DESIGN GUIDANCE ON LOW IMPACT DEVELOPMENT PRACTICES FOR STORMWATER MANAGEMENT AND CONTROL IN OKLAHOMA

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Bachelor of Science in Agricultural Sciences and Natural Resources

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Stillwater, Oklahoma

2005

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2011

DESIGN GUIDANCE ON LOW IMPACT

DEVELOPMENT PRACTICES FOR STORMWATER

MANAGEMENT AND CONTROL IN OKLAHOMA

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ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my present Advisor, Dr. Jason Vogel for his expertise, patience and understanding. I would also like to thank my former Advisor Dr. Mike Smolen who helped me begin this journey and always remained positive when I encountered a problem. My sincere thanks are also expressed to my committee members, Dr. Daniel Storm, Dr. Art Stoecker, Dr. Mike Smolen and Dr. Jason Vogel for their guidance and willingness to work around my career.

I am very thankful to Mr. Joe Willingham for his review of, comments and suggestions on my Thesis. My appreciation also goes to my supervisor, Mr. Steve Manek. Without his understanding of my situation and willingness to allow time away from my job I would not have been able to pursue and complete this degree. I also acknowledge the support by my fellow co-workers who were always willing to listen and provide their thoughts and advice.

Finally, I take this occasion to express my deepest gratitude to my beloved husband, daughter, parents, brother and sister-in-law, grandparents, mother and father-in-law and other family and friends for their moral support and endless amount of patience during my studies at Oklahoma State University.

LIST OF ACRONYMS

BMP	Best Management Practice
CWA	Clean Water Act
EPA	Environmental Protection Agency
HHW	Household Hazardous Waste
LID	Low Impact Development
MCM	Minimum Control Measure
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
OCC	Oklahoma Conservation Commission
OCES	Oklahoma Cooperative Extension Service
ODEQ	Oklahoma Department of Environmental Quality
ODWC	Oklahoma Department of Wildlife Conservation
OSU	Oklahoma State University
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture

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CHAPTER I

INTRODUCTION TO THESIS

Background

Since the National Pollutant Discharge Elimination System regulations were first implemented in Oklahoma in 1990 stormwater management has evolved in many ways. One of these evolutions has come by the way of the EPA encouraging communities to utilize Low Impact Development (LID) to deal with both stormwater quantity and achieve water quality benefits as a result. In the last 5 years the installation of LID practices in the United States have grown tremendously. In many cities and states LID is becoming more of a common practice. In Oklahoma, there are several of these practices in place and in the planning stages. However, most of the projects have been sponsored by government entities and not private development.

My personal knowledge of and interaction with players in the development community affords me insight into the reasons for the lack of participation from the private development sector. Specifically, the uncertainty about how to design and install these practices as well as the lack of knowledge about the costs, benefits and maintenance of are the main factors that LID has such a low implementation rate in Oklahoma.

It is for this precise reason that a LID manual will be a valuable resource for all Oklahomans.

Objectives of Research

- Develop comprehensive fact sheets on each practice for use in future LID Manual
- Identify examples of LID practices currently in place in Oklahoma
- Provide additional resources for users to expand LID knowledge

Purpose

This series of fact sheets will provide a resource for the citizens of Oklahoma to utilize to determine if LID practices could be valuable to implement. The purpose of this endeavor is to research the existing technology and implementation surrounding LID and document the findings to educate a variety of groups such as engineers, homebuilders, developers, homeowners, and scientists.

Literature Review

It is important to note that research on stormwater and the effectiveness of LID is gaining in the United States. In a study conducted by Deitz and Clausen (2008) stormwater runoff and pollutant concentrations were measured as development progressed in both a traditional development, and a development that used low impact development techniques. TN and TP export from the low impact subdivision were consistent with export values from forested watersheds. The results of this study indicate that the use of low impact development techniques on a watershed scale can greatly reduce the impacts of development on local waterways.

Similar results were found with research on heavy metal removal. Investigations using pilot-plant laboratory bioretention systems and two existing bioretention facilities documented their effectiveness at removing low levels of lead, copper, and zinc from synthetic stormwater runoff. Removal rates of these metals (based on concentration and total mass) were excellent, reaching close to 100% for all metals under most conditions, with effluent copper and lead levels mostly less than 5 μg/L and zinc less than 25 μg/L (Davis et. al 2003).

Researchers at Oklahoma State University report promising findings on efforts to improve phosphorus and heavy metal adsorption in bioretention cells (Brown et al. 2009). Their research includes the use of fly ash in rain gardens as a way to improve adsorption rates.

Researchers from the University of Iowa created a group of preliminary experiments using relatively simple engineering tools to compare three basic scenarios of development: an undeveloped landscape; a fully developed landscape using traditional, high impact stormwater management; and a fully developed landscape using infiltration based, low impact design. "Based on these experiments, it appears that by manipulating the layout of urbanized landscapes, it is possible to reduce impacts on hydrology relative to traditional, fully connected stormwater systems. However, the amount of reduction in impact is sensitive to both rainfall event size and soil texture, with greatest reductions being possible for small, relatively frequent rainfall events and more pervious soil textures. Thus, low impact techniques appear to provide a valuable tool for reducing runoff for the events that see the greatest relative increases from urbanization: those generated by the small, relatively frequent rainfall events that are small enough to produce little or no runoff from pervious surfaces, but produce runoff from impervious areas. However, it is clear that there still needs to be measures in place for flood management for larger, more intense, and relatively rarer storm events, which are capable of producing significant runoff even for undeveloped basins (Dodds et al. 2003)."

Overall, the general consensus among researchers is that LID is effective as a way to improve water quality. The recurring theme throughout publications is that further research would be beneficial to further quantify benefits as well as improvements that can be made with these practices.

Structure

The Thesis document that follows will include chapters on the following Low Impact Development practices. Chapter II is a short introduction to the manual which will familiarize the user with water quality issues and a summary of LID.

Chapter III: Cost Comparison of Low Impact Development to Conventional

Chapter IV: Pollutant Source Reduction

Chapter V: Rain Gardens and Bioretention Cells

Chapter VI: Rainwater Harvesting

Chapter VII: Pervious Pavement

Chapter VIII: Natural and Engineered Wetlands

Chapