Freshwater and tidal wetlands cover 17,698 square miles of Florida. There are more than 1,000 known springs in Florida, with 33 considered first-magnitude springs. The detailed shoreline area is 8,426 statue miles, which includes bays and sounds (FDEP, 2014). The state's natural hydrography provides temporary storage of surface runoff. When the natural depressional storage is altered in an urban landscape, man made stormwater facilities must be created to mitigate the additional runoff associated with an altered landscape and increased impervious cover.

Originally, wetlands covered more than half of Florida. During the early settlement of Florida, wetlands were drained for farming ground and mosquito control, with little concern or knowledge of their beneficial hydrologic processes. Wetlands provide depressional storage of surface runoff, treatment of runoff, and aquifer recharge. Wetlands and uplands can be located adjacent to each other. With Florida's flat topography and high water tables, they frequently allow water and nutrients to flow into adjacent ecosystems thereby creating a closely integrated landscape (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001). *Ecosystems of Florida* (2001) describe the benefits of various wetlands such as: wildlife production, flood control, nutrient retention, water retention for stormwater, and water recharge of aquifers. Wetlands are considered benevolent for providing such services with no appreciable cost to the community for without these services, infrastructure costs rapidly increase when natural functions cease to exist.

Florida contains about 7,800 lakes greater than 0.4 hectares (1 acre) in surface area, which covers about 6 percent of the landscape. Thousands of these lakes are small in size, while there are a few large lakes. According to the Florida Lakes Database, three-quarters of the lakes are less than 5 meters (15 feet) in depth. Lake evaporation is roughly equivalent to annual rainfall on average. There is a strong hydrologic connectivity between lakes, some as far apart as 280 kilometers (174 miles). Residence time in Florida lakes can be ten times longer than in northern states making them vulnerable to the damaging consequences of urbanization (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001).

Southwest Florida has five first-magnitude springs, which discharge 64.6 million gallons of water per spring, per day. This includes the popular tourist destination Weeki Wachee springs. Springs are a direct conduit to the aquifer; water is infiltrated from surface rainfall to the aquifer and as pressure builds within the system, the water is discharged back to the surface through a spring vent. Springs provide natural habitat for wildlife including Manatees during winter months which draws tourism. The aquifer that feeds springs is the major source of drinking water for the State of Florida. Approximately 70% of the Tampa Bay Region's drinking water comes from ground water (Tampa Bay Water, 2015).

Water Resources Atlas of Florida describes the hydrologic cycle as a closed system with regard to water (Florida State University, Institute of Science and Public Affairs, 1998). Rain falls upon land surfaces and may be returned to the atmosphere by evaporation from land, water, and plant surfaces or ultimately flows toward the Gulf of Mexico via surface runoff. Upon making landfall, rainwater has a delicate interplay between the depressional storage provided by swamps, lakes, streams, and the ground (Bureau of Geology, Florida Department of Natural Resources, 1974). Remaining rainfall on the land may take many different paths such as overland flow or infiltration. Infiltration may occur through the soil surface directly or after residing temporarily in depressional storage (Florida State University, Institute of Science and Public Affairs, 1998). One connection of the availability for surface runoff is the difference between annual rainfall and evapotranspiration. In Southwest Florida, this potential difference has a negative value where evapotranspiration exceeds annual rainfall (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001).

Soil type plays a crucial role in many aspects of drainage. Geology influences soil type and geologic deposition materials have different drainage characteristics. For example, as a general rule, soils on the Central Ridge are very well drained, whereas soils on the Coastal Ridge may be poorly or very poorly drained (Florida State University, Institute of Science and Public Affairs, 1998). A large portion of the Florida landscape has soils with water tables within reach of plant roots for at least part of the year, mostly during the rainy season (Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission, 2001).

Florida has the largest acreage of Aquods, wet sandy soils with an organic stained subsoil, occuring on flatwood lands in the nation. The most widespread flatwood soil in Florida is the Myakka Fine Sand (MFS). Myakka Fine Sand is the Official Soil of the State of Florida. It is a native soil of Florida and is not present in any other state. Florida has more than one and one-half million acres of MFS, it is the most extensive soil in the state. As a flatwood soil, MFS has typical characteristics of flatwood soils such as being poorly or somewhat poorly drained, sandy texture, organic matter stained subsoil, low ion exchange capacity, low silt and clay content, and poor moisture retention (Florida Association of Professional Soil Classifiers & Florida Chapter of the Soil and Water Conservation Society, 1993)

The United States Department of Agriculture’s Soil Survey (1983) provides technical information on the Myakka Soil Series. The Myakka series is a deep, sandy soil which may be poorly or very poorly drained, depending on which sub-class occurs on site. Myakka Fine Sand is virtually level, with slopes from 0 to 2%, and occurs on broad plains on the flatwoods. The seasonal high water table fluctuates for one to four months of year to a depth of 10-12 inches from the land surface and during the remaining months, the water table recedes to an average depth of 40 inches. The Myakka series can be designated as MFS with a hydrologic soil group (HSG) of B/D, a MFS with a HSG of D, a MFS on urban land with a HSG of B/D, or a MFS on tidal land with a HSG of D. A dual HSG designation of B/D indicates the soil series has B, well drained, soil properties however, during the rainy season it can have D, very poorly drained, soil properties since the seasonally high water table comes within 1 foot or closer to the land surface. The HSG D is assigned to soils which flood year-round and the seasonally high water table is within a foot of or at the land surface from January to December.

Myakka Fine Sand is rapidly permeable through all soil layers, as such, the available water capacity is low. Permeability is a quality of the soil which allows water to move downward through the soil profile. Permeability has the units of inches per hour and is an indication of the amount of water that can infiltrate in an already saturated soil. For MFS, the permeability is considered rapid, since it can infiltrate 6.0 – 20.0 inches per hour in an already saturated soil. Available water capacity, also known as available moisture capacity, is the maximum amount of water a soil can hold for plant uptake. Available water capacity is generally defined as the difference between soil water at field capacity and wilting point. The units are inches of water per inch of soil. Myakka Fine Sand has a low available water capacity, which ranges between 0.02 - 0.05 in./in (NRCS Soil Survey, 1983).

Florida has a special set of natural hydrologic features that need to be considered when designing LIDs or traditional stormwater management. The rainfall patterns and soils are not necessarily complimentary across the board however, MFS does have an extremely high permeability and if rainfall rate does not exceed the infiltration capacity, infiltration-based LIDs can be a consideration as a method of stormwater management. Low topography, soils, and abundant hydrography create an inter-connected landscape that is highly sensitive to increased impervious area and pollutants from runoff.

2.3 Impacts of Urbanization and the Hydrology of Low Impact Development

Throughout the U.S. there are thousands of CWA section 303(d) waters listed as impaired for stormwater-source pollutants such as pathogens, nutrients, sediments and metals (EPAb, 2013). Runoff is the primary source of non-point source pollution as well as being linked to public health issues, economic losses, and stream and ecosystem degradation (Cizek & Hunt III, 2013). Urbanization and traditional stormwater management cause stream channel erosion, increased imperviousness, which reduces infiltration and runoff velocities, decreased stream baseflow components, alteration of natural flow patterns, loss of depressional storage, increased stream temperatures, increased incidence of flooding and more costly damage, and the need for imported water for consumer use (Cheng, et al., 2001; Cheveney & Buchberger, 2013; Holman-Dodds, et al., 2003). As land use transitions to more urbanization, waterbody impairments from stormwater sources may increase and thereby may require additional TMDLs. Incorporating LID into TMDL reduction plans can encourage implementation actions that can reduce stormwater runoff loads and erosive effects, and help meet pollutant loadings identified in the TMDL (EPA, 2008).

As urbanization transforms the natural landscape or open space by increasing impervious areas to create residential, commercial, or industrial land uses, it simultaneously causes hydromodifications, such as reduced soil-water storage and reduced base flows due to terrain alteration, modification of vegetation and soils. Although controlling runoff volume is essential, runoff reduction alone will not be enough to protect water bodies without consideration of relevant hydrologic and geomorphic regimes that affect stream stability and beneficial uses.

Mitigating the impacts of hydromodification include: peak flow control of stormwater runoff, maintaining time of concentration, promoting groundwater recharge, controlling stormwater runoff volume, and flow duration control (Palhegyi, 2010).

Conventional stormwater management falls short in providing environmental protection because it does not address all changes of the flow regime. Though the cumulative effects of small-scale stormwater management on the basin scale hydrology are not fully understood, the argument can be made for a more encompassing approach to stormwater management that also includes restoring ecologically important aspects of the pre-development hydrology. By emphasizing restoring small-scale hydrologic processes, such as those offered by LID, it is possible to restore the ecological function and structure of urban streams. Small-scale, flow-regime, stormwater management systems protect vulnerable, small, headwater streams, which have their own equally important ecological value (Burns, et al., 2012).

Burns et al. (2012) discussed changes in patterns and volume of infiltration, evapotranspiration, and surface and subsurface flows associated with conventional approaches to stormwater management. These changes include increased frequency, magnitude, and volume of runoff as a result of directly connected impervious areas; increased runoff as a result of reduced evapotranspiration from vegetative cover; and reduced stream baseflow as a result of reduced infiltration. Stormwater BMPs and LID lessen the impacts of urbanization by increasing water storage and infiltration, which in turn, decreases urban stormwater runoff volumes (Cheveney & Buchberger, 2013). Low Impact Development carefully manages stormwater runoff by directing it to an adjacent pervious area thereby reducing surface runoff, recharging local groundwater aquifers and streams, reducing stream bed erosion and widening, and improving water quality (Holman-Dodds, et al., 2003).

Research into the sustainability of LID requires accurate methods of quantifying and analyzing the effects of urbanization as well as the hydraulic benefits of Low Impact Development (Hollander, Eyring, & Schmidt, 2006); (Cheveney & Buchberger, 2013). Quantifying the performance of the full range of stormwater management technologies available for restoring or protecting pre-development hydrology is essential for models to accurately represent the relationship between small-scale stormwater management and catchment-scale responses (Burns, et al., 2012). Holman-Dodds, et al. (2003) posed significant LID research opportunities or challenges to quantify the implementation of LID practices. They discussed quantifying results of vegetative and soil properities, providing design guidance for urban lanscape planning with respect to location and surface treatment of infiltration zones, and quantifying hydrologic impact and design parameters to satisfy municiaplity concerns regarding urban runoff and flooding.

2.3.1 LID Hydrology Case Studies

Palhegyi (2010) discussed LID requirements to mimic pre-development hydrology from a proposed development so that it protects receiving water bodies. The paper states that for stormwater management controls to be successful, they must be based on scientifically sound principles aligned to in-stream process such as erosion potential. Several studies have shown flow duration control has a more positive impact on stream protection than peak flow matching and hydrograph matching. Flow duration control maintains pre-development runoff magnitude, duration, and frequency. It is successful when the post-development flow duration curves match pre-development curves.

Palhegyi (2010) promotes the use of flow duration control for stormwater discharges to maintain predevelopment magnitude, frequency, and duration of hourly runoff thereby, maintaining the distribution of instream work. Aside from the standard stormwater detention/retention ponds, infiltration based LID practices, such as infiltration swales and bioretention, can be used for flow duration control. Using HEC-HMS, the Laguna Creek watershed was modeled using flow duration control measures to mimic pre-development stream flow. For stormwater management control of runoff in the model, small basins and bioretention were utilized. Flow duration control methods matched the 49-year historic record average of stream flow and discharge rate from the watershed.

According to Cheng et al. (2001), LID hydrologic design employs a distributed control approach to stormwater management by using integrated management practices and safeguarding a hydrologically functional landscape. The distributed control approach hydrologically regulates stormwater runoff to maintain pre-development time of concentration by storing runoff in discrete units (integrated management practices) distributed throughout the site. To compensate for hydrologic transformations of development, both structural and non-structural practices may be required to preserve the hydrologic regime of pre-development conditions. These integrated management practices are what most know as individual LID technologies or practices today. Integrated management practices make use of micro-scale, distributed practices which, when implemented properly, allow post-development runoff and peak volume match pre-development runoff. A hydrologically functioning landscape preserves as much undisturbed land as possible; it also retains high infiltration capacity soils. Combining distributed control, integrated management practices, and a hydrologically functioning landscape together during development can sustain the pre-development conditions, enhance aesthetics, and retain habitat value.

Cheveney & Buchberger (2013) conducted a water balance study in the Mill Creek Watershed, which is located in southwestern Ohio and contains 169 mi^2 of the Cincinnati metropolitan area. The water balance study was performed using the modeling software, Aquacycle. They looked at the pre-development (historic) water balance, the current water balance, and the water balance after implementing green infrastructure. When comparing pre-development and current, developed conditions, two values were noticably altered, the total volume of water entering and leaving the watershed increased 28% and the annual evapotranspiration declined by 22% compared to pre-development conditions. In the conclusion, the paper mentions that with proper planning and implementation of appropriate GI, there could be a reduction in some of the undesirable hydrologic impacts of urban development. For Florida, it is plausible that evapotranspiration may remain the same in a post-development landscape as large, regional wet detention ponds are often utilized in series for stormwater management.

Holman-Dodds et al. (2003) conducted a water balance study on the North Branch of the Ralston Creek watershed in Iowa City, Iowa; specifically, the water balance included precipitation, evaporation, transpiration, soil water storage, and deep soil drainage. The study conducted the water balance on three development scenarios: pre-development, where the entire landscape is vegetated; high impact, where traditional pipe and concrete stormwater management is utilized; and low impact, where runoff is directed to a pervious area for infiltration. A variety of SCS soil classifications were modeled using UNSAT-H, as well as storm events ranging from 0.5 inches to the 100-year, 24-hour design storm depth of 7.13 inches.

In this modeling study for high infiltration capacity soils, like those in Florida, the potential increased use of LID on the watershed level could be utilized to reduce runoff, increase infiltration, and promote aquifer recharge. The study results for high infiltration soils show the LID case only slightly generated more runoff than the pre-devleopment case when compared to the high impact development case. For the pre-development case, less than 10% of runoff was generated for rainfall up to 7 inches; for the LID case, less than 10% of runoff was generated up to 5 inches of rainfall and for 5-7 inches of rainfall, runoff increased gradually to 20%; and for the high impact case, 50% of runoff was generated consistently for all rainfall scenerios, which is consistent with the 50% impervious area. When measuring the difference in runoff between pre-development and high impact development for more pervious soils, it appears the relative impacts of urbanization is greater. However, the potential for mitigation of the impacts of urbanization through runoff reduction is also much greater for high infiltration capacity soils. Having a greater potential for mitigation for Florida's highly pervious soils is significant in that it opens the door for more research in quantifying the benefits of LID.

The storm hydrographs for all three development cases show LID is most effective in replicating pre-development for the 2-year, 24-hour design storm compared to the 100-year, 24-hour design storm in the North Branch Ralston Creek watershed. During the 20-year water budget simulation period for the three development scenarios, high impact development, with traditional stormwater management, had the largest increase in direct runoff and the largest decrease in groundwater recharge and evapotranspiration. The LID scenario still had double the amount of direct runoff compared to pre-development; however, recharge and evapotranspiration were closer to pre-development than high impact development.

Burns et al. (2012) compared the effects of conventional, drainage-efficiency stormwater management and load-reduction approach to stormwater management to identify their hydrologic shortcomings. The land-parcel scale study was conducted in Australia within two adjacent watersheds of similar size; Brushy Creek, an urbanized catchment, and Olinda Creek, a primarily forested catchment. Continuous modelling software, MUSIC, was utilized to model stormwater runoff, quality, and treatment. MUSIC was used to model surface runoff generated and infiltration of a 500 m^2 of forest and then model the same parcel as if it were 100% impervious. The hydrology of the land parcels, forested and 100% impervious, was compared with 1) traditional stormwater management, 2) load-reduction stormwater management using a biofiltration system with an underdrain, and 3) flow-regime stormwater management using a combination of rainwater harvesting and a rain garden. It should be noted the biofiltration system was what is typically known as a modified bioretention with an internal water storage zone. Runoff from the impervious surface was highest using traditional stormwater management, load-reduction management reduced runoff only slightly as it contains an underdrain, and flow-regime management produced the least runoff and was the closest to the forested condition.

2.4 Implementation of LID Nationally

Low impact development implementation is encouraged by EPA in both their TMDL and MS4 permit programs. For TMDL reduction, LID is encouraged to help with erosive stormwater velocities and nutrient reduction potential (EPA, 2008). For the MS4 permit, LID is encouraged as a more environmentally sustainable method of stormwater management (EPAe, 2014). Implementation levels vary by state and muncipality. The EPA lists Prince George's County, Maryland and Pugent Sound as their primary implementation case studies (EPAe, 2014). For EPA's Community Scale Studies, the common thread for LID implementation is for the reduction of Combined Sewer Overlfows (CSOs) (EPAg, 2014).

Due to a violation of the CWA by CSOs, Consent Decrees are a mandatory mechanism to implement LID to achieve overflow reductions. A small sampling of major cities with Consent Decrees include Harrisburg, PA; Philadelphia, PA; Washington, DC; Kansas City, MO; Chicago, IL; and Milwalkee, WI (Milwaukee Metropolitan Sewerage District, 2012; Philadelphia Water

Department, 2015; United States District Court for the District of Columbia, 2003; EPAa, 2015; EPAb, 2015; EPAc, 2015). Though some cities were once required by Consent Decree imposed by EPA to reduce CSOs through the use of LID, they have since come to embrace such practices. For example, Milwaukee, Philadelphia and Washington, DC have dedicated publications and websites providing stakeholder education on LID implementation and ecological services potentially provided when installed properly (Milwaukee Metropolitan Sewerage District, 2012; Philadelphia Water Department, 2015; District of Columbia Water and Sewer Authority, 2015).

Statewide adoption of LID implementation can vary in their strategies. The State of Vermont aimed to make their LID implementation successful by focusing on successes, barriers, and mistakes made by other agencies across the United States. They contacted agencies involved in stormwater management ranging in size from EPA to small agencies with few staff. This background investigation has lead to Vermont's 2014-2019 Green Infrastructure Implementation Plan (Vermont Department of Environmental Conservation, 2003).

Other states that have incorporated LID into their stormwater management include Rhode Island, Maryland, Virgina, and Minnesota. Rhode Island has incorporated LID implementation as the "industry standard" in their stormwater management policies. The three main goals of the Rhode Island incorporation of LID in development and redevelopment projects is to avoid unnecessary environmental impacts, reduce environmental impacts, and manage environmental impacts at the source. Maryland has incorporated LID through the use of an Environmental Site Design. To the "Maximum Extent Possible" development sites must utilize better deisng techniques, alternative surfaces, non-structural LID techniques, and small-scale LID practices. Some of the LID practices include downspout disconnection, green roofs, permeable pavements, bioretention, and other infiltration based practices. Virgina utilizes a Runoff Reduction

Approach. The Runoff Reduction Approach decreases the total runoff volume through canopy interception, infiltration, evapotranspiration, and rainwater harvesting. Minnesota incorporates Minimal Impact Design Standards (MIDS). Minnesota anticipates that by the utilization of MIDS this will become the next generation in stormwater management and is intented to implement LID as the primary method for new development. These are just a few states that have incorporated LID into their state stormwater design manuals as a method to overcome water quality and water quantity issues associated with stormwater (Vermont Stormwater Management Program, nd).

The Center for Neighborhood Technology (2007) investigated implementation of LID and green infrastructure (GI) by five major US local governments. This included the Metropolitan Water Reclamation District of Greater Chicago (MWRD), the City of Chicago, the City of Philadelphia, the City of Seattle, and the Milwaukee Metropolitan Sewerage District (MMSD). The case studies of these five government entities reviewed resources that were devoted to GI as of the date of publication, actively promoted LID practices, and projects or planned projects to further public education and achieve an increased presence of GI within their communities. A breakdown of each government entity's date of updated stormwater regulations, which include implementation of GI on some level, amount of designated funds for GI implementation, if available, pilot projects demonstrating GI/LID practices, specific campaigns addressing GI, and any specific LID practices that are actively promoted for that entity is provided in Table 2.2.

Struck et al (2011) evaluated the required scale of implementation and quantified benefits associated with several LID projects that were being assessed or applied to achieve objectives beyond localized stormwater management. The research objective for two projects, Toledo, OH and Los Angeles County, CA, was to highlight the integration of LID along with regional management strategies to control water quantity and water quality as well as supplement current infrastructure. An additional goal of this project was to provide further information on managing urban watersheds through the use of LID and potentially inform regional or national approaches to watershed management.

Table 2.2 Case Studies of Green Infrastructure Implementation by Five Major U.S. Local Governments (adapted from Center for Neighborhood Technology, 2007)

Government Entity	Updated Stormwater Regulations with GI components	Money Designated to Green Infrastructure Implementation	Pilot Projects	Green Infrastructure Initiatives	Specific LID practices
MWRD	2004	$909,132 or 22.2% of the 2007 Stormwater Fund expenditures	Native Prairie Landscaping at District properties	Native Prairie Landscaping at District properties	Not addressed
				Rain barrel distribution in CSO areas	
				Wetland nutrient abatement downstream of treatment plant outflows	
City of Chicago	2008	$13.1 million over 5 separate departments	Road realignment and grade separation to divert runoff to new pond and vegetated swale rather than directly discharging runoff into nearby river	Rain Barrel and Rain Garden Program	Bioswales
			Green Alley Program	Water Outreach Campaign	Downspout disconnection
			Green Streetscape	Green Roof Grant Program	Pervious pavement
				Green Alleys	Tree planting
					Green roofs
					Rain barrels
					Rain gardens
					Public education and outreach
City of Philadelphia	2006	Not addressed	Green Roofs Tax Credit	Watershed plans	Public education and outreach
				Schuylkill Action Network	Rain gardens
				Best Management Practices Recognition Program	Green roofs
				Fairmount Park Water Works Interpretive Center	Permeable pavement
				Rain barrel distribution	Bioswales

Table 2.2 (Continued)

Government Entity	Updated Stormwater Regulations with GI components	Money Designated to Green Infrastructure Implementation	Pilot Projects	Green Infrastructure Initiatives	Specific LID practices
City of Philadelphia (cont'd)				TreeVitalize GI implementation at public schools Golf Course program to encourage BMP use Transformation of vacant lots into green spaces	Tree plantings
City of Seattle	2008	$31.9 million or 12.7% of the Public Utilities Drainage and Wastewater Budget	Viewlands Cascade ditch retrofit with vegetated cascading step pools	Natural Drainage Systems	Public education and outreach
				Completed retrofit of existing streets with LID practices	Vegetated swales
				Street Edge Alternatives	Native landscaping
				Restore Our Waters Strategy	Drywells
				Public Utilities Department Comprehensive Drainage Plan	Pervious pavement
					Rain barrels
					Cisterns
MMSD	2003	$5.2 million or 35% of the budget	Stormwater BMP demonstration projects	Rain barrel distribution program	Public education and outreach
			Wet Weather Peak Flow Reduction program	Greenseams land acquisition program	Downspout disconnection
			Water Quality studies	Rainwater Rerouting Project – GI to divert stormwater from CSOs	Rain gardens
				Strategic Plan for Stormwater Runoff Reduction	Green parking lots Pocket wetlands Rain barrels Green roofs Stormwater trees Bioretention Drywells

Toledo, OH was under a Consent Decree to develop a Long Term CSO Control Plan. One aspect of the Consent Decree included the utilization of GI to reduce the number of overflows per year. In order to reduce the number of overflows and implement GI projects, Ohio's Water Pollution Control Loan Fund (WPCLF) Green Project Reserve received $220,623,100 in funding from the American Recovery and Reinvestment Act (ARRA) to stimulate the economy through water pollution control projects. Approximately 20% of the

Federal funding received was reserved for GI, water/energy efficiency, and environmental innovation. Ohio subsidized most of its green reserve projects by providing 100% principal loan forgiveness up to $5,000,000 (Struck, et al., 2011).

The WPCLF Green Project Reserve funded a pilot project on Maywood Avenue located in Toledo to address its frequent street and basement flooding as well as its contribution to CSO overflows. Out of the fifteen GI funded projects, the Maywood Avenue Project is one of two projects employing bioswales and rain gardens to address stormwater runoff. In addition to offseting drainage inadequacies in the neighborhood, the site was chosen to demonstrate to the local area that the City is concerned about residents' quality of life. Public outreach and engagement were vital for this project, as previous experience in similar neighborhoods to the Maywood area had shown the residents were leery of local government. By engaging residents throughout the project, it helped them understand the connection between planning, managing stormwater, improving street aesthetics, and alleviating basement flooding.

For this project, preliminary design considered not only the existing infrastructure but investigated any potential geotechnical issues as well as pedestrian, bicycle and automotive traffic and parking requirements. Final design included updates to inlets of the storm sewer system, pervious pavement, and bioswales. Updating the inlets to the storm sewer system will help to hydraulically separate the two systems and reduce surface flooding that flows towards Maywood Avenue and the bioswales will reduce peaks flows within the storm sewer system. Focusing on the GI practices, pervious pavement was installed in sidewalks and driveways and bioswales were installed parallel to the road in the right of way. This combination was determined to be the most cost effective and least maintenance intensive options. The bioswales provided 0.35 inches of watershed runoff storage in addition to providing an aesthetic amenity to the neighborhood (Struck, et al., 2011).

In addition to Toledo, Ohio, Struck et al. (2011) reviewed GI implementation in Los Angeles County for the Ballona Creek and Los Angeles River at both the county and municipality level. Los Angeles County is the NPDES permit holder for the incorporated areas of the area and therefore, is responsible for the water quality at receiving water bodies. The project objectives were to identify areas of opportunity for green infrastructure solutions to meet TMDL pollutant targets. The County wanted to improve water quality in addition to increasing infiltration to aquifers and providing aesthetic amenities in public areas.

Los Angeles County and the City of Los Angeles origninally had differing opionins on how to best manage stormwater to address water quality, water quantity, and water supply issues. The County determined a regional, mostly centralized approach of managing stormwater. Dry detention and infiltration basins were the large, centralized stormwater management facilities the County felt met their cost/benefit goals. Since the stormwater was flowing into the City, the City evaluated the utilization of distributed LIDs for implementation upstream of the County's centralized systems. The City of Los Angeles and Los Angeles County catgeorized the following LID practices to supplement the effectiveness of the centralized systems in order of preference: bioretention, pervious pavement, and bioswales. The City and County determined these were the best LID practices based on their applicability, cost effectiveness, and climatic considerations of the sub-watersheds within the project area.

The distributed LID BMP pilot study in Los Angeles County was to make use of the County datasets to investigate and review BMP optimization solution techniques as well as evaluate the cost and benefits of proposed management options, focusing on structural BMP solutions. A two-step approach was applied to investigate, review, and optimize site-scale LID distribution and implementation. The first step identified the optimal, site-scale LID practices for each type of land use. The second step incorporated the optimal, site-scale LID practices from step one and applied them along with the centralized systems to an entire watershed. The simulation in step two determined which LID practices, as well as centralized stormwater management systems, would achieve the Waste Load Allocations determined by the watershed's TMDL thereby providing Los Angeles County the ability to prioritize projects and funding (Struck, et al., 2011).

Successful integration of LID into stormwater management is key to encouraging other states and municipalities toward greater LID implementation. Initial LID deployment and subsequent continued use has been increasingly executed at various government levels, each with its own individual reason and method. According to The Center for Neighborhood Technology (2007), successful implementation orginates from strong environmental leadership and installation of pilot projects. In this report, strong leadership is described as one that addresses the barriers to implementation, shares cost with partnerships on pilot projects, and if necessary, pass ordinances that require development and re-development to incorporate green infrastructure. Pilot projects are also instrumental in LID acceptance and success. They provide a means of measuring LID performance and can reveal hidden costs as well as other design parameters that should be taken into account regionally. Struck et al. (2011) observed sucessful implementation occurs when modeling and other tools are utilized for spatial and cost optimization as well as incorporation in future Capital Improvement Projects.

2.5 Florida LID Implementation

There is growing interest in LID among those working in the environmental and stormwater management community in Florida; however LID installation are still sparse. Unlike other states, Florida does not have many CSOs nor is the State under a Consent Decree requiring implementation of LID and GI to address water quality issues associated with stormwater. The Florida Aquarium pervious pavement and associated bioretention strips are a frequently cited LID practice in Florida, despite approaching two decade old research (EPA, 2000). When looking at the National LID map provided by the Low Impact Development Atlas, the majority of LID implementation is clustered around the Mid-Atlantic region, the Northeast, and along the West Coast of the U.S. Unfortunately, there is no one central location containing data of Florida sites with LID implementation. Implementation information is scattered amongst various data sources.

The International Stormwater BMP Database is generally discussed as the initial 'go-to' website to obtain detailed BMP/LID data in a state. Florida has eighty-four BMPs listed, of which, thirty-seven fall under the general definitions of LID. These categories include grass swales/strips, infiltration trenches, media filters, wetland basins, and wetland channels. For Florida, most of the project descriptions state they are from the FDEP database. A summary of LID practices, the county they are located in, and their drainage area are provided in Table 2.3, Note that some projects have multiple practices on one site and others have the same practice with the same drainage area repeated for study purposes (International Stormwater BMP Database, 2014).

Table 2.3 International Stormwater BMP Database Summary of LID Practices in Florida
(adapted from: International Stormwater BMP Database, 2014)

LID Practice	County	Drainage Area (ha)	Number of Units
Grass swale/strip	Orange	unknown	2
		< 0.1	4

Table 2.3 (Continued)

LID Practice	County	Drainage Area (ha)	Number of Units
Grass swale/strip	Monroe	9.85	
	Hillsborough	< 0.1	5
Infiltration Trench	Brevard	1.55	3
		0.66	3
		41.48	2
		6.27	
Media Filter	Orange	48.93	Media: Other
		10.12	Media: Other
	Leon	1105	Media: Sand
		0.32	Media: Sand
	Hillsborough	4.21	Media: Other
Wetland Basin	Osceola	4047	1
	Hillsborough	53.58	1
		8.35	1
	Orange	213.28	1
	Okeechobee	89.03	1
	Seminole	22.42	1
Wetland Channel	Leon	1105	1
	Orange	16.84	1

The National LID Atlas (University of Connecticut, nd) is another website that provides a database of LID implementation throughout the U.S. Florida has five LIDs listed; that do not appear to repeat projects listed in the International Stormwater BMP Database. Of the five listed, four are pervious pavement. The fifth is listed as a bioretention/rain garden in Tampa installed by the University of South Florida’s Department of Civil and Environmental Engineering recent Ph.D. graduate, Ryan Locicero.

The University of South Florida, Tampa campus, has ongoing LID research and outreach. The Patel Center for Global Sustainability installed a green roof and large cistern used to non-potable water uses such as toilet flushing. The Patel Center for Global Sustainability is currently working on planning tool software to assist in management decisions when transitioning from grey to green infrastructure. In addition to traditional structural LID practices, there is a focus on Urban Forestry as well as non-structural practices.

The Department of Civil and Environmental Engineering is active in promoting LIDs for nutrient removal and providing public outreach. Ryan Locicero, a recent doctoral graduate, has installed eight bioretention systems in East Tampa (Locicero, 2015). Seven of the bioretention systems were installed with students at local schools. The last bioretention system was installed at a local leader's residence in order to facilitate discussion within the community and address localized flooding issues on the property. His dissertation focused on developing a Green Spaced Based Learning curriculum as well as bioretention native plant selection. He has provided public outreach and education on environmentally sound stormwater management.

With a grant provided by the Tampa Bay Estuary Program, the Department of Civil and Environmental Engineering has installed two side-by-side bioretention cells in East Tampa. The purpose of this research is to conduct field level investigations into pollutant load reduction provided by traditional bioretention and bioretention with an internal water storage zone. The bioretention cells are installed at the Corporation to Develop Communities Audrey Spotford Youth and Family Center. They will also serve as an educational tool for the community and youth who visit. The Department is providing green construction training and environmental stewardship awareness to students who are seeking to obtain their General Equivalency Diploma through the Corporation to Develop Communities and the Tampa Vocational Institute. To date, students have been instrumental in the installation of two bioretention systems. They have also had the opportunity to develop critical thinking skills when conducting a site assessment, selecting materials, and staying within the budgeting requirements.

The American Society of Landscape Architects website provides several Florida projects that have incorporated LID into the site design. All projects listed contain special features and vary from site to site; however, the implementation of LID is a common thread. Each case study submits the name and location of the project, the project description, LID design features, costs, and community benefits. A summary of each project with LIDs installed is provided in Table 2.4.

Table 2.4 Low Impact Development Practices Showcased by the American Society of Landscape Architects (ASLA, 2015)

Project Name	Location	Project Description	Design Features	Regulatory Environ-ment	Cost Impact for Conservation	Performance Measures	Awards
Naples Botanical Garden	Naples	Stormwater discharges out pipe into River of Grass graded to preserve natural flow path	Bioretention Rain garden Bioswale	Supportive	Higher than conventional but long term benefits were a major consideration	River of Grass is at the core of the botanical gardens	Yes (x 4)
Tampa Bay Office Park Waterscape	Tampa	Create prestigious office complex through preservation and restoration of wetlands	Bioretention Porous pavers Curb cuts	Supportive	10% or greater savings over conventional; Significantly reduced construction and operation & maintenance costs	Initially used as a model stormwater management site by FDEP	Yes (x 4)
Hillsborough Community College – Southshore	Ruskin	Parking lot fitted with bioswale, cistern for toilet flushing & irrigation	Bioretention Rain garden Bioswale Cistern	Indifferent	Slight increase in project cost	Maximized RWH and stormwater treatment	Yes (x 1)
Florida Civil Water Center	Jacksonville	New construction to include green technologies and LID	Bioretention Rain garden Bioswale Green roof	Supportive	Significantly reduced cost; 10% or greater savings	Promotion of cultural, heritage, and nature tourism	Yes (x 1)
Florida Aquarium	Tampa	Parking lot runoff used in treatment train approach	Rain garden Bioswale Pond	Indifferent	Saved money by reducing curbing and pipes	Public education	Yes (x 4)
Magdalene Reserve	Tampa	Reduced clearing and grading, hybrid wet and dry stormwater management	Bioretention Bioswale Downspout removal Preservation of native soils and vegetation	Supportive	Lot by lot grading more expensive; due to design, 2 more lots were added which resulted in a net reduction in cost	By preserving native soils and vegetation, infiltration is increased resulting in terminal pond rarely discharging	Yes (x 5)

There are a number of “green” communities within Southwest Florida. Though direct implementation of LIDs is not always evident, the concept and design phase utilized the initial evaluation of site characteristics, retention of natural features, and preservation of open space, which is the first step in LID implementation. The Florida Green Building Coalition has certified four communities and one golf course within Southwest Florida (Florida Green

Building Coalition, 2015). These subdivision and golf course development projects are Harmony, located in Central Florida; FishHawk Ranch, located in Lithia; Lakewood Ranch, located in Sarasota; Glen Cairn Cottages, located in Dunedin; and the Venetian Golf & River Club, located in Venice. These projects received points for one or more of the following practices: developing a management plan for preserved, created or restored wetlands/uplands, conducting a vegetation and tree, topographical, soil, and wildlife survey prior to design, conservation areas and nature parks, maintenance or creation of wildlife corridors, preservation of upland buffers to enhance preserved wetlands, environmental education signs, and irrigation supply is from stormwater or reuse water.

River Forest, located in Manatee County, and Encore!, located in downtown Tampa, are two master planned communities that are executing LID practices, though neither is green certified. River forest is a neighborhood where the homes are intertwined with the natural landscape and all land is considered a conservation area. Roads were designed around existing trees and are narrow to reduce impervious area. Stormwater is collected in 21 vegetated basins and vegetated swales to mimic pre-development hydrology. Additionally, the natural grade was preserved to ensure existing pine flatwoods and their ecosystem are allowed to thrive amongst the housing units (Center for Urban & Environmental Solutions, 2007). Encore! is a 40-acre mixed-use, master-planned community. The builders are seeking LEED Neighborhood Development certification. Encore! will utilize captured stormwater that is stored in an underground vault and use it for irrigation of native landscaping (Encore!, 2015).

2.6 Barriers to LID Implementation

General themes of barriers to LID implementation are common across the U.S. including funding issues, lack of political leadership/support, resistance to change, conflicting regulations, the need of technical training, overcoming the concept of being considered a new stormwater practice, cost, and operation and maintenance (EPA, 2011). These barriers are so common that the EPA has created a series of “Barrier Buster” fact sheets, which aim to explain LID in clear terms and provide examples of how the particular barrier was dealt with successfully. Eight fact sheets have been created primarily for state and local decision makers who might be considering adoption of LID. The fact sheet summaries challenge the perception that LID isn't worthwhile, provide general background information that outlines hydrologic and economic benefits provided by LID, and addresses the perception that LID is too expensive, unattractive, that LID doesn't work, or is too difficult or costly to maintain (EPAb, 2014).

As recently as 2011, the Water Environment Federation (WEF) met with the EPA to discuss barriers to LID/GI implementation and followed up with a memo to the EPA. The Water Environment Federation provided the EPA their perspective on overcoming implementation obstacles and possible solutions. The obstacles and possible solutions are presented in Table 2.5.

Table 2.5 Water Environment Federation Barriers to LID/GI Implementation and Solutions (WEF, 2011).

Barrier	**Possible Solution**
Funding and cost of implementation	Incentives to incorporate LID/GI in development or redevelopment Paradigm shift of calculating cost and focusing on the Triple Bottom Line benefits, which are people, planet, and prosperity
Regulatory impediments	Permitting and enforcement agencies working together at all levels of government Encourage flexibility in permitting in recognition of the variable nature of LID/GI
Lack of LID/GI acceptance by municipalities and stormwater ordinances not addressing or inadvertently discouraging LID/GI use	Identifying early adopters and show casing their work Education of local leaders Integrate LID/GI into stormwater regulations and encouraging regionally adapted Standards of Practice
Transitioning from grey to green infrastructure	Increasing funding for local education campaigns Developing training materials illustrating inter-agency coordination efforts by early adopters

Table 2.5 (continued)

Barrier	Possible Solution
Transitioning from grey to green infrastructure	Encouraging LID/GI retrofits when replacing or repairing grey infrastructure
Long-term maintenance	Education of private property owners or ordinances to enforce poorly maintained practices
Design and construction hurdles associated with local climate, dominant soils, groundwater levels, and other site-specific parameters	Development of practitioner-level guidance materials Regionally appropriate boilerplate codes or ordinances that can serve as a launching point for communities

In 2009, the University of Florida Program for Resource Efficient Communities (PREC), in conjunction with the St. Johns River Water Management District (SJRWMD), conducted four regional LID workshops for practitioners. At each of the workshops, attendees were asked to participate in an exercise identifying barriers to LID implementation and to rank them in order of importance. Presented in Table 2.6, are side-by-side comparisons of Florida's obstacles to increasing LID based on the SJRWMD and PREC study and four case studies of barriers to implementation, how they have been overcome, or how they are being addressed. Regions represented in the table are the State of Washington, Puget Sound, the State of Utah, and the State of Colorado. Each region listed faced some, or all, of the same obstacles to increasing LID execution as Florida.

Table 2.6 Comparison of Florida's Barriers to LID Implementation with Other U.S. Regions (adapted from FWEA & AWRA FL, 2011; Doberstein, Kirschbaum, & Lancaster, 2010; Wulkan, 2008; Burian, et al., 2008; Earles, et al., 2009)

Major Challenges Identified in Florida	Utah Solution	Colorado Solution	Washington State Solution	Puget Sound Solution
Insufficient LID design and approval criteria		Emphasis of volume reduction in SWM manual	LID design guidelines exist; Updating manual to address unintended restrictions; In-depth regional training to disseminate information until updated LID manual issued; Rule of thumb sizing allowed on small sites	LID manual developed to ensure consistency with SWM manual
Lack of public awareness and acceptance		Municipalities to take the lead on LID implementation		Conducted workshops, held regional training sessions

Table 2.6 (Continued)

Major Challenges Identified in Florida	**Utah Solution**	**Colorado Solution**	**Washington State Solution**	**Puget Sound Solution**
Lack of public awareness and acceptance				provided educational material on local pilot studies
Uncertainty regarding cost/benefits		LID pilot studies in Rocky Mountain region	LID design and performance rapidly evolving; reflected in region design guidelines. Education provided to shift mindset 'traditional' is always right	
Conflicting regulations between agencies		Improved regional guidance, better coordination between engineering, planning, parks, etc. Consider applying for a variance if necessary	LID design guidelines exist; Updating manual to address unintended restrictions.	Water Quality Plan directed 120+ cities and counties to adopt LID friendly ordinances. Assistance provided to update ordinances if managers and elected officials demonstrated commitment.
Lagging framework for long-term maintenance and operation		LID pilot studies in Rocky Mountain region – including long-term maintenance and operation		
Lack of political will/overcoming status quo		Municipalities to take the lead on LID implementation		Water Quality Plan directed 120+ cities and counties to adopt LID friendly ordinances
Lack of qualified experts with appropriate training	University of Utah offering classes to students on LID site design and controls. Bioregional Planning now a graduate degree	Expanded training courses through municipalities and professional organizations		Coordinated financial and technical support for regional workshops. University of Washington's Professional Engineering Programs and Extension Specialists conduct biannual LID training
Lack of research, demonstration projects	Future development on the aquifer recharge area of Salt Lake Valley will have infiltration-based LIDs to promote recharge lost from development	LID pilot studies in Rocky Mountain region		Numerous LID projects showcased in local publications.
Lack of collaboration among stakeholders, i.e. inter-agency and general public		Evaluation of ordinances where LID has been more widely adopted		

CHAPTER 3: RAINWATER HARVESTING AS A LID PRACTICE

Rainwater harvesting (RWH) is rarely promoted as its own initiative, but instead is viewed as part of GI, stormwater management, LID, water conservation, and drought management goals. Rainwater harvesting consists of using either rain barrels or cisterns to capture impervious runoff, generally from roofs, and storing it for later use. Rainwater harvesting is not a new technology and is a relatively simplistic, low technology in design (Briggs & Reidy, 2010) and has been documented in Jordan dating back to 3,000 BC (Jones, Hunt, & Wright, 2009).

RWH is considered the first step in implementing greener stormwater management, reduction in potable water demand for non-potable uses and sustainable living (Gold, et al., 2010). It is promoted as a LID practice due to its ability to provide decentralization of stormwater management and water supply simultaneously (Steffen, et al., 2013). Harvested rainwater can be used for irrigation, toilet flushing, cement mixing, outdoor water features, cooling towers, storage of water for fire suppression, building power washing, street sweeping, vehicle washing, or flushing kennels at animal shelters (DeBusk, Wright, & Hunt, 2010; Forasté & Hirshman, 2010; Jones, Hunt, & Wright, 2009; Gold, et al., 2010).

Significant environmental benefits are associated with widespread implementation of RWH. The positive impacts of RWH include stormwater management, pollution reduction, decrease water treatment needs, provide supplemental water supply, reduce demand on potable water resources, reduce energy consumption for water treatment and transport, functions as an educational tool, and resiliency in emergency preparedness (Briggs & Reidy, 2010)(Gold, et al., 2010).

3.1 Rainwater Harvesting Design Considerations

Rainwater harvesting as a method of stormwater management LID practice is a function of maximizing captured rainwater, whether it's a household level rain barrel or a commercial scale cistern. Rain barrels are typically implemented in one or more barrels with a volume of approximately 55-gallons, where cisterns start at hundreds of gallons. Year-round and continuous utilization is key to functionality through either indoor use, outdoor use, and/or use through a secondary runoff reduction infiltration practice (Forasté & Hirshman, 2010). The harvested rainwater must be utilized as much as possible between storm events to be a viable stormwater management solution (Jones, Hunt, & Wright, 2009).

Rain barrel performance is a function of size (Steffen, et al., 2013). Rain barrels should be emptied onto lawns and gardens by homeowners so it can function as a stormwater control measure for the next rain event. Without this important step, a rain barrel overfills and acts a disconnected downspout. Homeowners have shown modest satisfaction rates with rain barrels as a result of needing to empty or utilizing the water after a significant rainfall event. Having another asset that takes advantage of the harvested rainwater yields to increased homeowner rain barrel maintenance (Litofsky & Jennings, 2014).

When included as part of the watershed management plan, RWH has the ability to reduce stormwater pollution and provide relief on potable water demands by meeting the non-potable needs of residential and commercial establishments. Watershed management plans are considered responsible plans when communities are required to conserve and protect the quality of their water resources. A detailed water balance must be calculated and maintained in an effort to take into account all inputs into the system such as precipitation, runoff, and irrigation as well as withdrawals from the system including outflow, infiltration, and discharge on both the site and watershed scale (Gold, et al., 2010).

Effective RWH design strategies include consideration of site conditions, end use, and physical feasibility. Forasté and Hirshman (2010) reviewed the physical feasibility and site conditions required for effective implementation of RWH strategies. The necessary design considerations include available space, existing site constraints, building or utility setbacks, site topography as it pertains to roof drain slopes, elevation changes in system components, inlet and outlet orifice inverts, and available head as it relates to pumping, locating the cistern, and end uses. Briggs (2010) stated that a cistern’s usable volume, catchment area type, and areal extents are the crucial geometric parameters for design. The Cistern Design Spreadsheet was developed to assist designers in proper sizing of RWH systems in the State of Virginia. Additionally, Virginia’s guidelines for tank sizing include incremental volumes for stormwater management, such as low water cut off, treatment volume, channel and flood protection volume, and freeboard and overflow volume (Forasté & Hirshman, 2010).

The science and engineering of sizing RWH systems is fundamentally important to its long-term success and viability (Briggs & Reidy, 2010). For RWH to be an effective stormwater management tool, it must control runoff volume and peak discharge (Jennings, et al., 2013). Cistern size is often chosen arbitrarily, which can lead to under-sizing or over-sizing (Briggs & Reidy, 2010). Jensen et al. (2010) recommend the four primary elements of rainwater harvesting systems are collection area, conveyance, storage, and end use. According to Briggs and Reidy (2010), RWH design decisions should include ultimate end use as a function of the project objectives, pattern and magnitude of harvested supply compared to demand, treatment requirements, project geometry, and client and end user preferences and budget.

Often RWH is promoted as an alternative water source instead of a stormwater management practice; as a result, designer, planners, and reviewers do not have a common language regarding design features and applicability resulting in systems being typically designed in isolation from the site's stormwater management regime. A consistent method of evaluation is needed among designers and plan reviewers to quantify benefits relating site conditions, water usage, and stormwater management. Without a detailed design guideline, similar to what is available for most BMPS in most state stormwater management manuals, an information void exists and RWH adoption as a BMP could be limited (Forasté & Hirshman, 2010).

3.2 Policy Surrounding RWH

Gold et al. (2010) reviewed RWH policies on both the municipal and federal levels. As a result of stormwater management concerns, water supply needs, sustainable design, and drought management, RWH policies are on the rise with municipalities having the most progressive policies regarding RWH. Federal policies regarding RWH are targeted more towards GI and stormwater management. There are four Federal policy or incentive programs for RWH: Clean Water State Revolving Fund (1987), Energy Independence and Security Act of 2007, America Recovery and Reinvestment Act (2009), and Water Use Efficiency and Conservation Research Act (2009). Nineteen states have either local or state implementation of rainwater harvesting; of those nineteen, ten states have RWH as a state law, and nine provide some sort of financial incentive for the implementation of RWH. Most states and municipalities view cisterns as the most beneficial form of capturing rainwater in meeting water supply demands and reducing stormwater runoff with the top three motivators being water supply demands and conservation, stormwater management, and grassroots and public support.

3.3 Rainwater Harvesting Case Studies

Jones (2009) monitored five RWH systems in North Carolina, measuring cistern water levels and rainfall. The results showed rainwater was typically under utilized. Rainwater harvesting was most utilized at locations where it was used strictly used for toilet flushing. The other locations had access to both potable water and harvested rainwater; when given a choice, employees chose potable water for a variety of reasons, including ease of use and health concerns associated with lack of education. DeBusk (2010) installed cisterns at three distinct locations with different uses. The cistern at the Craven County Animal Shelter was to be utilized flushing soiled kennels. They found the shelter employees often left the water running once the switch was turned on for water access; therefore, a timer was installed.

Talebi and Pitt (2012) studied the use of rain barrels for landscape irrigation in low and medium density residential areas within six U.S. rain zones. Birmingham, Alabama was the rain zone for the Southeast United States. The study evaluated proper sizing needed for optimal, beneficial stormwater use. WinSLAMM continuous simulations were utilized for monthly rainfall infiltration calculations. Additionally, roof runoff and water tank storage production functions were calculated for each site. The Southeast region had moderate levels of maximum control as a result of greater rainfall. For all areas, the smallest roof runoff control assumed the residence would have about five rain barrels per 1000 ft^2 of roof; the largest would have two 6' high by 10' diameter tanks per 1000 ft^2 resulting in an efficiency for the Southeast US of 34% and 42%, respectively.

Jensen et al. (2010) provided a regional US comparison of RWH performance for both water supply and stormwater management. A water budget analysis using RWHTools was utilized to calculate mass balance using historical precipitation data and total water use, both indoor and outdoor. Tampa, Florida was the city analyzed for the Southeast US. To achieve approximately 70% catchment efficiency in Tampa, a homeowner would need approximately fourteen 55-gallon rain barrels or a 750-gallon cistern. At this size, for total indoor and outdoor use, a water capture and use efficiency of about 25% is achieved. When harvested rainwater was for outdoor use only, it yielded a slightly lower capture and use efficiency of approximately 20%. The authors concluded that precipitation and water demand patterns should be evaluated jointly instead of solely on climate in determining potential RWH benefits. This study showed water supply and stormwater management are not competing objectives in urban water management. Additionally, optimal stormwater management is gained by increasing cistern size.

Steffen et al. (2013) studied residential RWH for 23 cities in seven climatic regions to quantify water supply and runoff reduction. A daily time step of the water balance was used to determine water-saving efficiency. SWMM was utilized to analyze RWH with each cistern represented as a storage unit within the modeling software. For this study, it was assumed that 50% of the rooftop drained to the RWH system. For the Southeast US, including Tampa and Miami, for a 5678-liter (1500-gallon) cistern, the water-saving efficiency for indoor and outdoor non-potable water use was 36%. If the non-potable water harvested was strictly used for indoor use, the water-saving efficiency increased to 95%. For a single 50-gallon rain barrel that serves outdoor use only, the water-saving efficiency is 10% for Tampa, Florida. For the Southeast regional area, if a single 50-gallon rain barrel was implemented on a neighborhood scale, the runoff reduction is a meager 4% whereas if a 500-gallon cistern were implemented on the neighborhood scale, the runoff reduction would increase to 12%. The RWH potential for water supply and stormwater management depends on factors such as precipitation, size, and water consumption pattern. For the Southeast US, the higher rainfall increases water-saving efficiency however; it also has a lower stormwater management potential.

Jennings et al. (2013) studied rain barrel implementation along with urban gardens in Ohio. For any LID practice to be successful on the watershed level, a high level of community participation is required. The study found rain barrels require significant homeowner participation to be effective; however, some homeowners consider them unsightly. Urban gardens were implemented to increase rain barrel performance and community acceptance. For this case study, a roof collection area of 500 ft^2 was utilized for the rain barrel, the rain barrel size was 50 gallons, and the urban garden was 150 ft^2. Any rainfall in excess of 0.17 inches would cause the rain barrel to overflow, even if it was empty at the beginning of the rainfall event. Using 11 years of rainfall data and 1-, 2-, and 3-day irrigation frequencies for the urban garden, roof service-area runoff reductions were calculated for the growing season, for the entire year, and annual whole-roof runoff reductions. For the growing season and the irrigation frequencies listed, the runoff reduction was 21.7, 14.7, and 9.8%, respectively. For the entire year, the roof service-area reduction and the three irrigation schedules were 12.5, 8.5, and 5.7%, respectively. The total annual whole roof runoff reductions and the three irrigation schedules were 3.1, 2.1, and 1.4%, respectively. The authors reported these were somewhat unexpected results, as most rain barrel advocates assume rain barrels are more effective than what the study revealed.

Jennings et al. (2013) determined RWH performance could be improved by increasing roof service area, rain barrel capacity, or garden size. All three options face obstacles; increasing roof service area would require an increase rain barrel size and the redirection of several downspouts, increasing rain barrel capacity would increase homeowner resistance, and increasing garden size is limited by lot size and homeowner commitment to gardening. Rain barrels support a beneficial use of the captured stormwater for urban gardening, which adds additional merit, but reductions in stormwater runoff would be modest. Evaluating the degree to which reductions of this magnitude would have a beneficial hydrologic and aquatic ecosystem effects should be addressed before committing to this management strategy.

Litofsky et al. (2014) elaborated on Jennings et al. (2013) study of rain barrels and urban garden usage. Their rain barrel size was set at 64-gallons to capture 500 ft^2 of rooftop and irrigate a 150 ft^2 garden. Their study included results for Miami and Tallahassee, Florida regarding service area runoff reduction and irrigation demand satisfied. Rainfall patterns determine how successful rain barrels can be in providing runoff reduction and the ability to meet irrigation demand. For Miami, service area runoff reduction was 9.1% and irrigation demand was 47.8%. For Tallahassee, service area runoff reduction was 7.5% and irrigation demand 50.4%. To put these numbers in perspective with other states, Arizona had approximately a 45% runoff reduction with the same study parameters. Vermont had approximately 80% of its irrigation demand satisfied with the same study parameters. The authors concluded that the rain barrel-urban garden strategy would have maximum stormwater reduction benefit in areas with the lowest annual precipitation. Nonetheless, they still encourage gardeners to take advantage of harvested rainwater to supplement irrigation needs.

Cheveney & Buchberger (2013) modeled GI on the watershed level for the Mill Creek Watershed located in the metropolitan area of Cincinnati, Ohio. One type of GI modeled was rain barrels; all residential, commercial, and industrial properties within the Mill Creek

Watershed were assumed to have a 55-gallon rain barrel. After running Aquacycle, it was found that catchment scale implementation of rain barrels did not significantly impact the water balance. The widespread use of rain barrels yielded a 0.6% reduction in average annual drinking water inflow and the average annual wastewater and streamflow were reduced by 0.2%.

CHAPTER 4: INFILTRATION-BASED LID PRACTICES

When designed properly, infiltration-based LIDs have the ability to mitigate groundwater disruptions that result from urbanization, minimize receiving water body hydrology, and reduce pollution discharges to surface waters (Duchene, McBean, & Thomas, 1994). A variety of low cost, infiltration-based designs such as rain gardens, swales, drywells, infiltration trenches, and bioretention systems are promoted LID practices. Infiltration-based LID practices can be an effective tool in maintaining pre-development site conditions as they fulfill multiple aspects in restoring site hydrology such as storing, detaining, evaporating, and infiltrating stormwater runoff. While all surfaces evaporate, perhaps what drives the aesthetics and subsequent implementation rates of various infiltration-based LID practices is their evapotranspiration and associated vegetation. Rain gardens, bioretention systems, and swales contain the most vegetation for evapotranspiration. Drywells are generally covered by grass and have a minor evapotranspiration component; however, they do not have the strong aesthetic component associated with rain gardens and bioretention areas. A grassed buffer generally surrounds infiltration trenches and the filtering surface area tends to be exposed.

The National LID Manual lists the following infiltration-based practices: bioretention, drywells, filter/buffer strips, swales, and infiltration trenches. The Manual provides details for each LID practice regarding site constraints, hydrologic function ranking, and design components. Rain gardens are not specifically addressed in the National LID Manual however, The Center for Watershed Protection (CWP) has included rain gardens in their urban watershed manual (CWPa, 2007). In the urban watershed manual appendices, the CWP describes the difference between a rain garden and a bioretention system. A rain garden is defined as a shallow bioretention area with relatively permeable soils that do not possess underdrains and are typically installed with volunteer labor. Examples of rain gardens with volunteer labor include homeowner installation or a demonstration site (CWPb, 2007).

In the National LID Manual, it is stated that thinking small is the key to concept in LID and is a change in traditional stormwater management perspective. Low Impact Development practices can be installed in small sub-catchments, on residential lots, and in common areas to allow for the distributed control of stormwater throughout the entire site. This affords the opportunity to maintain the site’s important hydrologic functions such as infiltration, depressional storage, interception, and a reduction in the time of concentration. Runoff is directly related to rainfall abstraction of the aforementioned hydrologic functions therefore, trying to capture these natural hydrologic functions through end-of-pipe stormwater management would be a difficult task. By placing LIDs as closely as possible to the source, compensation for development disturbances of these hydrologic functions is provided (PG County, MD, 1999).

When proper siting requirements are met, all of the infiltration-based LID practices have the potential to improve the hydrology of the developed site. Proper siting begins at the initial stages of land development or re-development. It includes reviewing the natural landscape features of the proposed development or retrofits such as available space, soils, and slope. Once these have been thoroughly reviewed, it is then possible to choose a LID practice, or practices, that suit the landscape. All infiltration-based LID practices require some level of geotechnical investigation to ensure suitability. Whether native soils or engineered soils are used, these practices can increase groundwater recharge, reduce runoff volumes, reduce thermal impacts on streams, and increase community aesthetics when vegetation is utilized. For example, rain gardens can infiltrate 30% more rainfall than a grassed lawn, bioretention can achieve a runoff reduction of 35 to 50%, and swales can reduce runoff volumes by 40% on average (CWPa, 2007) (CWPb, 2007). These benefits are achievable when the generally accepted design guidelines are provided in Table 4.1. These are National standards therefore; they should be considered a guideline and adapted accordingly to regional conditions. In Florida, depending on the location of the development or retrofit site, the seasonal high water table can vary widely. Additionally, the type of storms and antecedent moisture conditions should be included in the design considerations for each LID practice. The following studies review the surface-groundwater interaction and the hydrology of bioretention, infiltration trenches, swales, and drywells.

4.1 Infiltration-based LID Hydrology Case Studies

4.1.1 Bioretention

Bioretention is a landscape feature for the treatment of stormwater runoff from new development and for retrofit sites. Bioretention cells receive surface runoff into a shallow landscaped depression. During rainfall events, runoff temporarily ponds a few inches above the top surface until it infiltrates through the soil or media. If the infiltration capacity is not sufficient to empty in a reasonable time, an underdrain is installed. Native soils can be used if the site has a highly permeable soil, a low groundwater table, and a low risk of groundwater contamination (CWPa, 2007). An example of a bioretention cell is provided in Figure 4.1.

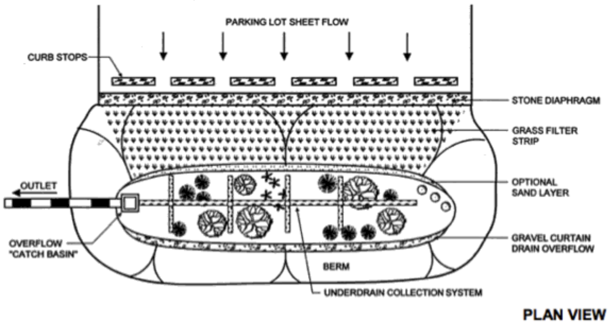


Figure 4.1 Bioretention Plan and Section View (MDE, 2009)

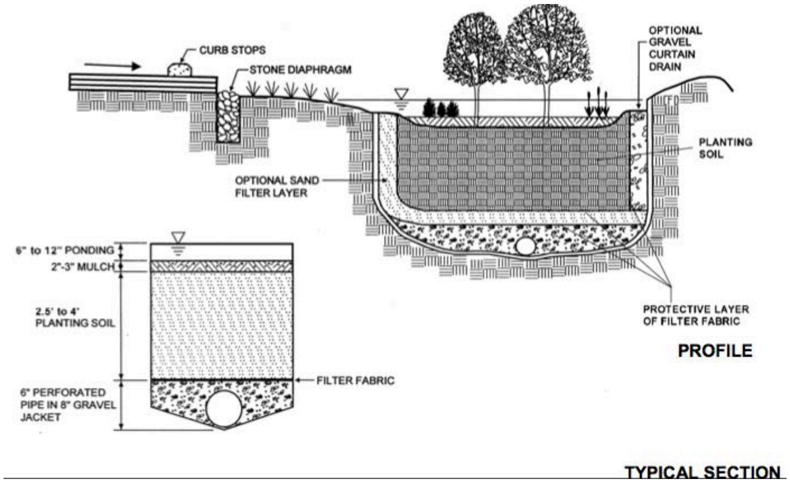


Figure 4.1 (continued)

Davis et al. (2012) reviewed the empirical nature of bioretention design that typically does not account for varying geologic and climate conditions. Due to natural site conditions, such as geology and climate, bioretention hydrologic performance will vary from site to site and within a site for different rainfall events. Bioretention has a finite capacity to mitigate runoff. They are typically designed for small storm events. During large storm events, they overflow, discharge from the underdrain, or both. If bioretention cells were designed with a higher storage volume, such as deeper media or larger surface area, they may provide better hydrologic performance in mitigating runoff and underdrain discharge.

In order to encapsulate the natural processes and features of bioretention cells, the authors derived a design equation based on soil properties and antecedent moisture conditions. Native soils dictate percolation based on their hydraulic conductivity and hydraulic gradient. Highly conductive soils surrounding the bioretention cell can increase the flow-through rate. Antecedent moisture conditions control the amount of pore space available for water storage in the bioretention cell. If enough time has passed between storm events, the potential for water storage is greater. If, however, the water in the bioretention cell has not percolated into the

Table 4.1 Generally Accepted Design Standards for Infiltration-based LID Practices
(adapted from: CWP(2), 2007; PG County, MD, 1999)

LID Practice	Space and Sizing Requirements	Soil Characteristics	Slope Limitations	Depth to Water Table Clearance	Offset from Building Foundations	Minimum or Maximum Depth	Ponding Depth	Vegetation	Pre-treatment	Other Design Notes	Maintenance
Bioretention	Min. width: 5-10 ft; Min. length: 10-20 ft; Size should be 5-10% of contributing drainage area	Infiltration rates: ≥ 0.5 in./hr, no underdrain required; ≤ 0.5 in./hr, underdrain required	More a design consideration than a limitation	2-4 ft	10 ft offset & locate down-gradient of building foundation	Min. depth: 2-4 ft	6-9 in.	Native species; Typically min. of 3 species	Required if anticipating heavy sediment loading	Non-erosive velocities (≤ 0.5 ft/sec)	Low
Rain Garden	10-30% of rooftop area	Should match those of bio-retention but usually installed by homeowners	Avoid steep slopes but more a design consideration than a limitation	2-4 ft	10 ft offset & locate down-gradient of building foundation	Typically 6-18 in. deep	Not addressed	Native species; Typically min. of 3 species	Not required	Empty within 24 hours	Low
Drywell	Min. width: 2-4 ft; Min. length: 4-8 ft; 500 ft^2 of roof per drywell	Infiltration rates: ≥ 0.27 - 0.5 in./hr	Avoid steep slopes but more a design consideration than a limitation	2-4 ft	10 ft offset & locate down-gradient of building foundation	Min. depth: 4-8 ft	No ponding depth	Typically covered by grass	Not required	Empty within 48 - 72 hours	Low
Filter/ Buffer Strip	Min. length: 15-20 ft; Size should be 5-15% of contributing drainage area	No soils limitation but permeable soils preferred	More a design consideration than a limitation; Usually 1% min. slope	Generally not considered a constraint	10 ft offset & locate down-gradient of building foundation	Not addressed	Not addressed	Typically covered by grass	Typically is the pre-treatment method itself	Used to control sheet flow only; Avoid erosive discharge velocities	Low
Swale - (grass, infiltration, wet)	Bottom width: 2-6 ft; Size should be 5-15% of contributing drainage area	Type of swale dictated by soil type; No soils limitation but permeable soils preferred	3:1 sides slopes or flatter; Longitudinal slope min. 1% & 6% max.; Avoid erosive discharge velocities	Generally not considered a constraint	10 ft offset & locate down-gradient of building foundation	Not addressed	Min. 4.0 in. for water quality treatment; Can be up to 12 in. in depth	Native vegetation or grass	Not addressed	Manning's *n* value changes with water depth; Trapezoid or parabola shape preferred; Channel length sufficient for 10 minute residence time	Low
Infiltration Trench	Min. width: 2-4 ft Min. length: 4-8 ft; Size: 0-5% of contributing drainage area	Infiltration rates: ≥ 0.52 in./hr	More a design consideration than a limitation	2-4 ft	10 ft offset & locate down-gradient of building foundation	3–12 ft typical depth	Not addressed	Not addressed	Pre-treatment required for removal of sediment and debris	Design should consider overflow path and avoid erosive discharge velocities	Moderate to high

subsurface by gravity and another storm event arrives, the cell will most likely overflow through surface discharge or underdrain discharge.

Bioretention Abstraction Volume (BAV) is the amount of water captured from surface runoff that is evapotranspired or percolated. BAV is also the amount of water that is not discharged to surface waters. The authors present an equation to determine BAV based using the concepts of bowl and pore storage. This equation can be applied regionally and used as a design guideline since it takes into account each site's climate and soils conditions. Using bowl volume, root zone volume of the media, the lower media storage volume, and soil characteristics, BAV equations were developed to represent average volume and volumes available during long and short antecedent moisture conditions, respectively. The BAV equations for a bioretention cell without an underdrain were presented as:

$$BAV_{avg} = V_b + RZMS(SAT - WP) \tag{1}$$

where BAV_{avg} is the average BAV, V_b is bowl volume, RZMS is the media storage volume in the root zone, SAT is saturated moisture content of the media (or soil), and WP is the plant wilting point of the soil. Equation 2 would be utilized when the abstraction volume is highest.

$$BAV_{highest} = V_b + [RZMS(SAT - WP) + LMS(SAT - FC) \tag{2}$$

where $BAV_{highest}$ is the maximum BAV storage, V_b is bowl volume, RZMS is the media storage volume in the root zone, SAT is saturated moisture content of the media (or soil), WP is the plant wilting point of the soil, LMS is the lower media storage volume for native soils, and FC is the field capacity of the soil. When only the bowl is available for storage, the least amount of capture is described in Equation 3.

$$BAV_{low} = V_b \tag{3}$$

where BAV_{low} is equal to the Bowl Volume (V_b).

The BAV equations for a bioretention cell with an underdrain are defined as:

$$BAV_{avg\_underdrain} = RZMS(SAT - WP) + LMS(SAT - FC) \tag{4}$$

where $BAV_{avg\_underdrain}$ is the average BAV storage, RZMS is the media storage volume in the root zone, SAT is saturated moisture content of the media (or soil), WP is the plant wilting point of the soil, LMS is the lower media storage volume, and FC is the field capacity of the soil.

$$BAV_{highest\_underdrain} = V_b + [RZMS(SAT - WP) + LMS(SAT - FC) \tag{5}$$

where $BAV_{highest\_underdrain}$ is the maximum BAV storage, V_b is bowl volume, RZMS is the media storage volume in the root zone, SAT is saturated moisture content of the media (or soil), WP is the plant wilting point of the soil, LMS is the lower media storage volume, and FC is the field capacity of the soil.

$$BAV_{low\_underdrain} = RZMS(SAT - WP) \tag{6}$$

where $BAV_{low\_underdrain}$ is the minimum BAV, RZMS is the media storage volume in the root zone, SAT is saturated moisture content of the media (or soil), and WP is the plant wilting point of the soil.

The authors state that these equations, when used in bioretention design, can have the greatest impact on volumetric management due to the moisture holding capacity of the media or soil, which is defined by water holding capacities of the media, media volume, and root depth. Field data from bioretention cells, in the Mid-Atlantic region and North Carolina, have agreed with the calculated BAV; therefore, it is possible to use these equations as a quantitative design tool for bioretention in Florida since the equations utilize soil moisture characteristics (Davis, et al., 2012).

Machusick and Traver (2009) evaluated stormwater infiltration on a shallow unconfined aquifer at a bioretention site located at Villanova University. The site was a vegetated bioretention traffic island on campus with approximately 0.53 hectares of contributing drainage area as well as 35% directly connected impervious area (DCIA). The bioretention cell was designed to infiltrate the first 2.5 cm of precipitation and was a retrofit to an existing traffic island. Four monitoring wells were located around the site one up gradient, one down gradient, and two adjacent to the traffic island. The research focused on mounding since it can be detrimental in groundwater flow regimes, underground utilities, and building structures.

During the ten-month study period, approximately 79 cm of precipitation was recorded. For most storms, the precipitation was less than 2.5 cm. It was reported the great majority of runoff was infiltrated on site however, during large, more intense storms the bioretention cell remained at capacity, which resulted in runoff rather than infiltration. For storms less than 1.9 cm, the infiltration rate was sufficient to avoid groundwater mounding. For larger storms, infiltration occurred for long enough duration to cause increased groundwater elevation. Infiltration rate was found to be a factor in contributing to groundwater mounding as well as temperature. Though mounding occurred, the researchers reported that the vadose zone had enough storage capacity to accommodate larger storms without negatively affecting the local subsurface (Machusick & Traver, 2009).

Braga and Fitsik (2008) assessed performance results, design information, and challenges for four bioretention cells and two rain gardens in six Massachusetts neighborhoods. Performance results were conducted after installation utilizing a double ring infiltrometer, while following protocols outlined in ASTM D3385-94. Design information included media depth, use of geotextile fabric, and use of an underdrain. The performance challenges faced by certain sites varied from compacted soils to heavy sediment loading. These performance challenges were hindsight discoveries and provide information on lessons learned to avoid failure in future sites.

The results from this study are summarized in Table 4.2. Though the study provided a review of these individual LID practices, it should be noted that these sites utilized other BMPs to improve water quality and water quantity. These six locations included one or more of the following: downspout disconnection, vegetated swales, a constructed wetland, porous pavement, drywells, and maximizing open space.

Table 4.2 Bioretention and Rain Garden Design Parameters, Performance, and Challenges in Six Massachusetts Neighborhoods (adapted from Braga & Fitsik, 2008)

Site Location	**Installation Date**	**Type**	**Min. Media Depth (in)**	**Stone Depth (in)**	**Geotextile Used?**	**Underdrain Installed?**	**Infiltration Rate (in/hr)**	**Challenges**
Tyngsborough	2004	Bioretention	48	n/a	Yes	No	5.01	Performing as expected
Littleton	2005	Rain garden	18	12	Yes	No	3.82	Not addressed
Wilmington	2006	Bioretention	18	18	Yes	Yes	22.73	Performing as expected
		Bioretention	18	18	Yes	Yes	21.94	Performing as expected
		Rain garden	18	12	Yes	No	12.38	Performing as expected
Wayland	2006	Bioretention	24	n/a	Yes	Yes	0.34	Underlying soils found compacted during construction Infiltration rates limited by native soils
Ipswich	2006	Rain garden	18	n/a	No	No	0.63	Infiltration rates limited by native soils
Lundenburg	2007	Bioretention	18	12	Yes	Yes	3.30	Receives heavy sediment loading from roadside runoff
Acton	2008	Bioretention	18	12	Yes	No	17.63	Performing as expected

Wardynski and Hunt (2012) reviewed forty-three bioretention cells, in twelve regulatory districts, to evaluate performance while simultaneously comparing pre-2005 and current North Carolina’s state design requirements. They reviewed and compared as-builts, existing soil conditions, and level of maintenance. By ensuring as-builts were within acceptable tolerance of the original design dimensions; the bioretention cells should perform as expected. Bioretention cell infiltration and water quality performance is directly dependent on the installed soil media. Additionally, executing a diligent inspection process during construction and implementing a post construction inspection program will dictate future performance of the bioretention cell is functioning as anticipated. Though the authors hypothesize the bioretention cells were still functioning, even if marginally, most were lacking in one or more evaluated parameter.

For the purposes of this study, the authors determined a bioretention cell was within design specification if the pond area surveyed was within 10% of the intended design. Further cell categorization included moderately under/oversized if within 10-25% of the intended design, and severely under/oversized if the surveyed area was greater or less than 25% of the intended design. When comparing the bioretention surveyed surface storage capacity to intended surface storage capacity, 35% were severely undersized, 17.5% were moderately undersized, 17.5% were within acceptable range, 10% were moderately oversized, and 20% were severely oversized. The authors investigated further to determine the causes of numerous undersized bioretention cells. It was revealed the undersized cell occurred in seven of the twelve regulatory jurisdictions. Three of these seven jurisdictions do not have an annual inspection and maintenance program. The correlation being that a lack of annual inspection and maintenance programs might also be an indicator of a lack of construction inspection(s) and/or inspection personnel.

A bioretention cell's exisiting soil and media condition following long term use is an indicator of how well it is functioning. For this North Carolina study, the bioretention media had two separate design requirements, pre-2005 and current specification. The pre-2005 soil media recommendation stated that sand should be 43-50% of the mixture, fines can be <50% silt and <7% clay. The current design standards, established in 2009, state that sands should be 85-88% of the mixture, fines can be 8-12%, and organic matter can be 3-5% of the mixture. The permeabilty is the same under both design specifications, 1-6 inches per hour. The average results of all bioretention soil particle size analysis showed 29% adequately met design specifications, 37% contained too many fines, and 34% contained too much sand. This study reports a decrease in the used of fines in bioretention cells from 2008-2010; this may have been a result of increased inspection, mainenance, and education. The amount of fines found were a function of original soil media rather than incoming fines from the watershed. Additionally, the study revealed the presense of hydric soil indicators in 2 cells, and mottling of soils in 22% of cells, which may indicate the cells were not draining efficiently.

A visual inspection was conducted on the forty-three bioretention cells to assess the level of maintenance as well as to determine common maintenance issues. Over 50% of the cells were in need of some level of maintenance. Sediment deposition was the largest individual maintenance issue, with 44% of the cells exhibiting detrimental sedimentation which lead to clogging and drainage inefficiency. Internal erosion was the next most dertrimental maintenance issue, with 30% exhibiting erosion at the inlet. The last three maintenance issue categories represented the smallest portion of issues. These included, for a combined total of 17%, no plants present, wetland plants present outside the forebay, and overgrown or limited access. The authors noted that some of the causes of maintenance issues, such as erosion, occurred where there was no forebay and no regular inspection to ensure sedimentation issues are identified early and dealt with in a timely manner (Wardynski & Hunt, 2012).

4.1.2 Infiltration Trench

Infiltration trenches function similarly to bioretention in that they receive surface runoff and temporarily store runoff until it is infiltrated into surrounding soils. It is generally considered a good practice to have some sort of pre-treament of runoff before entering the trench as they can clog, and subsequently fail, due to heavy sediment loading and debris. If favorable conditions are present, infiltration trenches can reduce runoff volumes, improve water quality, and increase groundwater recharge (CWPa, 2007). An example of an infiltration trench is provided in Figure 4.2 (MDE, 2009).

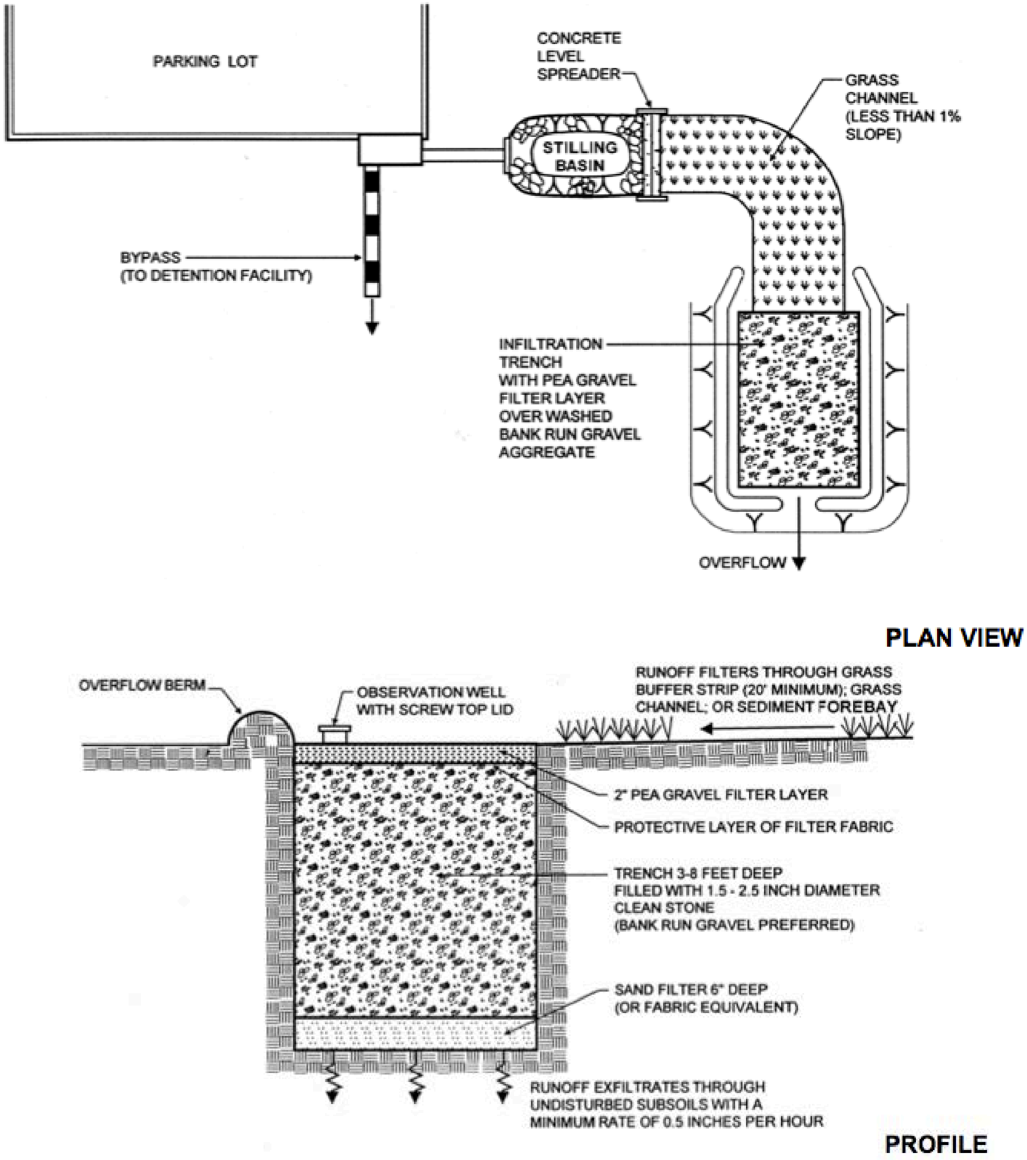


Figure 4.2 Infiltration Trench Plan and Section View (MDE, 2009)

Duchene, et al (1994) used two-dimensional, finite element method modeling of infiltration trenches and compared it to the infiltration rate estimated by Darcy’s law. The infiltration rates determined by Darcy’s law were considered conservate to the authors compared to finite method modeling. The study compared sandy soils and silt soils, trapezoidal and rectangular geometries, the impact of clogging on the system, and infiltration to surrounding soils.

Latoral and horizontal infiltration rates into the surrounding soil from the infiltration trench are dependent on factors such as water depth in the trench, saturated hydraulic conductivity of the surrounding soil, distance of the water table to the bottom of the trench, and antecedent moisture conditions. This study compared infiltration rates using both Darcy's law and the modeling software 2DUSAT, which uses a modified version of Richard's equation. The modeling parameters for this case study were both sand and loam soils, 1m wide by 1m deep and 2m wide by 1m deep trench geometries, the soil boundaries around the trench was 10 meters wide by 5 meters deep, depth of water varied from 0.25, 0.5, and 1.0 meters, and depth to water table of 3 meters.

When comparing the 1m by 1m infiltration rates to the 2m by 1m rates, the 1m by 1m trench infiltrated faster, since lateral infiltration decreases and trench width increases. Modeled infiltration rates for the 1m by 1m trench were between 1.25 and 3.5 times greater than the 2m by 1m trench for the ranging depth of water head. Reviewing the 2m depth to water table results for bottom and side percentage of infiltration for a sandy soil, which is a closer approximation for Southwest Florida conditions than 3m depth to water table, the corresponding percentage of bottom infiltration decreases with increasing water head in the trench and the percentage of lateral infiltration increases with water head in the trench. These values ranged from 77-58% for bottom infiltration and increasing head and from 23-42% for lateral infiltration and increasing head. The loam soil showed the same bottom and lateral infiltration characteristics for this portion of the study.

The study also compared a 2m and 3m depth to water table on infiltration rates. The greater the distance to water table, the higher infiltration rate. The greater the difference between the bottom of the trench to the water table, the greater the negative pressure, which draws water down. Additionally, the greater the distance to the water table, the less mounding and lateral spreading of the mound. When comparing the 2m depth to water table to the 3m depth to water table results, the sandy soil infiltration rate decreased by 20%, while the loam soil decreased by 8%.

The authors modeled the effects of clogging and antecedent mositure conditions on bottom and lateral infiltration rates. A 5 cm thick layer of sandy clay loam and clay were used to represent fines that can accumulate and clog infiltration treches when no sedimentation pre-treatment is in place. No matter the type of fines in the bottom of the trench and the head in the trench, the overall and bottom infiltration was reduced. When head in the trench was at its lowest, 0.25 m, infiltration reduction was at its highest value however, when trench head was the highest, 1.0 m, overall infiltration, bottom infiltration, and lateral infiltration increased. Antecedent moisture conditions also impact infiltration rates. Drier soils have the ability to absorb more water than soils that are already moist. The overall reduction on infiltration rates was approximately 10% compared to drier soil. Additionally, as the head increased in the trench, the wetter soil steadily decreased infiltration capacity (Duchene, McBean, & Thomas, 1994).

Chahar et al. (2012) evaluated the engineering design aspects of infiltration trenches. The authors provide a numerical solution in quantifying infiltration rate and recharge of groundwater as well as the drain time of the trench. Infiltration rates of a trench are characterized by physical parameters such as trench dimensions, depth of water in the trench, hydraulic conductivity of the media, depth of the drainage layer, and depth to ground water table.

Trench empyting time is a critical design consideration. If the time between storms is not greater than emptying time, the infiltration trench outflow should be directed to another stormwater facility.

The modeling program, MATLAB 2010, was utilized to evaluate when the infiltration trench first starts to empty. For modeling purposes, the authors assumed the soil surrounding the trenches was saturated. During initial draw down in the trenches, the media is unsaturated and infiltration rates are high. As the draw down continues, the surrounding soil becomes more saturated and infiltration rates decrease exponentially with time. When antecedent moisture conditions are high, the saturation of surrounding soil and infiltration rates are faster. The authors suggest saturated seepage rates should be utilized rather than infiltration rates of the surface material as using the latter will cause an underestimation of infiltration rates and an overestimation of draw down time within the trench.

The authors worked with the City of Lyon, France to help the city evaluate alternative stormwater management practices such as infiltration trenches. Both rectangle and trapezoidal infiltration trenches had their performance evaluated. When the starting water depth of both geometries was 0.30m, they both had similar emptying times of approximately 40 minutes. As the depth of water increased incrementally to 0.9m, the rectangular trench emptied more quickly than the trapedzoidal trench by an average of 20 minutes for each discrete water depth. Rectanglular trenches seem to be easier to construct and have a slightly higher efficiency however, in Southwest Florida, trapezoidal infiltration trenches seem best suited as sandy soils are less cohesive than other soil classifications (Chahar, Graillot, & Guar, 2012).

Currier et al. (2001) examined siting requirements and post-construction insights of two infiltration trenches installed in California. For both infiltration trenches studies, the drainage area was 1.7 acres (0.69 ha), with one being located in Los Angeles County and the other in San Diego County. Siting infiltration-based LIDs requires accurate knowledge of the site's soil type, seasonally high ground water table, and field permeability. Post-construction insights include infiltration rate, groundwater elevation, and soil characterization discrepencies.

Eight sites had a geotechnical investigation to determine suitablity for infiltration trench installation; only the Los Angeles and San Diego County sites marginally met selection criteria. The measured permeability was 40 and 31 inches per hour, respectively, and groundwater separation was 2-plus feet with the geotechnical engineer reporting no groundwater was encountered during boring. Both sites had a grass filter strip as a pre-treatment measure before stormwater runoff entered the trenches as well as both being designed to have an emptying time of 72 hours.

Of the two infiltration trench sites, the Los Angeles County trench is functioning as designed. The post-construction investigation of the San Diego County trench found there was an inaccurate estimation of infiltration capacity and draw down time was found to be twice as long as anticipated. The trench was installed on a fractured sandstone soil mix under the guidance of the geotechnical engineer after conducting a drill hole permeability test. Only after excavation began was it revealed few fractures were present and the fractures were not homogeneous therefore, permeability became limited. It is worth noting no laboratory soil analysis was conducted for either site in this study.

After completing this implementation study, the authors propose modifications to siting and design requirements. For infiltration testing, it is recommended to apply a conservative factor of safety to the lowest measured infiltration rate and to increase the number of tests per facility footprint. Groundwater exploration should occur in a timely fashion so that it correlates to seasonally high ground water elevation. Additionally, it should be noted during site investigations any evidence of mottling or soil color change occurs, as this is an indicator of groundwater flucuations. Having a shorter drawn down time than 72 hours will result in a larger facility and a longer interval between required maintenance. It is speculated 48 hours is a more appropriate requirement for draw down time. Lastly, a laboratory soil characterization should be done at the site footprint (Currier, et al., 2001).

4.1.3 Infiltration-based LID Design Considerations

The National LID Manual provides useful information regarding the generic characteristics and site considerations for each practice; however, it is lacking in technical information. The Maryland Stormwater Design Manual (2009) provides detailed design information on traditional, centralized stormwater management, LIDs, and micro-practices. Maryland has adopted performance factors to alleviate the impacts of stormwater runoff. The performance factors include minimizing stormwater runoff, maximization of pervious areas, providing groundwater recharge equivalent to pre-development volumes, and an acceptable level of water quality protection. The overall goal of the manual is to guide the engineering consultant in proper installation and long-term performance of these stormwater management practices.

Groundwater infiltration testing, depth to water table investigation, sequence of construction, material specifications, and landscaping requirements are a few of the details provided in the Maryland Stormwater Design Manual. Groundwater infiltration testing and depth to water table should be evaluated close to initial concept design to ensure proper infiltration-based LID functioning. Materials specifications help ensure the stormwater facility is functioning according to a set standard. Landscaping requirements not only provide site stabilization but aesthetics to the community as well. Detailed, consolidated descriptions of these technical guidelines are provided in Appendix C of this thesis. It is worth noting infiltration trenches call for cleaned, washed aggregate; while this is not specified for rain gardens, bioretention, or swales, it is normally washed at the plant however; it does not do any harm to require washed aggregate on construction specifications.

Infiltration-based LIDs are appropriate for most land use types. However, care must be taken to avoid infiltration of pollutants into groundwater. Groundwater pollution can happen when contaminants move rapidly through soils with a high infiltration capacity, like those in Florida; therefore, consideration must be given to the drainage area's surrounding land use and possibly providing pre-treatment, if necessary (Chahar, Graillot, & Guar, 2012; Duchene, McBean, & Thomas, 1994). In the Maryland Manual, wet swales are the only LID or micro-practice that explicitly prohibits runoff from a designated hot spot. All other practices must have either pre-treatment for hydrocarbons, trace metals, and toxicants or install an impermeable liner to avoid direct groundwater infiltration. Hot spots are generally heavily industrialized operations such as salvage yards, vehicle maintenance facilities, fleet storage areas, marinas, outdoor loading/unloading facilities, hazard waste facilities, and commercial container nurseries (MDE, 2009).

4.2 Other Infiltration-based LID Practices

Bioretention and infiltration trenches appear to be the most widely studied LID practices, while rain gardens have gained acceptance with homeowners. Listed below are many more infiltration-based LID practices which receive less recognition while other practices based on LID principles might be desirable in Southwest Florida when there are high seasonal water tables or limited space concerns.

4.2.1 Rain Gardens

A rain garden is a shallow landscape feature consisting of a saucer-shaped depression that temporarily holds runoff. Rain gardens typically consist of infiltrating soil bed, a mulch layer, and plants such as shrubs, grasses, and flowers. Captured runoff from downspouts, roof drains, or driveways may temporarily pond as it slowly filters into the soil over 24 to 48 hours. Rain gardens may be used in retrofitting and redevelopment applications as well as new construction (MDE, 2009). A section view of a rain garden is provided in Figure 4.3.

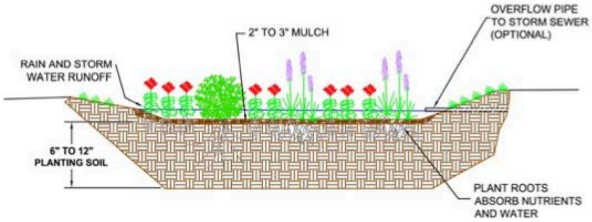
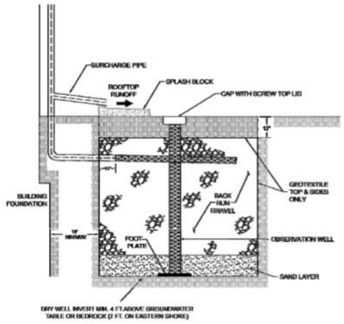


Figure 4.3 Rain Garden Section View (MDE, 2009)

Section

4.2.2 Dry Well

A dry well is an excavated pit with gravel or stone, which provides temporary storage of stormwater runoff from rooftops until it is infiltrated before the next storm event. The dry well storage area may be a shallow trench or a deep well. Dry wells can be used in residential and commercial sites however; runoff should be from small drainage areas such as a single rooftop or downspout. Successful implementation is dependent upon soil type and depth to groundwater (MDE, 2009). A section view of a dry well is provided in Figure 4.4.



Section

Figure 4.4 Dry Well Section View (MDE, 2009)

4.2.3 Swales

Swales are linear channels that can provide surface runoff conveyance, flow attenuation of stormwater runoff, and water quality treatment. They can be used for primary or secondary stormwater treatment on residential, commercial, industrial, or institutional sites. Swales are suitable for new development, re-development, and retrofitting. Their linear feature allows their use in place of curb and gutter structures along roadways. Swales can provide pollutant removal through vegetation, sedimentation, biological uptake, and infiltration into the underlying soil media. There are usually three design variations such as grass swales, wet swales, and bio-swales. Wet swales are used for treating roadway runoff in low-lying or flat terrain with high groundwater. Wet swales may be useful in Florida due to its flat terrain and high water table characteristics. Bio-swales can be used in all soil types since an underdrain is typically utilized. Grass swales are best suited along highway and roadway projects. Implementation of each swale type is highly dependent upon site soils, topography, and drainage characteristics (MDE, 2009). Pictured in Figures 4.5 and 4.6 below are typical wet and bio-swale configurations.

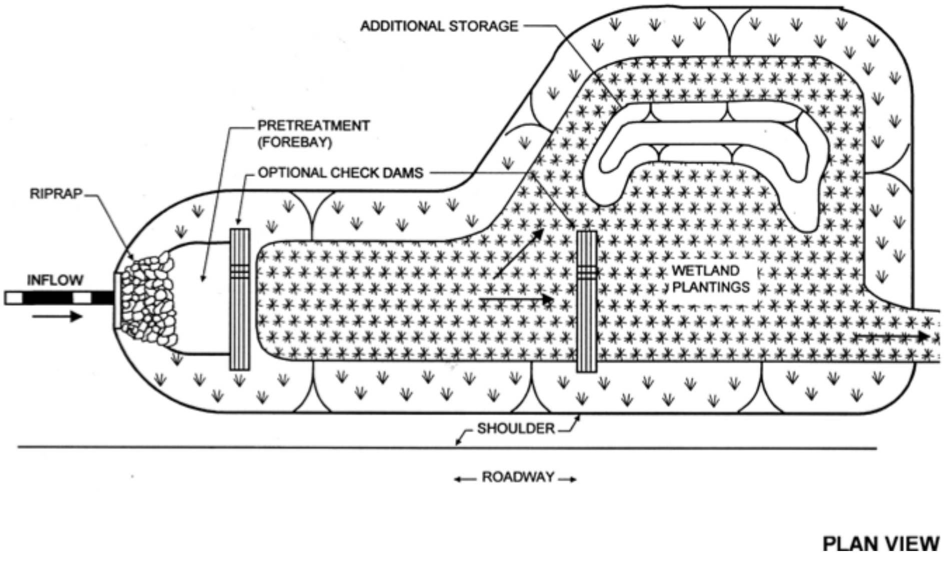


Figure 4.5 Wet Swale Plan and Section View (MDE, 2009)

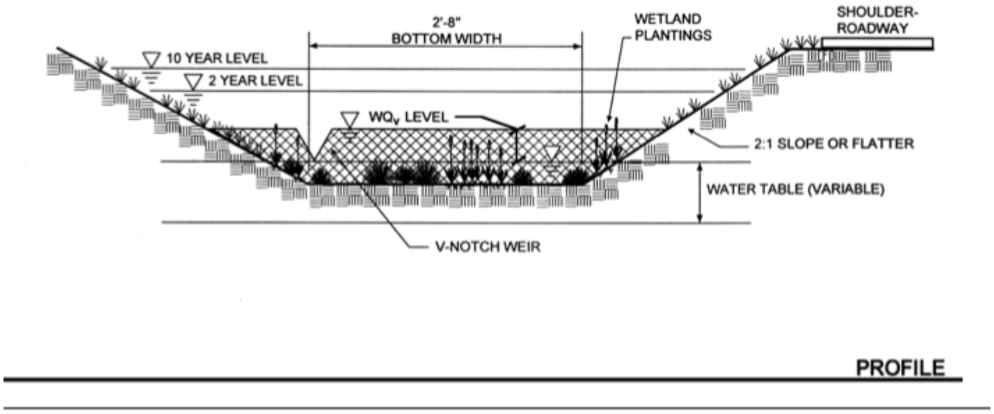


Figure 4.5 (continued)

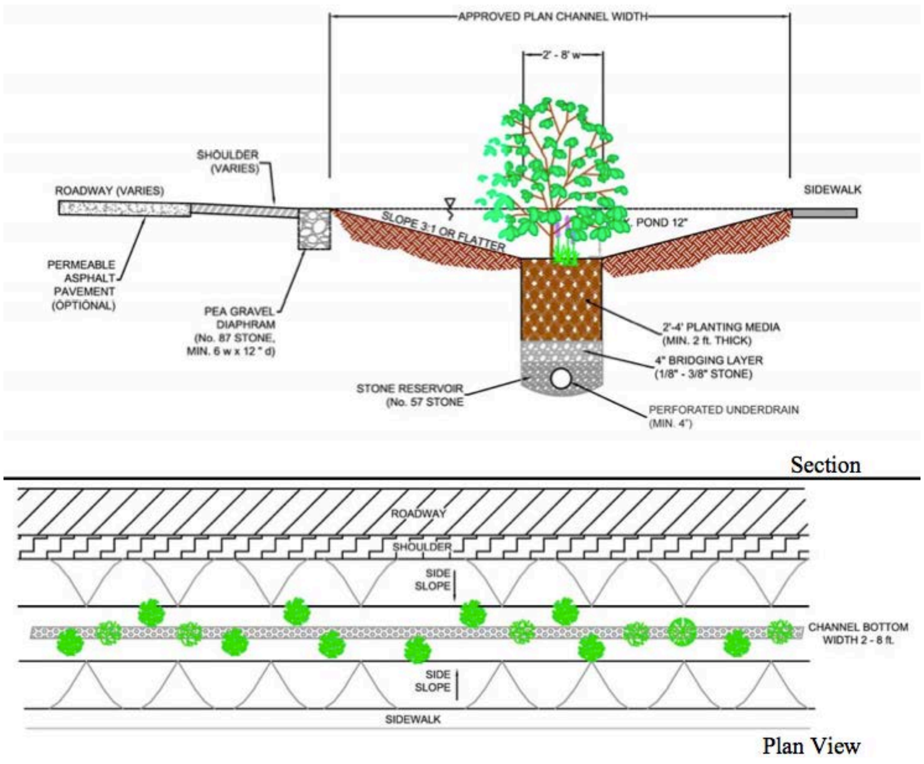


Figure 4.6 Bio-swale Plan and Section View (MDE, 2009)

4.2.4 Level Spreader

Level spreaders used in conjunction with a vegetated filter strip may be used in areas where the seasonally high water table may prevent the use of other infiltration-based LID practices. Hunt et al. (2010) conducted a study on a level spreader and vegetated filter strip combination in North Carolina. A previous study had shown this type of combination showed promise in fulfilling pre-development hydrology associated with LID implementation. During the 2010 study, an 85% runoff volume reduction was achieved compared to 49% in the previous 2009 study. The impervious area to vegetated filter strip ratio was lower in the 2010 study than the 2009 study, 8:1 and 28:1 respectively. Additionally, the 2010 study graded the slope to 1.25% and added 8 inches (20 cm) of a sandy loam, presumably to increase infiltration capacity. It appears this combination may have less outflows during storm events than bioretention however, this may due to the naturally occurring site features (Hunt, et al., 2010). This structural/nonstructural combination may have applicability in Florida due to the flat slopes, sandy soils, and areas with occasionally high seasonal water table. The configuration of the level spreader and a vegetated filter strip is shown in Figure 4.7.

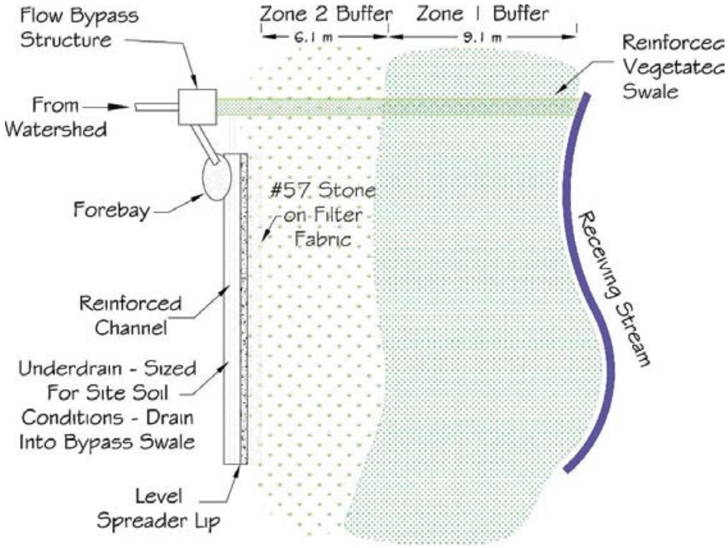


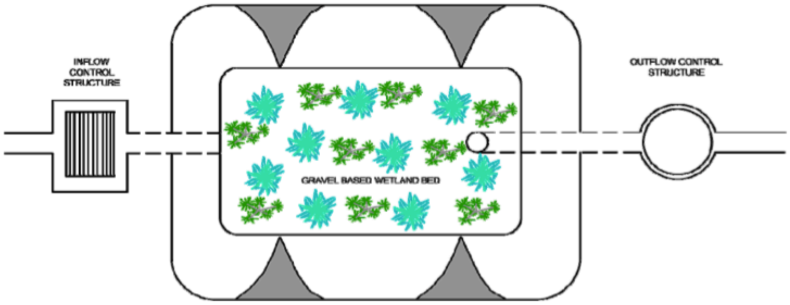
Figure 4.7 Combined Level Spreader and Vegetated Filter Strip Plan View
(Hunt, Hathaway, Winston, & Jadlocki, 2010 with permission from ASCE see Appendix A)

4.3 Micro-scale Practices

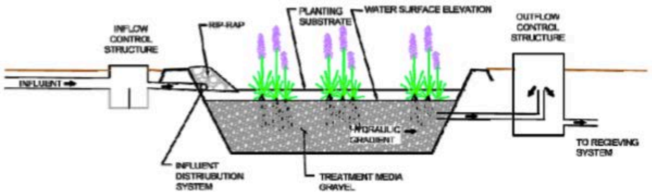
Micro-scale practices are small water quality treatment devices that typically resemble larger structural practices. These practices are used to capture and treat stormwater runoff from discrete impervious areas, usually less than one acre, and typically include natural systems, vegetation, and soils, which may be interconnected to create a more natural drainage system. These practices can be distributed throughout the project site to provide stormwater management at the source unlike their larger, structural relatives that are typically “end-of-pipe” treatment for larger drainage areas. Micro-scale practices are used in new development to promote runoff reduction and water quality treatment via infiltration, filtration, evapotranspiration, or a combination of techniques. Additionally, they are to promote recharge in new development and be planted as part of the landscaping plans (MDE, 2009). Their implementation in Florida appears promising given the state’s naturally occurring sandy soils along with coastal areas that have high seasonal water tables. These micro-scale practices are outlined below along with their coordinating figures.

4.3.1 Submerged Gravel Wetlands

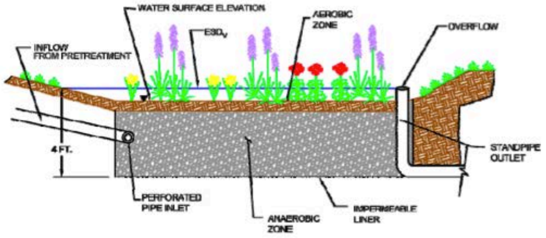
A submerged gravel wetland is a small-scale filtration practice utilizing wetland plants in a rock media to provide water quality treatment. The lowest elevation of the wetland receives runoff and is distributed throughout the system, ultimately discharging at the surface. A submerged gravel wetland can be located in limited spaces such as landscaping areas for traffic islands or roadway medians. Pollutant removal is achieved through biological uptake from algae and bacteria growing within the filter media. Wetland plants provide additional nutrient uptake while the physical and chemical treatment processes allow filtering and absorption of organic matter. Submerged gravel wetlands are well suited in areas where a high water table or poorly drained soils are present. This practice is not generally recommended for individual residential lots. If the site characteristics do not allow for a standing pool, a larger drainage area may be required to maintain saturated conditions within the wetland (MDE, 2009). A plan and section view of a submerged gravel wetland is provided in Figure 4.8.



Plan View



Section



Section

Figure 4.8 Submerged Gravel Wetland Plan and Section View (MDE, 2009)

4.3.2 Micro-Bioretention

Micro-bioretention practices capture and treat runoff from discrete impervious areas by passing it through a filter medium. Surface runoff is stored temporarily and filtered in shaped, landscaped facilities. The filtered stormwater is either returned to the stormwater conveyance system or infiltrated into the soil. Micro-bioretention practices can be adapted for use anywhere there is landscaping. Micro-bioretention can be used for new development, redevelopment, or retrofitting applications in residential, commercial, and industrial projects. Micro-bioretention not only has the potential to provide water quality treatment and aesthetic value to the community, it can be applied to a variety of projects such as concave parking lot islands, linear roadway or median filters, residential cul-de-sac islands, and ultra-urban planter boxes (MDE, 2009). A plan and section view of micro-bioretention is provided in Figure 4.9.

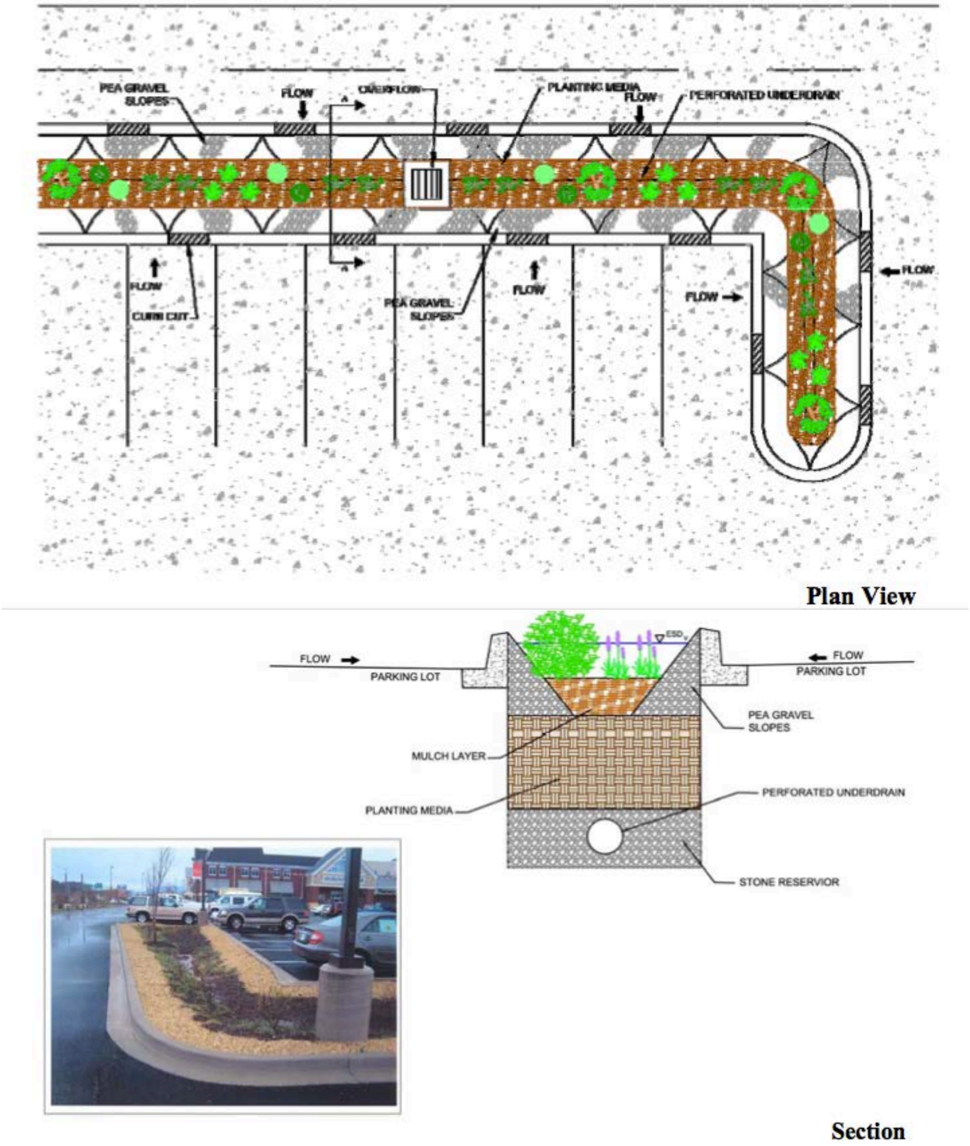


Figure 4.9 Micro-bioretention Plan and Section View (MDE, 2009)

4.3.3 Pocket Practices

These are practices with small, discrete drainage areas and can be distributed throughout the project site. The pocket sand filter should be applied to small sites where sediment loads are expected to be moderate to low. The pea gravel allows runoff into the filter system should the surface should become clogged. The term pocket wetland refers to a wetland that has such a small contributing drainage area there is little or no baseflow available to sustain water elevations during dry weather. Alternatively, water elevations are heavily influenced and may be maintained by a locally high water table (MDE, 2009). Pictured in Figures 4.10 and 4.11 below are typical “pocket” sand filter and wetland configurations.

All of these under-represented and micro-scale practices share the same goal of providing stormwater management and treatment at the source, helping to maintain pre-development hydrology, and some also possess the potential to provide groundwater recharge. Given Southwest Florida’s topography, hydrology, geology, and climate, it is possible to implement these practices on a larger, more widespread scale.

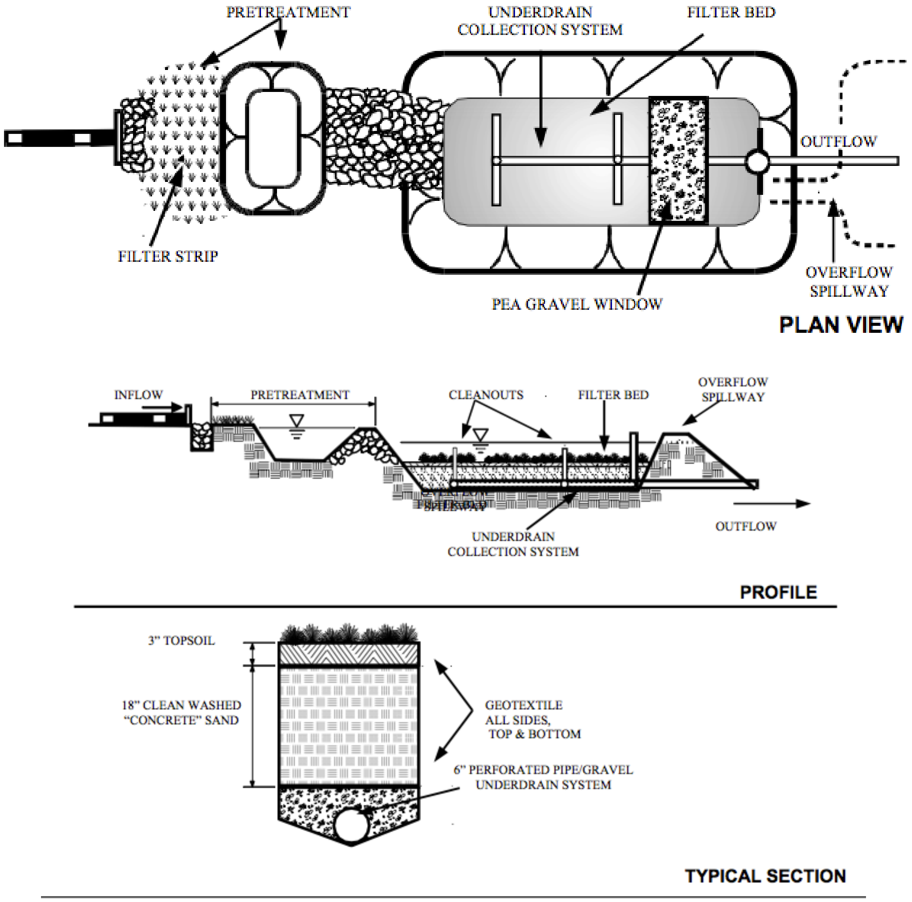


Figure 4.10 Pocket Sand Filter Plan and Section View (MDE, 2009)

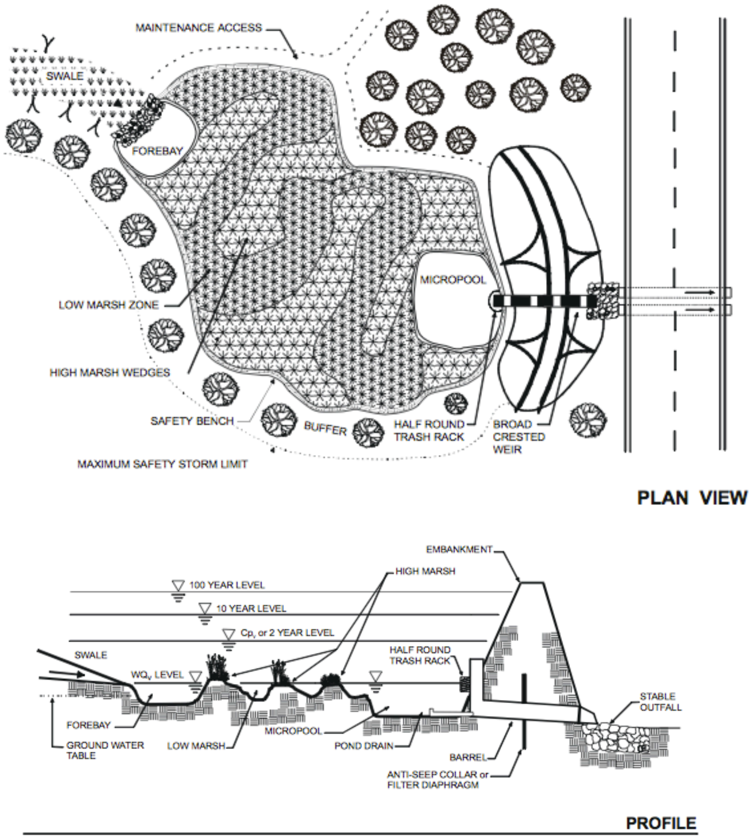


Figure 4.11 Pocket Wetland Plan and Section View (MDE, 2009)

CHAPTER 5: PROSPECT OF LID IMPLEMENTATION IN FLORIDA

5.1 Local LID Pursuits

Several local governments in Southwest Florida have in place, or are planning to execute mechanisms toward increasing LID implementation within their communities. Additionally, LID has been promoted as a sustainable stormwater practice in the preservation of springs. The largest government entity addressing LID promotion is Sarasota County followed by the City of Winter Haven. Pinellas and Hillsborough Counties are also working to remove regulatory barriers that might prohibit LID use.

In 2008, the Florida Department of Environmental Protection (FDEP) and the Florida Department of Community Affairs (FDCA) published *Protecting Florida's Springs: An Implementation Guidebook* to address water quality and water quantity issues facing springs. Low Impact Development is one component in the protection of Florida's springs. The value added by the implementation of LID is applicable to the state as a whole, which is facing a reduction in aquifer recharge and increased groundwater consumption. This publication discusses how creating a pre- and post- development recharge requirement to stormwater management, along with the implementation of LIDs and conservation cluster design, can help ease the burden placed on the aquifer (FDEP & FDCA, 2008).

Sarasota County's LID Manual (2011) was developed in an effort to provide much needed design tools for LIDs in Southwest Florida. The manual is for guidance purposes only and not a regulatory requirement (County, 2015). Upcoming Sarasota County Commissioner meetings will be held to incorporate LID into the Land Development and Zoning Codes. The

LID manual states that it is to be used as a supplement to County and SWFWMD stormwater design criteria. The intended audience includes planners, engineers, developers, and county officials. The format is closely aligned with the National LID Manual regarding planning considerations to retain natural site features and minimize clearing and grading followed by acceptable LID practices. The Sarasota County LID Manual states it provides key considerations for the design of shallow bioretention, pervious pavements, stormwater harvesting, green roof stormwater treatment, rainwater harvesting, and detention with biofiltration, also known as bioretention with an internal water storage zone.

In Chapter 2 of the Sarasota County LID Manual, site assessment and preservation of natural features are discussed as an important LID component. As such, it is stated an LID site should consider preserving existing site assets, control runoff at the source, promote infiltration, minimize site disturbance, and preserve the on-site seasonal high groundwater table. From a design perspective, words like “shall” and “must” are noticeably absent. From a plan review perspective, having “shall” and “must” reduces review time as the process has been standardized to some extent; thereby, potentially increasing review time and possibly increasing the installation of LIDs due to consistent standards and practices. Once LID becomes officially adopted as a stormwater management technique, the language will be changed to include “shall” and “must”. The LID Manual states that eleven separate county documents should be referenced together with this manual, by inclusion, for guidance on LID projects. This might be an inadvertent barrier to implementation by forcing parties interested in implementing LIDs on a site to review requirements in various other ordinances as opposed to providing general information with a comment to follow up in the actual ordinance, if necessary.

Some aspects of this LID Manual might inadvertently discourage the implementation of LIDs in Sarasota County. The manual addresses common issues that arise to those unfamiliar with LIDs such as appropriate siting, pollutant removal ability, draw down time, long-term maintenance and operation. While attempting to address these issues, more barriers to implementation may have been created, such as having a lack of confidence in LID performance, overly restrictive and costly nutrient-adsorption layers, and unrealistic testing requirements after LID installation. In keeping with the theme of this thesis, the bioretention systems will be discussed since, RWH in the Sarasota County LID Manual is not its own practice and associated with green roofs.

Chapter 2 of the Sarasota LID Manual provides a comparison of LID options in meeting site and watershed goals for each practice. The tabular feedback provides information on whether the practice meets general site considerations, environmental site considerations, and special watershed site considerations. At a glance, the design engineer would have general guidance on how each practice can meet the specific considerations. The LID practices promoted in Sarasota County are generally ranked as feasible and practical for general site and environmental site considerations. However, when the same practices are ranked in special watershed site considerations, such as discharging to an Outstanding Florida Water (OFW), they are given a lower overall use potential, stating the practice may be feasible but also may require additional design components. This might be an unintentional disincentive for LID implementation, especially for bioretention systems. In Sarasota County, bioretention systems have explicit requirements on the nutrient-adsorption layer in addition to being required to meet the 1-inch pollution control volume. It would seem bioretention systems designed this way could be treating the stormwater more effectively such that they could be used or encouraged when discharging to an OFW.

The manual states neither bioretention system will likely satisfy the storage capacity requirements for water quantity control in Sarasota County and SWFWMD. Chapter 3 of the Sarasota County LID Manual provides discussion on design considerations, maintenance, and testing for the two types of bioretention, pervious pavement, green roofs with cisterns, and stormwater harvesting. The manual states shallow bioretention and detention with biofiltration, also known as bioretention with an internal water storage zone, are designed for water quality purposes only.

The bioretention systems appear to be treated as a landscape island rather than a stormwater facility. Landscaping is an important aesthetic component in bioretention. Proper plant selection can eliminate the need to excessive maintenance and fertilizer applications. Both systems allow the use of fertilizer application, though records must be maintained. Fertilizer application could be avoided all together if the use of native plants, those that are amiable to inundation and periods of drought, were installed or required.

In Section 3.1.2.3, Planting Soil Filter Bed and Nutrient-Adsorptive Layer, the planting soil filter bed and the nutrient-adsorption layer contain extensive and potentially costly media. It is unclear if both layer requirements refer to a particular product description, though it is not referenced. When comparing the draft LID manual (2007) to the current manual (2011), specific construction materials, such as #57 stone, were left out in these sections as the County felt it important to not perform the system design for the end user. In addition to the cost of materials, the cost of installation will be greatly increased due to the contractor creating and uniformly mixing two distinct media layers. The design consideration section does not address a requirement for infiltration capacity minimums in the planting soil filter bed and the nutrient adsorption layer. Minimum permeability and porosity are discussed. Permeability for the nutrient adsorption layer is to be 0.03 to 0.25 inches per hour and is measured at the dry unit weight. If this were a true soil, permeability would be conducted under saturated conditions to evaluate the ability of water to move vertically.

Strict testing requirements after bioretention installation appear to create inadvertent barriers to LID installation. The manual places a proper incentive for a pre-treatment filter strip by requiring testing every 3 years as opposed to every 18 months for a bioretention system without a filter strip. In addition to having the appearance of a lack of confidence in the performance of bioretention, the testing requirements for both bioretention systems seems overly burdensome to the stormwater facility owner. To meet the testing requirements, the bioretention owner with a pre-treatment filter strip must conduct three double-ring infiltration tests at different locations within the system and submit the results to the County.

Pervious pavement, green roofs with a cistern, and stormwater harvesting from a wet pond receive overall credit for meeting runoff flow attenuation. Rainwater harvesting is considered an auxiliary benefit and does not count toward runoff reduction; specifically, SWFWMD does not consider rain barrels, even if used in series, a stormwater BMP. Shallow bioretention and detention with biofiltration systems are for supplementary water quality treatment only and do not count toward overall stormwater management. Since there is no regulation of stormwater volume control for small design storm events, the incentive appears to be installing LIDs is for water quality treatment only.

The City of Winter Haven has embraced infiltration-based LIDs as part of their Sustainable Water Resource Management Plan. In their document, *Sustainable Water Resource*

Management (2010), they state the overarching goal is to restore the pre-development hydrology in the uplands and lowlands to ensure water and other natural resources for future generations. Utilizing infiltration-based LIDs such as rain gardens, percolation ponds, swales, and pocket wetlands can restore the hydrologic connectivity between reaches and aquifer recharge can be increased. Post-development hydrologic conditions such as recharge, water quality, storage, and conveyance are to match pre-development conditions as much as possible. The City has installed numerous rain gardens and roadside swales to provide relief from localized flooding and to act as demonstration sites for public education (City of Winter Haven, 2010).

Pinellas and Hillsborough counties are in the process of either reviewing their stormwater management manual or reviewing regulatory barriers to LID implementation. Pinellas County is incorporating LIDs into their Draft Stormwater Manual (Pinellas County, 2015). Incorporation of LIDs into a local stormwater management manual have the potential to increase audience exposure to such practices and eliminates the need to switch back and forth between manuals for design guidance. It details the pre-development design considerations for minimizing site disturbance, retaining natural site features that can provide conveyance or depressional storage. Low Impact Development practices outlined in the draft manual include vegetated treatment swales, exfiltration trenches, vegetated natural buffers for pre-treatment, pervious pavement, green roofs with cisterns, stormwater harvesting, managed aquatic plant systems, and biofiltration.

The design criteria information provided is similar to the Sarasota County LID Manual, though more information is provided for the engineer's use on calculating BMP retention recovery and acceptable testing procedures for soils and depth to seasonally high ground water. For bioretention systems, the media layers are very similar, except Pinellas County requires a total depth between the planting soil bed and nutrient-adsorption layers of 36 inches as compared to 12 inches in Sarasota County, excluding the mulch layer. The testing requirements are identical in that the system must under go three double-ring infiltration tests at different locations every 3 years. Additionally, it appears the lack of confidence in LIDs continues to Pinellas County as exfiltration trenches, underground storage and retention, vegetated natural buffers, and biofiltration on County owned, operated, or dedicated property will not be accepted.

Tetra Tech (2014) was contracted by Hillsborough County to identify GI/LID inconsistencies and barriers in local codes; additionally, Tetra Tech was charged with providing guidance on removing any barriers identified. Tetra Tech's Green Infrastructure Opportunity Checklist identifies five potential areas where regulatory barriers might exist. These include minimizing connected impervious area, preserve and enhance the hydrologic function of pervious areas, RWH for either potable or non-potable supply, allow and encourage the use of multi-use stormwater controls, and manage stormwater to sustain stream functions. After reviewing Hillsborough County's Land Development Code, Stormwater Management Technical Manual, Transportation Technical Manual, and Development Review Procedures Manual, Tetra Tech found the regulations either mute or conflicting in the five areas where barriers might exist previously listed. Hillsborough County reviewed these initial findings and concluded their highest priority changes were to address stormwater harvesting and reuse, provide multiple benefits of developed space, alter driveway design to reduce impervious area, update green street design to include rain gardens, tree boxes or other LID practices, and alter off-street parking design requirements. The tentative implementation schedule is staggered throughout 2015 and includes significant changes to the Transportation Technical Manual so that roadside LIDs may be implemented as well as the reduction of impervious area by updating the Joint Use and Shared Parking code (Tetra Tech, 2014).

5.2 Low Impact Development Implementation Perspective Research

As discussed in Chapter 2 of this thesis, LID implementation faces numerous barriers toward greater placement throughout watersheds. These barriers occur both nationally and locally. Most notably, there are consistent, recurring obstacles toward fulfilling widespread LID installations. Whether the barriers are real or perceived, they have occurred from Tampa Bay to Puget Sound and communities in between. Many communities have been successful in overcoming these obstacles; one goal of this thesis is to provide information and guidance to decision makers regarding the application of various low cost LID practices in Southwest Florida.

5.2.1 Concerns of LID Implementation Locally

A brief social/ behavioral research study was conducted to gauge interest, knowledge, acceptance, and evaluate the implementation of LID within the SWFWMD boundaries. Comments were reviewed from the graduate level Urban Hydrology class at the University of South Florida, Tampa campus, where group presentations were made on various LID practices. This research is important because education of LID is not only a part of Phase II NPDES compliance (Rittenhouse, Kloss, & Weinstein, 2006) but also education of stormwater professionals has been identified as a barrier to implementation (Coffman, 2004). Therefore, the attitudes of Water Resources Engineering students before and after the topic was covered in a relevant course provide insights into whether this intervention can help to overcome this barrier. Additionally, the study conducted interviews and documented comments regarding LID implementation from five meetings with local government agencies. A copy of the IRB study confirmation is provided in Appendix D of this thesis.

5.2.1.1 Methodology

The objective of the research was to obtain a general level of information from the participants on a broad topic. In the Urban Hydrology class, individual LID practice presentations were observed, comments made on Canvas by fellow classmates were reviewed, and follow-up comments from each group of presenters were also analyzed. The demographics of the Urban Hydrology class included a mix of graduate students that were working towards an advanced degree beyond the Master's level to those who worked full-time while pursuing a Master's degree. Groups of two students each gave a 30-minute presentation on their assigned LID practice focusing on an introduction to that particular LID, engineering design guidelines, two case studies, and applicability to Florida. The LID practices presented were green roofs, pervious pavement, grassed swales, bioretention, rain gardens, rain barrels, dry wells, urban agriculture, and policies and public outreach regarding LID. To further LID understanding, each student not presenting was required to post a follow up question on Canvas regarding each practice and no single question could be repeated. Lastly, the presenters were required to provide answers on Canvas to the questions posed by their fellow students.

For the interviews with local government agencies, personal interviews were conducted with staff from five government agencies associated with stormwater management within the SWFWMD boundaries. The purpose of the interviews was to determine the level of LID implementation within each community. Either before the meeting or during the meeting, some participants requested anonymity. Therefore, all comments were anonymized. The number of personnel present during the interviews, excluding USF participants, ranged from two and up to five. The allotted time for the meetings was generally set for an hour; however, meetings frequently went over due to the interest in this discussion topic.

Each interview was approached with the intention of asking the same set of questions. These questions were 1) Is LID actively promoted within your agency? 2) If so, which ones? 3) How are they promoted? 4) Are pre-development meetings held? 5) Are LIDs considered part of the overall stormwater management plan? 6) Do you provide sole or overriding approval authority? 7) Do you offer incentives for LID implementation?

5.2.1.2 Results

Spring 2014 was the first time LIDs were incorporated into the Urban Hydrology curriculum. Graduate students who took Urban Hydrology learned how to design traditional stormwater management practices and have now begun to gain exposure to LID. Most students did not have significant exposure to LID before taking Urban Hydrology and found the concept discussion provoking. Some of the questions that arose can be attributed to a lack of understanding in the applicability of LID to Florida and subsequently, a barrier to overcome in the implementation of LIDs locally.

Initially, most students were skeptical of LIDs and their implementation in Florida; especially, those who worked as full-time engineers. Following the first presentation on drywells, comments included statements such as questioning how will it work in Florida given the state's climate and high water table as well as matter-of-fact statements that it will not work in Florida such as "I have to disagree with you regarding its (drywells) applicability to Florida. I don't think it will work here given the amount of rain we get from year to year...". Though students had to pose an original question, with no repeating questions per presentation, the most frequent questions or comments were regarding the lack of Florida design standards as most presenters had to use out-of-state design guidelines, operation and maintenance guidelines, planting requirements for vegetation dominant practices, and recurring confusion over nomenclature such as distinguishing between a rain garden and bioretention and how an engineered bioswale is different than the typical roadside swales seen in the state.

As the class progressed, the students became more receptive to LID implementation and began to evaluate how LIDs can be incorporated in the stormwater management landscape. Over the course of the semester, responses to presentations became more about how to provide this information to the general public and regulators in a manner that is understandable. It is likely that the students became more receptive as they researched their LID of choice and became more familiar with design requirements in addition to intangible benefits provided by the LID practice such as aesthetics, pollution reduction benefits, and groundwater recharge. This hypothesis is based on comments such as “This is definitely a LID that deserves to be implemented more”, “How can we get more people to care about implementing LIDs?”, “How about local government Economic Development Departments encouraging developers to incorporate LID technologies into a project by offering additional tax incentives or credits?”.

For the interviews with local government agencies, upon asking the first question, 4 out of 5 conversations quickly evolved into a discussion of barriers they faced in attempting to implement LID within their communities. Looking at this pattern from another perspective, it appears local government agencies support LID implementation on a greater level and action to address the barriers will help facilitate greater LID installations throughout future site development. Common barriers to LID implementation identified in these interviews are presented in Table 5.1.

Table 5.1 Regional Barriers to LID Implementation

Identified Barrier	Number of Respondents
Education of upper level management	5
Public buy in for sustainable growth	5
Proper incentives for LID implementation	4
Need for consistent, regionally appropriate design standards	3
Change in stormwater management to include design storms	3
Identify a way to reduce "burden of proof" required by SWFWMD to approve alternate stormwater designs	3
More stringent enforcement of HOAs responsibility to maintain stormwater management facilities	3

5.2.1.3 Discussion of Study Results

When comparing the above study results to what has been previously studied both nationally and locally, it appears widespread LID implementation in Southwest Florida might undergo the same growing pains as other regions have faced, such as the Utah case study (Burian, et al., 2008). Education and increased exposure appear to be the most important component to greater LID implementation. Education would come in many forms depending on the audience. In academia, the Urban Hydrology course was an example of how to incorporate general knowledge on LID and for students to gain an understanding of design requirements. Education for the development community might include public meetings and training courses once municipalities remove regulatory barriers to LID implementation. The development community might also benefit from a standardized design manual specifically for Southwest Florida that could be produced by either FDEP or SWFWMD. Public education could take the form of informational meetings at County Extension offices or by non-profit environmental organizations such as the Tampa Bay or Sarasota Bay Estuary Programs. Education of governing boards and elected officials could include providing information regarding the cost of excess, untreated runoff compared to providing localized treatment and retention at the source.

Another key factor revealed in the study was addressing a monetary motivator for the development community to increase LID implementation. Tax incentives, stormwater runoff reduction credits, and cost-sharing opportunities are enticing when agencies are attempting to introduce new technologies. However, the incentive generally associated with constructing LIDs is the runoff reduction credit associated with small design storm events such as the 2-year, 24-hour event. Florida's method of strictly capturing anywhere from 0.5 inches to 1.0 inches of runoff for pollution control versus volume control, i.e. a design storm event, conflicts with the reduction of directly connected impervious areas and the restoration site hydrology associated with LID. Non-directly connected impervious area is considered in the design volume of a stormwater management system; however, no explicit impetus has been found to limit directly connected impervious area. Therefore, it may prove difficult to provide stormwater reduction credits implementation of LID in Florida under the current method of stormwater management; nevertheless, cost-sharing and tax incentives might still be viable options.

5.3 Possible Solutions to Increase LID Implementation in Florida

Low Impact Development implementation is an alternative to conventional stormwater management that is slowly gaining momentum within the SWFWMD jurisdiction. As discussed in Chapter 2, education is paramount in LID success. Education includes engineers, developers, planners, local government agencies, and the public. When evaluating other success stories, like those provided in Chapter 2, local governments took a stake in implementing LIDs and installing pilot projects; subsequently, the value placed on LID implementation increased within the community.

Since Southwest Florida coverage reaches from the coastline to the central ridge, a mnemonic device has been created to guide others in the understanding of proper LID placement. The idea is tagged as “Let’s Make LIDs RADD”. ‘RADD’ is short for site reconnaissance (R), appropriate practice (A), drainage investigation (D), and finalize the design (D). Site reconnaissance (R) includes conducting a neighborhood investigation, hotspot identification, open space or natural resource inventory, and verifying desktop assumptions match what is seen in the field. Choosing an appropriate LID practice (A) is based on impervious area, site aesthetic requirements, and the surrounding landscape. The drainage investigation (D) is probably as important as conducting site reconnaissance. It determines whether the initial practice chosen is a dry or wet LID. The infiltration rate and seasonally high water table should be conducted at the site and at the proposed bottom elevation of the system. The tests should be conducted by a geotechnical engineer and field verified by the design engineer. Once all of this information is collected, it is then possible to finalize the site design (D) with confidence in the LID practice chosen.

CHAPTER 6: CONCLUSION

6.1 What Do the Hydrologic LID Case Studies Say?

Stormwater management is required due to development and alteration of the natural environment. It is heavily regulated in Florida and at the national level. Over the last two decades, LID has been promoted as a more sustainable and environmentally friendly method of controlling urban runoff. Hydrologic case studies of LID provided in Chapter 2of this thesis, show that greater watershed restoration and a more balanced water budget is possible when implementing LIDs. When measuring the difference in runoff between pre-development and high impact development for more pervious soils, it appears the relative impacts of urbanization is greater. However, the potential for mitigation of the impacts of urbanization through runoff reduction is also much greater for high infiltration capacity soils. Having a greater potential for urbanization mitigation in Florida's highly pervious soils is significant, in that it opens the door for more research in quantifying the benefits of LID. Southwest Florida is currently in its infancy when adopting LID on a broad-scale; however, several municipalities are in the process of incorporating LID into their stormwater management programs.

6.2 Rainwater Harvesting Options for Florida

Rainwater harvesting is a promoted LID practice that allows for peak flow reduction during wet weather events and reduces potable water demand for uses that would not normally require potable water quality. The two main options for RWH are rain barrels and cisterns. The difference between the two is a matter of scale. Rain barrels are typically implemented in one or more barrels with a volume of approximately 55-gallons, where cisterns start at hundreds of gallons. Effective Rainwater Harvesting design includes long-term supply and demand considerations as well as physical site considerations. Southwest Florida’s climate pattern is not compatible with rain barrels for runoff reduction due to their small volume; however, they still offer some water savings to homeowners. Given the type, duration, and frequency of storm events, cisterns are the most likely option for offering runoff reduction as well as reducing potable water demand. For example, in Tampa, Florida, in order to achieve approximately 70% catchment efficiency, a homeowner would need approximately fourteen 55-gallon rain barrels or a 750-gallon cistern. Conversely, for a single 50-gallon rain barrel that serves outdoor use only, the water-saving efficiency is 10% for Tampa.

6.3 Infiltration-based LID Practices and their Applicability to Florida

Infiltration-based LIDs have the ability to mitigate groundwater disruptions that result from urbanization such as minimizing receiving water body hydromodifications and reducing pollutant discharges to surface waters when designed properly and used in proper circumstances. These practices include systems such as bioretention, level spreaders, drywells, and “pocket” practices i.e. pocket wetlands. Infiltration-based LIDs may be wet or dry systems and rely on easily attainable construction materials such as gravel, sand, and native vegetation. This combination may have applicability in Florida due to the flat slopes, sandy soils, and areas with occasionally high seasonal water table. Infiltration-based LIDs help facilitate the main purpose of LID, which is to restore or maintain pre-development hydrology of the site. National standards for LID design should be considered a guideline and adapted accordingly to regional conditions. In Southwest Florida, it is possible to utilize any number of these practices though one of the key factors to success is proper knowledge of the seasonally high water table, especially along the coast line. Additional factors to ensure LID success include installing a pre-treatment filter strip, standardized infiltration rate testing, standardized materials specifications, proper sequence of construction, and diligent construction inspections during and following construction.

6.4 Increasing Widespread LID Implementation in Florida

The prospect of increased LID implementation within Southwest Florida appears promising. Municipalities are actively incorporating LID into their stormwater management recommendations. A behavioral study and interviews with staff from local governments regarding LID was conducted. The results from this study indicate that Southwest Florida is facing many of the same barriers to implementation that other communities across the nation had to overcome. These include lack of knowledge and education, lack of regionally specific design guidelines, and few “real world” pilot projects. Based on the behavioral study, it appears education could be the strongest key to LID acceptance. Over the course of three months, opinions regarding LID in Southwest Florida went from not possible to positively inquiring how to increase implementation. Since the region faces most of the same barriers to implementation, it may be possible to use other cities’ methods to increase LID acceptance and implementation as a template while modifying them so they are regionally appropriate. From a day-to-day engineering perspective, remembering the mnemonic device “RADD” may help increase successful LID projects.

REFERENCES

Armstrong, A. (2005). Ethical Issues in Water Use and Sustainability. *Royal Geograhical Society , 38* (1), 9-15.

American Society of Civil Engineers. (2013). *Report Card for Florida's Infrastructure*. Retrieved 2015 05-July from American Society of Civil Engineers: http://www.infrastructurereportcard.org/florida/florida-overview/

ASLA. (2015 nd). *American Society of Landscape Architects*. Retrieved 2015 03-May from Stormwater Case Studies: http://www.asla.org/stormwatercasestudies.aspx

Board of Regents of the State of Florida and the State of Florida, Department of State, for the Game and Fresh Water Fish Commission. (2001). *Ecosystems of Florida* (Vol. Second). Gainesville, FL, U.S.: University Press of Florida.

Braga, A., & Fitsik, R. (2008). LID Performance Monitoring Challenges and Results for Infiltrating BMPs: Bioretention Cells, Raingardens, and Porous Pavement. *Low Impact Development 2008* (pp. 1-12). American Society of Civil Engineers.

Briggs, J., & Reidy, P. (2010). Advanced Water Budget Analysis for Rainwater and Related Harvesting Applications. *World Environmental and Water Resources Congress 2010: Challenges of Change* , 475-484.

Bureau of Geology, Florida Department of Natural Resources. (1974). *Environmental Geology and Hydrology: Tampa Area, Florida* (Special Publication No. 19 ed.). Tallahassee, FL, U.S.: Bureau of Geology, Florida Department of Natural Resources.

Burian, S., Dietz, M., Pomeroy, C., Gorges, B., & Flower, W. (2008). Low Impact Development in Utah: Progress, Constraints, and Future Outlook. *2008 International Low Impact Development Conference* (pp. 1-10). American Society of Civil Engineers.

Burns, M. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., & Hatt, B. E. (2012). Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. *Landscape and Urban Planning* , 230-240.

Center for Urban & Environmental Solutions. (2007). *The Florida Planning Toolbox.* Florida Atlantic University. Fort Lauderdale: Florida Atlantic University.

Chahar, B. R., Graillot, D., & Guar, S. (2012). Storm-Water Management through Infiltration Trenches. *Journal of Irrigation and Drainage Engineering , 138* (3), 274-281.

Cheng, M.-S., Coffman, L. S., & Clar, M. L. (2001). Low-Impact Development Hydrologic Analysis. *Specialty Symposium on Urban Drainage Modeling at the World Water and Environmental Resources Congress 2001* (pp. 659-681). American Society of Civil Engineers.

Cheng, Y. (2010). Lateral Seepage Flow between Low Impact Development Drainage Devices and the Underground Water Level. *Low Impact Development 2010: Redefining Water in the City* (pp. 1443-1449). American Society of Civil Engineers.

Cheveney, B., & Buchberger, S. (2013). Impact of Urban Development on Local Water Balance. *World Environmental and Water Resources Congress 2013: Showcasing the Future* (pp. 2625-2636). American Society of Civil Engineers.

City of Dunedin. (nd). *Dunedin Waterfront Task Force Final Report Findings.* Retrieved 2015 12-March from City of Dunedin: http://www.dunedingov.com/modules/showdocument.aspx?documentid=3044

City of Winter Haven. (2010). *Sustainable Water Resource Management.* Winter Haven: City of Winter Haven.

City of Winter Haven. (2010 November). *Sustainable Water Resource Management Plan.* Retrieved 2015 12-March from City of Winter Haven: http://www.mywinterhaven.com/documents/FinalSustainableWaterResourceManagementPlan-LoResNov2010.pdf

Cizek, A. R., & Hunt III, W. F. (2013). Partitioning Pre-Development Hydrology in Order to Mimic Pre-Development Water Quality. *World Environmental and Water Resources Congress 2013: Showcasing the Future* , 266-279.

Coffman, L. (2002). Low Impact Development: Smart Technology For Clean Water - Definitions, Issues, Roadblocks, and Next Steps . *Global Solutions for Urban Drainage* (pp. 1-11). American Society of Civil Engineers.

Coffman, L. (2004). Low Impact Development: Smart Technology For Clean Water Definitions, Issues, Roadblocks, and Next Steps. *Global Solutions for Urban Drainage* (pp. 1-11). American Society of Civil Engineers.

County, S. (2015 26-August). Review Engineer. (L. Rankin, Interviewer) Sarasota, FL.

Currier, B., Taylor, S., Johnston, J., Yamaguchi, H., & Borroum, J. S. (2001). Siting, Design, and Operation of Infiltration BMPs: A Case Study. *Specialty Symposium on Intergrated Surface and Ground Water Management at the World Water and Environmental Resources Congress* (pp. 300-311). American Society of Civil Engineers.

CWPa. (2007). *Urban Subwatershed Restoration Manual No. 3 Urban Stormwater Retrofit Practices Version 1.0.* Center for Watershed Protection. Ellicot City: Center for Watershed Protection.

CWPb. (2007). *Urban Subwatershed Restoration Manual Series 3, Urban Stormwater Retrofit Practices (Appendices).* Center for Watershed Protection. Ellicot City: Center for Watershed Protection.

Davis, A. P., Traver, R. G., Hunt, W. F., Lee, R., Brown, R. A., & Olszweski, J. M. (2012). Hydrologic Performance of Bioretention Storm-Water Control Measures. *Journal of Hydrologic Engineering , 17* (5), 604-614.

DeBusk, K., Wright, J., & Hunt, W. (2010). Demonstration and Monitoring of Rainwater Harvesting Technology in North Carolina. *Low Impact Development 2010: Redefining Water in the City* , 1-10.

District of Columbia Water and Sewer Authority. (2015 nd-nd). *DC Water Proposes Modifying Long Term Control Plan for Green Infrastructure*. Retrieved 2015 30-April from District of Columbia Water and Sewer Authority: http://www.dcwater.com/education/green.cfm

Doberstein, C., Kirschbaum, R., & Lancaster, A. (2010). An Assessment of Barriers to LID Implementation in the Pacific Northwest, and Efforts to Removing those Barriers. *Low Impact Development 2010: Redefining Water in the City* (pp. 1089-1100). American Society of Civil Engineers.

Duchene, M., McBean, E. A., & Thomas, N. R. (1994). Modeling of Infiltration from Trenches for Storm-Water Control. *Journal of Water Resources Planning and Management , 120* (3), 276-293.

Earles, A., Rapp, D., Clary, J., & Lopitz, J. (2009). Breaking Down the Barriers to Low Impact Development in Colorado. *World Environmental and Water Resources Congress 2009* (pp. 914-923). American Society of Civil Engineers.

Encore! (2015 nd). *Encore!* Retrieved 2015 06-June from Encore! Fact Sheets: http://encoretampa.com/wp-content/uploads/2015/01/CentralPark_Devlpt_ENCORE_facts_rev012115.pdf

EPA. (2000). *Bioretention Applications.* U.S. Environmental Protection Agency, Office of Water. Washinton, DC: EPA.

EPA. (2008). *Incorporating Green Infrastructure Concepts into Total Maximum Daily Loads (TMDLs).* Washington, DC: Environmental Protection Agency.

EPA. (2010). *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure.* U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds. Washington, DC: EPA.

EPA. (2011). *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure.* U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds. Washington, DC: EPA.

EPAa. (2013 30-January). *Green Infrastructure Southeast Case Studies*. Retrieved 2015 28-April from Environmental Protection Agency: http://water.epa.gov/infrastructure/greeninfrastructure/gi_cssoutheast.cfm

EPAb. (2013 11-September). *Total Maximum Daily Loads (TMDLs) and Stormwater*. Retrieved 2015 28-April from Environmental Protection Agency: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/stormwater_index.cfm

EPAa. (2014 16-March). *Laws & Regulations.* Retrieved 2014 24-06 from Summary of the Clean Water Act: www2.epa.gov/laws-regulations/summary-clean-water-act

EPAb. (2014 28-May). *Low Impact Development.* Retrieved 2014 25-June from Water: Low Impact Development: water.epa.gov/polwaste/green/

EPAc. (2014 10-June). *Stormwater Discharges from Municipal Separate Storm Sewer Systems (MS4s).* Retrieved 2014 25-June from National Pollution Discharge Elimination System (NPDES): cfpub.epa.gov/npdes/stormwater/munic.cfm

EPAd. (2014 13-June). *What is Green Infrastructure?* Retrieved 2014 21-June from Water: Green Infrastructure: water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm

EPAe. (2014 02-July). *Post-Construction Stormwater Management in New Development & Redevelopment*. Retrieved 2015 28-April from Environmental Protection Agency: http://water.epa.gov/polwaste/npdes/swbmp/PostConstruction-Stormwater-Management-in-New-Development-and-Redevelopment.cfm

EPAf. (2014 3-October). *Water: Low Impact Development.* Retrieved 2015 8-June from U.S. Environmental Protection Agency: http://water.epa.gov/polwaste/green/bbfs.cfm

EPAg. (2014 29-October). *Community-Scale Studies*. Retrieved 2015 28-April from Environmental Protection Agency: http://water.epa.gov/infrastructure/greeninfrastructure/gi_scalestudies.cfm

EPAa. (2015 11-February). *City of Harrisburg Clean Water Act Settlement*. Retrieved 2015 30-April from Environmental Protection Agency: http://www2.epa.gov/enforcement/city-harrisburg-clean-water-act-settlement

EPAb. (2015 12-March). *Kansas City, Missouri Clean Water Act Settlement*. Retrieved 2015 30-April from Environmental Protection Agency: http://www2.epa.gov/enforcement/kansas-city-missouri-clean-water-act-settlement

EPAc. (2015 28-April). *Metropolitan Water Reclamation District of Greater Chicago Settlement*. Retrieved 2015 30-April from Environmental Protection Agency: http://www2.epa.gov/enforcement/metropolitan-water-reclamation-district-greater-chicago-settlement

EPAd. (2015 16-July). *Environmental Protection Agency*. Retrieved 2015 16-July from Watershed Assessment, Tracking & Environmental Results: http://iaspub.epa.gov/waters10/attains_state.control?p_state=FL&p_cycle=2010#content

FCOC. (2009 March). *Florida Coastal and Ocean Policy Report Card*. Retrieved 2015 05-July from Florida Coastal and Ocean Coalition: https://www.nrdc.org/oceans/flreport08/files/flreport08.pdf

FDEP & FDCA. (2008). *Protecting Florida's Springs: An Implementation Guidebook.* Florida Department of Environmental Protection and Florida Department of Community Affairs. Tallahassee: FDEP.

FDEP. (2007). *Evaluation of Current Stormwater Design Criteria within the State of Florida.* Tallahassee: Florida Department of Environmental Protection.

FDEP. (2015 11-February). *Florida Department of Environmental Protection*. Retrieved 2015 02-March from Total Maximum Daily Loads Highlights: http://www.dep.state.fl.us/water/tmdl/

FDEP. (2014). *Integrated Water Quality Assessment for Florida: 2014 Sections 303(d), 305(b), and 314 Report and Listing Update.* Florida Department of Environmental Protection, Division of Environmental Assessment and Restoration. Tallahassee: FDEP.

FDEP. (2013). *NPDES Phase I Municipal Separate Storm Sewer System (MS4) Permitting Resource Manual.* Tallahassee: Florida Department of Environmental Protection.

Florida Association of Professional Soil Classifiers & Florida Chapter of the Soil and Water Conservation Society. (1993). *Myakka Fine Sand - Florida's State Soil.* unknown.

Florida Climate Institute. (nd). *Florida Climate Institute*. Retrieved 2014 14-October from Frequently Asked Questions - Climate and Florida: Florida Climate Institute

Florida Green Building Coalition. (2015 20-May). *FGBC Green Local Government Certifications*. Retrieved 2015 5-June from Florida Green Building Coalition.

Florida State University, Institute of Science and Public Affairs. (1998). *Water Resources Atlas of Florida.* (E. A. Fernald, & E. D. Purdum, Eds.) Tallahassee, FL: Florida State University.

Forasté, A., & Hirshman, D. (2010). A Methodology for using Rainwater Harvesting as a Stormwater Management BMP. *Low Impact Development 2010: Redefining Water in the City* , 31-44.

FWC. (2014 November). *Economics*. Retrieved 2015 05-July from Florida Fish and Wildlife Conservation Commission: http://myfwc.com/about/overview/economics/

FWEA & AWRA FL. (2011 Winter). Implementing Low-Impact Development in Florida: Practitioner's Perspective. *The Florida Watershed Journal* , *4* (1), pp. 10-17.

Godfrey, D. (2013). *University of South Florida Scholar Commons.* Retrieved 2015 05-March from Theses and Dissertations: http://scholarcommons.usf.edu/etd/

Gold, A., Goo, R., Hair, L., & Arazan, N. (2010). Rainwater Harvesting: Policies, Programs, and Practices for Water Supply Sustainability. *Low Impact Development 2010: Redefining Water in the City* , 987-1002.

Gold, A., Goo, R., Hair, L., & Arazan, N. (2010). Rainwater Harvesting: Policies, Programs, and Practices for Water Supply Sustainability. *Low Impact Development 2010: Redefining Water in the City* (pp. 987-1002). American Society of Civil Engineers.

Hillsborough County Government. (2014 16-December). *Tampa Bay Estuary Program Technical Publications.* Retrieved 2015 12-March from Tampa Bay Estuary Program: http://www.tbeptech.org/TBEP_TECH_PUBS/2014/TBEP_08_14_Final_Technical_Memo_HillsboroughCo_GI_Code_Barrier_Evaluation.pdf

Hollander, D., Eyring, B., & Schmidt, A. (2006). Developing a Comparative Tool for both Conventional and Green Stormwater Management Techniques. *World Environmental Water Resources Congress 2006* , look up.

Holman-Dodds, J. K., Bradely, A. A., & Potter, K. W. (2003). Evaluation of Hydrologic Benefits of Infiltration Based Urban Storm Water Management. *Journal of the American Water Resources Association* , 205-215.

Horner, W., Adams, M., Potts, A., & McDaniels, S. (2007). Low Impact Development: A Better Approach for Water Resources in the Tampa Area . *World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat* (pp. 1-18). American Society of Civil Engineers.

Hunt, W., Hathaway, J., Winston, R., & Jadlocki, S. (2010 01-June). Runoff Volume Reduction by a Level Spreader-Vegetated Filter Strip System in Suburban Charlotte, NC. *Journal of Hydrologic Engineering , 15* (6), pp. 449-503.

International Stormwater BMP Database. (2014 30-December). *International Stormwater BMP Database.* Retrieved 2015 05-05 from International Stormwater BMP Database: www.bmpdatabase.org

Jennings, A. A., Adeel, A. A., Hopkins, A., Litofsky, A. L., & Wellstead, S. W. (2013 05). Rain Barrel - Urban Garden Stormwater Management Performance. *Journal of Environmental Engineering* , 757-765.

Jensen, M., Steffen, J., Burian, S. J., & Pomeroy, C. (2010). Do Rainwater Harvesting Objectives of Water Supply and Stormwater Management Conflict? *Low Impact Development 2010: Redefining Water in the City* , 11-20.

Jones, M., Hunt, W., & Wright, J. (2009). Rainwater Harvesting Experiences in the Humid Southeast USA. *World Environmental and Water Resources Congress 2009: Great Rivers* , 2105-2111.

Kinkade-Levario, H. (2008). Rainwater Harvesting, Low Impact Development Strategies, and Meeting the National Pollution Discharge Elimination System (NPDES) Stormwater Discharge Standards. *World Environmental and Water Resources Conference 2008* , 8.

Litofsky, A. L., & Jennings, A. A. (2014). Evaluating Rain Barrel Storm Water Management Effectiveness across Climatography Zones of the United States. *Journal of Environmental Engineering* , 1-10.

LMUAC. (2014). *State of Florida Land Management Uniform Accounting Council 2014 Annual Report.* LMUAC Members. Tallahassee: LMUAC.

Locicero, R. C. (2015 31-March). Mainstreaming Green Infrastructure: The Nexus of Infrastructure and Education Using the Green Space Based Learning (GSBL) Approach for Bioretention Plant Selection. Tampa, FL, U.S.: University of South Florida.

Machusick, M., & Traver, R. (2009). The Observed Effects of Stormwater Infiltration on Groundwater. *World Environmental and Water Resources Congress 2009: Great Rivers* (pp. 5343-5352). American Society of Civil Engineers.

MDE. (2009). *Maryland Stormwater Design Manual.* Retrieved 2015 20-May from Maryland Department of Environment: http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.aspx

Milwaukee Metropolitan Sewerage District. (2012). *Sustainable Water Reclaimation.* Milwaukee: Milwaukee Metropolitan Sewerage District.

National Oceanic and Atmospheric Administration. (2008 25-March). *National Oceanic and Atmospheric Administration.* Retrieved 2014 24-June from NOAA's National Ocean Service Education: Nonpoint Source Pollution: oceanservice.noaa.gov/education/kits/pollution/media/supp_pol02d.html

NRCS Soil Survey. (1983-April). *Florida Soil Survey.* Retrieved 2014 14-October from Natural Resource Conservation Service: http://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=FL

Office of Economic and Demographic Research. (2015 20-January). *Population and Demographic Data.* Retrieved 2015 28-June from Office of Economic and Demographic Research: http://edr.state.fl.us/Content/population-demographics/data/

Orlove, B., & Caton, S. C. (2010). Water Sustainability: Anthropological Approaches and Prospects. *The Annual Review of Anthropology , 39*, 401-415.

Palhegyi, G. E. (2010). Designing Storm-Water Controls to Promote Sustainable Ecosystems: Science and Application. *Journal of Hydrologic Engineering* , 504-511.

PG County, MD. (1999). *Low-Impact Development Design Strategies: An Integrated Design Approach.* Department of Environmental Resources, Programs and Planning Division. Largo: Prince George's County.

Philadelphia Water Department. (2015 nd-nd). *Green City, Clean Waters*. Retrieved 2015 30-April from Philadelphia Water Department: http://phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan

Pinellas County. (2015). *Pinellas County Draft Stormwater Manual.* Clearwater: Pinellas County.

Pinellas County Planning Department. (2012 24-July). *Green Pinellas* . Retrieved 2012 12-March from Pinellas County Government: http://www.pinellascounty.org/Plan/comp_plan/14compendium/11.pdf

Richey, A. S., Thomas, B. F., Lo, M.-H., Famiglietti, J. S., Swenson, S., & Rodell, M. (2015). Uncertainty in Global Groundwater Storage Estimates in a Total Groundwater Stress Framework. *Water Resources Research , 51*, 1-19.

Rittenhouse, B., Kloss, C., & Weinstein, N. A. (2006). Low Impact Development Strategies and Tools for NPDES Phase II Communities . *World Environmental and Water Resource Congress 2006* (pp. 1-4). American Society of Civil Engineers.

Ruppert, T., Ankersen, T. T., Capps, C., Garcia, C., Gonzalez, V., & Kim, P. (2008). *Weathering the Storm(water): Implementing Low-Impact Development Stormwater Management for New Residential Development in Florida.*

Sarasota County Government. (unknown). *Sarasota County Water Services*. Retrieved 2015 12-March from Low Impact Development: https://www.scgov.net/WaterServices/Pages/LowimpactDevelopment.aspx

Sarasota County. (2011 November). *Sarasota County Low Impact Development Manual.* Retrieved 2015 5-June from Sarasota County: https://www.scgov.net/WaterServices/Low%20Impact%20Development%20Resources/LID%20Manual.pdf

Shi, P., & Brown, A. (2014). *Florida Ecosystem Service Valuation Project*. Retrieved 2015 21-May from Duke University: http://sites.duke.edu/floridamp/

Steffen, J., Jensen, M., Pomeroy, C. A., & Burian, S. J. (2013). Water Supply and Stormwater Management Benefits of Residential Rainwater Harvesting in U.S. Cities. *Journal of the American Water Resources Association* , 810-824.

Stoner, N., & Giles, C. (2011 20-04). Memorandum. *Protecting Water Quality with Green Infrastructure in EPA Water Permitting and Enforcement Programs* , 2. Washington, DC, USA: Environmental Protection Agency.

Struck, S. D., Carter, S., Brescol, J., Cristian, D., Hufnager, C. L., & Sim, Y. (2011). APPLYING LOW IMPACT DEVELOPMENT PRACTICES TO MEET MULTIPLE OBJECTIVES: CASE STUDIES . *World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability* (pp. 608-618). American Society of Civil Engineers.

SWFWMD. (2013). *Environmental Resource Permit Applicant's Handbook Volume II.* unknown: Southwest Water Management District.

Talebi, L., & Pitt, R. (2012). Roof Runoff Harvesting Benefits for Regional Conditions in Low Density and Medium Density Residential Areas. *World Environmental and Water Resources Congress 2012: Crossing Boundaries* (pp. 3724-3731). American Society of Civil Engineers.

Tampa Bay Water. (2015 May). *Current Water Supply Sources in the Tampa Bay Region.* Retrieved 2015 3-June from Tampa Bay Water: http://www.tampabaywater.org/current-water-sources-in-use-tampa-bay-region.aspx

Tetra Tech. (2014). *Technical Memorandum - County of Hillsborough Final Summary of Green Infrastructure Inconsistencies and Barriers in Codes and Guidance with Action Items.* Tampa: Tetra Tech.

The Center for Neighborhood Technology. (2007). *Managing Urban Stormwater with Green Infrastructure: Case Studies of Five U.S. Local Governments.* The Center for Neighborhood Technology. Chicago: The Civic Federation.

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More Green Space is Linked to Less Stress in Deprived Communities: Evidence from Salivary Cortisol Patterns. *Landscape and Urban Planning , 105*, 221-229.

United States District Court for the District of Columbia. (2003 nd-nd). *EPA.* Retrieved 2015 30-April from EPA: http://www2.epa.gov/sites/production/files/documents/dcwasa-cd.pdf

University of Connecticut. (n.d.). *National Low Impact Development (LID) Atlas*. Retrieved 2015 28-04 from National Low Impact Development (LID) Atlas: http://lidmap.uconn.edu

USEPA. (2012 20-September). *Water: Clean Water Act 40th Anniversary.* Retrieved 2014 24-June from Environmental Protection Agency: water.epa.gov/action/cleanwater40/cwa101.cfm

Vermont Department of Environmental Conservation. (2003 nd-nd). *Green Infrastructure* Plans *and Reports*. Retrieved 2015 30-April from Watershed Management Division: http://www.watershedmanagement.vt.gov/stormwater/htm/sw_gi_plans_and_reports.htm

Vermont Stormwater Management Program. (nd nd-nd). *Examples of State-Level Approaches to Implementing LID and GSI.* Retrieved 2015 30-April from Stormwater Management: http://www.watershedmanagement.vt.gov/stormwater/docs/manualrevision/sw_Fact_Sheet_LID_And_GSI_State_Examples.pdf

Wardynski, B. J., & Hunt, W. F. (2012 12). Are Bioretention Cells Being Installed Per Design Standards in North Carolina? A Field Study. *Journal of Environmental Engineering* , 1210-1217.

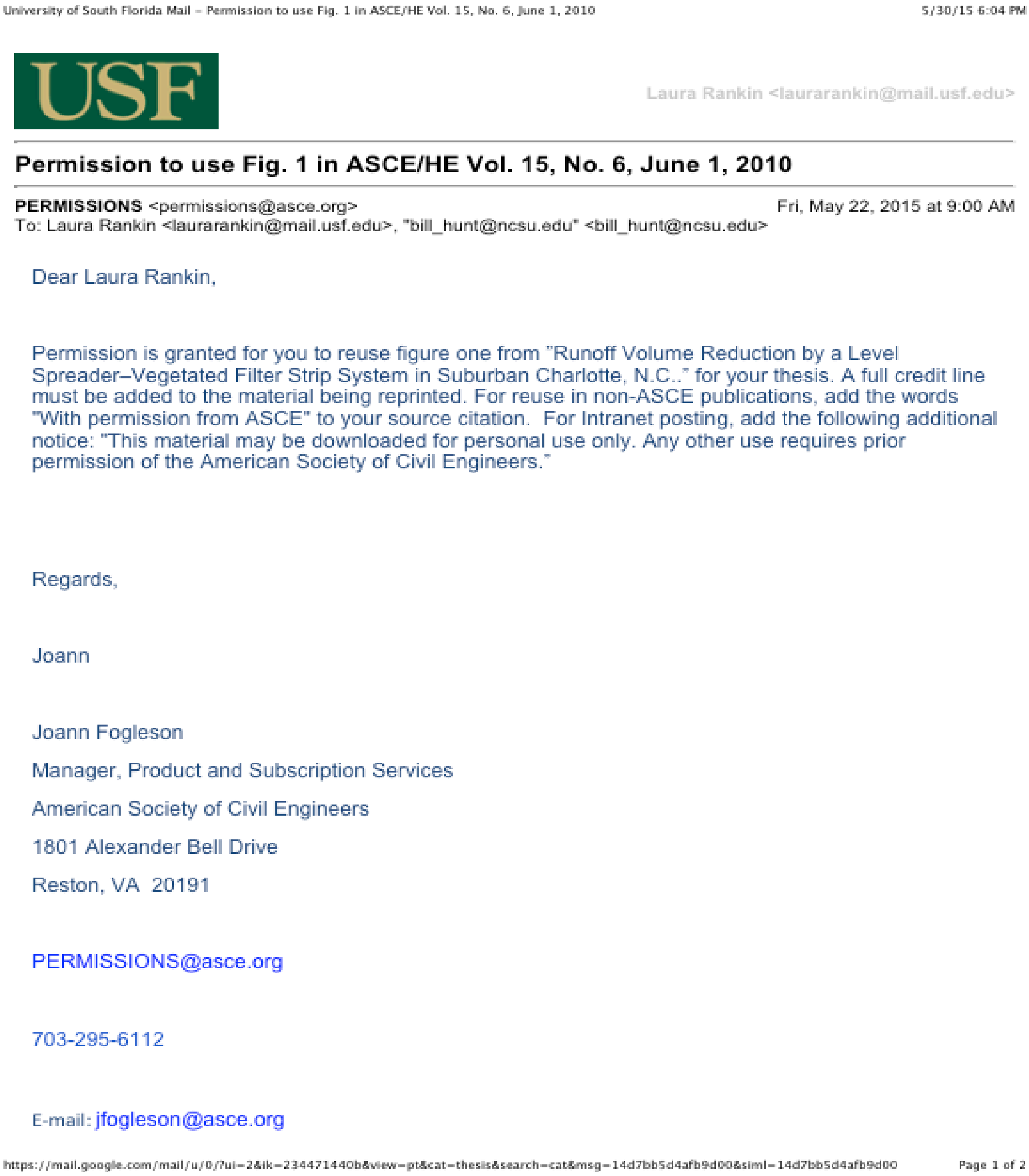
WEF. (nd). *WEF: Highlights.* Retrieved 2015 08-June from Water Environment Federation: http://www.wef.org/publications/page_archives.aspx?id=10046&page=newsandevents#WEF_Meets_With_EPA_on_Green_Infrastructure

Wilson, C., Hunt, W., Winston, R., & Smith, P. (2013). A Comparison of Runoff Quality and Quantity from an Urban Commercial Infill Low Impact Development and a Conventional Development. *World Environmental and Water Resources Congress 2013: Showcasing the Future* (pp. 2910-2923). American Society of Civil Engineers.

Wulkan, B. (2008). Promoting Low Impact Development in Puget Sound through Regulatory Assistance and other Measures. *2nd National Low Impact Development Conference* (pp. 1-8). American Society of Civil Engineers.

APPENDIX A: CITATION PERMISSIONS

The following is permission to use Figure 4.7.



University of South Florida Mail - Permission to use Fig. 1 in ASCE/HE Vol. 15, No. 6, June 1, 2010   5/30/15 6:04 PM

USF

Laura Rankin <laurarankin@mail.usf.edu>

Permission to use Fig. 1 in ASCE/HE Vol. 15, No. 6, June 1, 2010

PERMISSIONS <permissions@asce.org>   Fri, May 22, 2015 at 9:00 AM
To: Laura Rankin <laurarankin@mail.usf.edu>, "bill_hunt@ncsu.edu" <bill_hunt@ncsu.edu>

Dear Laura Rankin,

Permission is granted for you to reuse figure one from "Runoff Volume Reduction by a Level Spreader–Vegetated Filter Strip System in Suburban Charlotte, N.C.." for your thesis. A full credit line must be added to the material being reprinted. For reuse in non-ASCE publications, add the words "With permission from ASCE" to your source citation. For Intranet posting, add the following additional notice: "This material may be downloaded for personal use only. Any other use requires prior permission of the American Society of Civil Engineers."

Regards,

Joann

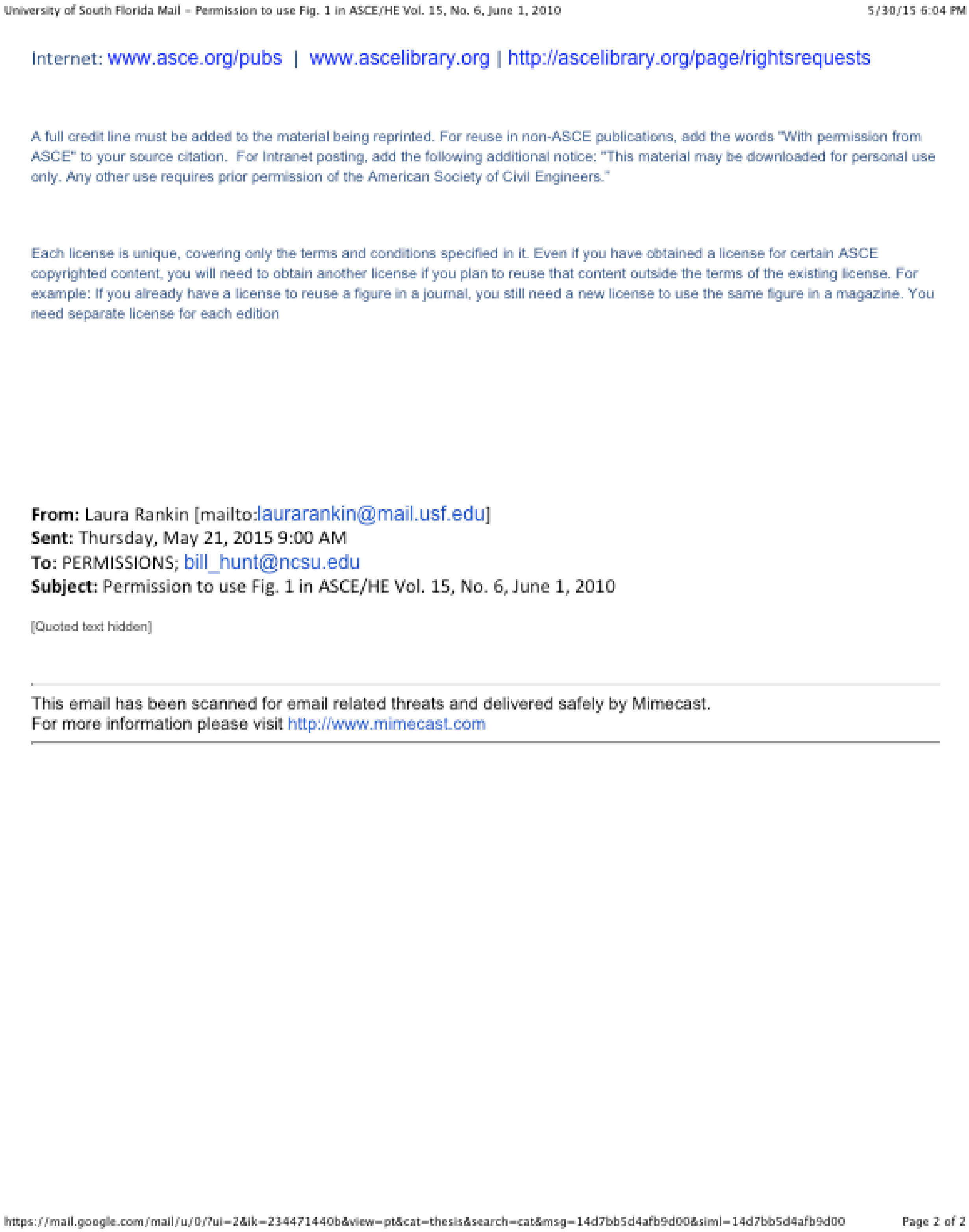
Joann Fogleson
Manager, Product and Subscription Services
American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, VA 20191

PERMISSIONS@asce.org

703-295-6112

E-mail: jfogleson@asce.org

https://mail.google.com/mail/u/0/?ui=2&ik=234471440b&view=pt&cat=thesis&search=cat&msg=14d7bb5d4afb9d00&siml=14d7bb5d4afb9d00   Page 1 of 2



Internet: www.asce.org/pubs | www.ascelibrary.org | http://ascelibrary.org/page/rightsrequests

A full credit line must be added to the material being reprinted. For reuse in non-ASCE publications, add the words "With permission from ASCE" to your source citation. For Intranet posting, add the following additional notice: "This material may be downloaded for personal use only. Any other use requires prior permission of the American Society of Civil Engineers."

Each license is unique, covering only the terms and conditions specified in it. Even if you have obtained a license for certain ASCE copyrighted content, you will need to obtain another license if you plan to reuse that content outside the terms of the existing license. For example: If you already have a license to reuse a figure in a journal, you still need a new license to use the same figure in a magazine. You need separate license for each edition

From: Laura Rankin [mailto:laurarankin@mail.usf.edu]
Sent: Thursday, May 21, 2015 9:00 AM
To: PERMISSIONS; bill_hunt@ncsu.edu
Subject: Permission to use Fig. 1 in ASCE/HE Vol. 15, No. 6, June 1, 2010

[Quoted text hidden]

APPENDIX B: ACRONYMS

2DUSAT – Two dimensional saturated-unsaturated finite-element-method modeling software

AASHTO – American Association of State and Highway Transportation Officials

ARRA – American Recovery and Reinvestment Act

ASTM – American Society for Testing and Materials

BAV – Bioretention abstraction volume

BMP – Best management practice

CSO – Combined sewer overflow

CWA – Clean Water Act

CWP – Center for Watershed Protection

DCIA – Directly connected impervious area

EPA – Environmental Protection Agency

FAC – Florida Administrative Code

FC – Field Capacity moisture content of soil

FDEP – Florida Department of Environmental Protection

GI – Green Infrastructure

HEC-HMS – Hydrologic Engineering Center - Hydrological Modeling System

HGWT – Height of ground water table

HSG – Hydrologic Soil Group

IRB – Institutional Review Board

LEED – Leadership in Energy & Environmental Design

LID – Low Impact Development

LMS – Lower Media Storage

MATLAB – Technical computing software

MDE – Maryland Department of Environment

MFS –Myakka Fine Sand

MIDS – Minnesota’s Minimal Impact Design Standards

MMSD - Milwaukee Metropolitan Sewerage District

MS4 – Municipal Separate Storm Sewer System

MUSIC - Model for Urban Stormwater Improvement Conceptualisation

MWRD – Metropolitan Water Reclamation District for Greater Chicago

NPDES – National Pollution Discharge Elimination System

OFW – Outstanding Florida Water

PREC – University of Florida’s Program for Resource Efficient Communities

RADD – Mnemonic device developed for increasing LID success

RWH – Rainwater Harvesting

RWHTools – University of Utah’s rainwater harvesting modeling software

RZMS – Root zone media storage volume

SAT – Saturated moisture content of soil

SCS – Soil Conservation Service

SHGWT – Seasonally high ground water table

SJRWMD – St. Johns River Water Management District

SWFWMD – Southwest Florida Water Management District

SWMM – Stormwater Management Model

TMDL – Total Maximum Daily Load

UNSAT-H - a FORTRAN computer code used to simulate the one-dimensional flow of water, vapor, and heat in soils

V - Volume

WEF – Water Environment Federation

WinSLAMM - Source Loading and Management Model for Windows

WP – Wilting point moisture content of soil

WPCLF – Ohio's Water Pollution Control Loan Fund

APPENDIX C: TABLE C.1

Table C.1 Comprehensive Details of Design Materials and Specifications for Infiltration Trenches, Bioretention Cells, and Swales (adapted from (MDE, 2009)

Infiltration Feasibility Criteria	**Test pit/Boring Requirements**	**Infiltration Conveyance Criteria**	**Pre-treatment Techniques**	**Infiltration Trench Construction Specifications**	**Bioretention Construction Specifications**	**Swale Performance Specifications**	**Swale Construction Specifications**	**Landscaping Requirements**
On-site septic percolation test, within 50 ft of trench and 200 ft of bioretention, and on same contour	Excavate or dig to a depth of 4 feet below facility bottom	Designed so excess flow discharge does not exceed erosive velocities	Redundant methods in place to protect long-term integrity of infiltration rate.	Facility may not be constructed until contributing drainage area stabilized	Facility may not be constructed until contributing drainage area stabilized	Longitudinal slopes of less than 4%	Dry swale: Soil – silt, silty sand or clayey sand Sand – ASTM C-33 fine aggregate concrete sand	Infiltration trench: Dense vegetation on side slopes and floor. Sufficient to prevent erosion and sloughing
Encased boring may be substituted for test pit	Determine depth to water table, within the 4 ft of bottom, and again 24 hours later	All infiltration systems to fully dewater within 48 hours	Use 3 of the following per infiltration trench: a) Grass channel b) Grass filter strip: minimum of 20 ft and only if sheet flow established and maintained	Heavy equipment and traffic to avoid proposed location during site construction	Heavy equipment and traffic to avoid proposed location during site construction	Peak velocity of 10-year storm discharge shall be non-erosive	Dry Swale: 6 inches of free-board; 4:1 or flatter slopes; Facility bottom 2 feet above seasonally high water table Bottom width – 2 ft min & 8 ft max	Infiltration trench: Fescue family recommended for seeding due to their adaptability to sandy soils, drought resistant, hardiness, and ability to withstand brief inundations.

Table C.1 (Continued)

Infiltration Feasibility Criteria	Test pit/Boring Requirements	Infiltration Conveyance Criteria	Pre-treatment Techniques	Infiltration Trench Construction Specifications	Bioretention Construction Specifications	Swale Performance Specifications	Swale Construction Specifications	Landscaping Requirements
0.52 in./hr infiltration rate Confirmation by geotechnical tests	Conduct Standard Penetration Testing every 2ft to a depth of 4ft below facility bottom	Designed to be off-line system if runoff delivered by storm drain pipe	c) Upper sand layer – 6 inch minimum, with filter fabric at sand-gravel interface d) Bottom sand layer e) Washed bank run gravel as aggregate	Tree roots trimmed to avoid filter fabric puncturing	Under-drains to be placed on a 3ft section of filter cloth. Pipe is placed next followed by gravel bedding	3 inches of freeboard must be provided and safely convey the 10-year storm	<u>Wet Swale:</u> Generally same guidelines as dry swale with the exception of the seasonally high water table; it may be located at swale bottom and inundate swale	<u>Infiltration trench:</u> Mow twice a year
No infiltration from designated hot spots	Determine soil textures at proposed facility bottom and within 4ft of bottom	Stormwater outfalls shall be provided for overflow associated with 10-year design storm event	Sides of infiltration trench shall be lined with filter fabric	Class “C” geotextile or better. Geotextile width to conform to trench perimeter irregularities and provide a 6 inch overlap	If no observation well, pipe ends to be capped	All ponding must be drained within 48 hours	<u>Filter Strips:</u> Pea gravel diaphragms to be 12 ft min and 24 ft deep max Slopes should be between 2 - 6%	<u>Bioretention:</u> Landscaping crucial to performance
May be prohibited on karst topography	Determine depth to bedrock if within 4ft of bottom		Extreme care during construction extends longevity of infiltration facilities	Washed, AASHTO-M-43, Size 9 or 10 sand if a 6 inch sand filter on bottom	Main underdrain collector pipe shall have a 0.5% minimum slope	6 inch inlet drop	<u>Filter Strips:</u> Pea gravel to be ASTM-D-48 and washed	<u>Bioretention:</u> Native plants should be used over non-native plants
2 feet to water table	Soil description of all soil horizons			Stone aggregate placed in 12 inch lifts, “bank run” gravel preferred	Observation well for every 1000 ft^2 of surface area	Underdrain may be used to meet 48 hour draw down time		<u>Bioretention:</u> Plants based on zone of hydric tolerance

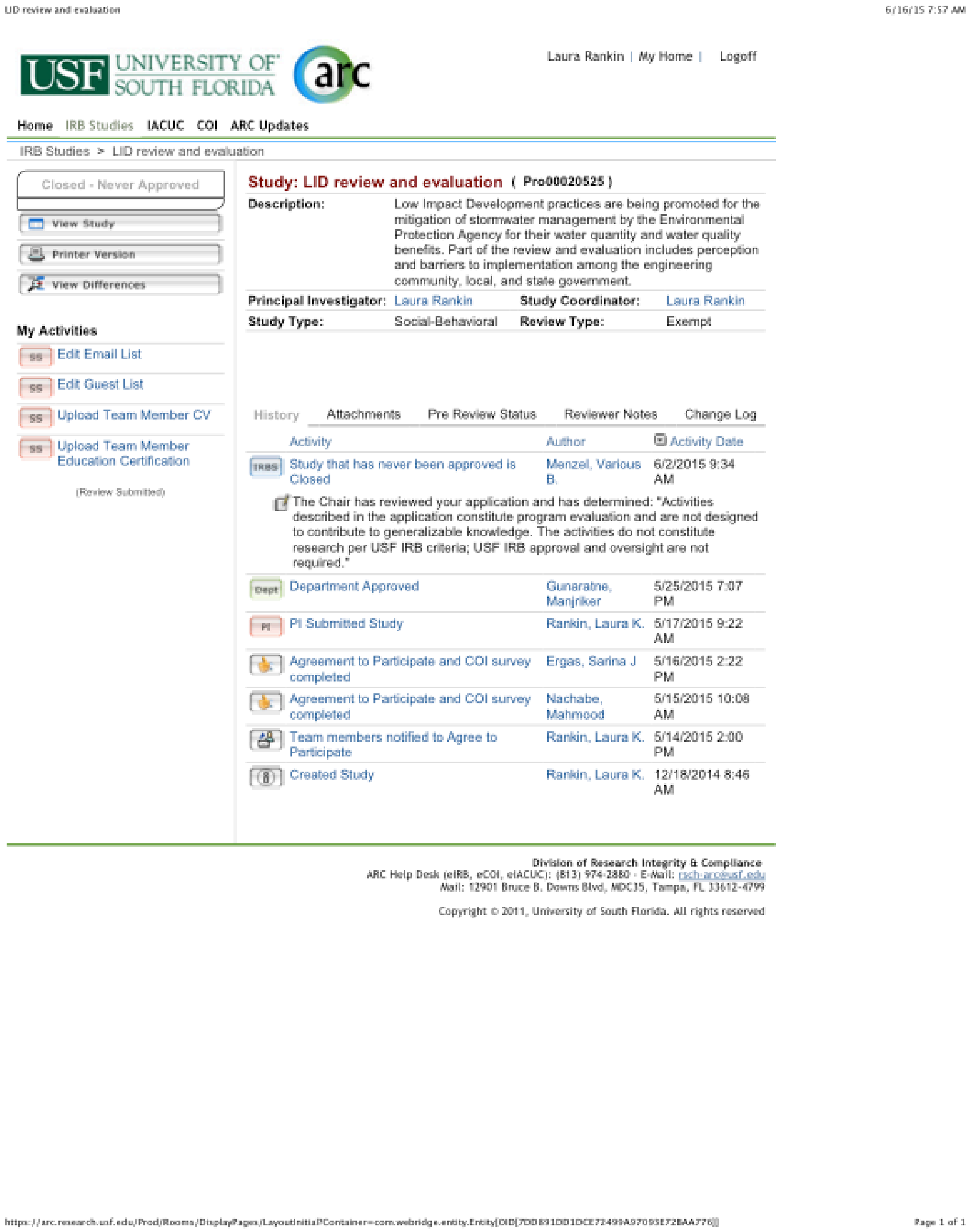
Table C.1 (Continued)

Infiltration Feasibility Criteria	Test pit/Boring Requirements	Infiltration Conveyance Criteria	Pre-treatment Techniques	Infiltration Trench Construction Specifications	Bioretention Construction Specifications	Swale Performance Specifications	Swale Construction Specifications	Landscaping Requirements
				Stone aggregate must be washed and meet AASHTO-M-43, Size 2 or 3				
Maximum 5ac. drainage area	Pit/boring stakes are to be left in the field and labeled as such		Infiltration LIDs not constructed until contributing drainage area stabilized	After aggregate placement, filter fabric folded over with a 6 inch longitudinal overlap	When backfilling, use 12-18 inch lifts	Check dams at inlets may be used to provide pre-treatment storage of 0.1 inch of impervious runoff		Bioretention: Trees and an understory of shrubs and herbaceous materials should be provided
100 ft offset from water supply well			Infiltration facilities cannot serve as sediment control device during site construction	Avoid native soil or fill mixing with aggregate	Mulch shall be shredded hardwood with a minimum of 6 months of aging	Maximum bottom width – 8 ft		Bioretention: No woody vegetation at inlet
10 - 25 foot offset from structures				Prohibit voids between filter fabric and side walls	Planting soil: 2.5 – 4 ft deep USDA soil type: loamy sand, sandy loam, or loam	Wet swales discouraged in residential areas		Swales: Native vegetation appropriate for inundation frequency
No negative impact down gradient of facility				For soft cohesive or cohesionless soils, flat side slopes required	Class "C" geotextile or better. Geotextile width to conform to perimeter irregularities and provide a 6 inch overlap			

Table C.1 (Continued)

Infiltration Feasibility Criteria	Test pit/Boring Requirements	Infiltration Conveyance Criteria	Pre-treatment Techniques	Infiltration Trench Construction Specifications	Bioretention Construction Specifications	Swale Performance Specifications	Swale Construction Specifications	Landscaping Requirements
				PVC distribution pipes: Schedule 40 and meet ASTM-D-1785. Fittings: ASTM-D-2927. Perforations: 3/8 inch in diameter	Underdrain gravel must meet AASHTO-M-43, size should be 0.375 – 0.75 inches			
				Observation well placed near longitudinal center, 6 inch diameter perforated PVC Schedule 40 pipe with cap 6 inches above ground level	Sand shall be: 1 foot deep, AASHTO-M-6 or ASTM-C-33, and 0.02 – 0.04 inches in size			
					6 inch drop inlet			

APPENDIX D: IRB STUDY REPORT



LID review and evaluation 6/16/15 7:57 AM

Laura Rankin | My Home | Logoff

IRB Studies > LID review and evaluation

Study: LID review and evaluation (Pro00020525)

Description:	Low Impact Development practices are being promoted for the mitigation of stormwater management by the Environmental Protection Agency for their water quantity and water quality benefits. Part of the review and evaluation includes perception and barriers to implementation among the engineering community, local, and state government.

Principal Investigator:	Laura Rankin	**Study Coordinator:**	Laura Rankin
Study Type:	Social-Behavioral	**Review Type:**	Exempt

My Activities

- SS Edit Email List
- SS Edit Guest List
- SS Upload Team Member CV
- SS Upload Team Member Education Certification

(Review Submitted)

	Activity	Author	Activity Date
IRBS	Study that has never been approved is Closed	Menzel, Various B.	6/2/2015 9:34 AM
	The Chair has reviewed your application and has determined: "Activities described in the application constitute program evaluation and are not designed to contribute to generalizable knowledge. The activities do not constitute research per USF IRB criteria; USF IRB approval and oversight are not required."		
Dept	Department Approved	Gunaratne, Manjriker	5/25/2015 7:07 PM
PI	PI Submitted Study	Rankin, Laura K.	5/17/2015 9:22 AM
	Agreement to Participate and COI survey completed	Ergas, Sarina J	5/16/2015 2:22 PM
	Agreement to Participate and COI survey completed	Nachabe, Mahmood	5/15/2015 10:08 AM
	Team members notified to Agree to Participate	Rankin, Laura K.	5/14/2015 2:00 PM
	Created Study	Rankin, Laura K.	12/18/2014 8:46 AM

Division of Research Integrity & Compliance
ARC Help Desk (eIRB, eCOI, eIACUC): (813) 974-2880 - E-Mail: rsch-arc@usf.edu
Mail: 12901 Bruce B. Downs Blvd, MDC35, Tampa, FL 33612-4799

https://arc.research.usf.edu/Prod/Rooms/DisplayPages/LayoutInitial?Container=com.webridge.entity.Entity[OID[7DD891DD1DCE72499A97093E728AA776]] Page 1 of 1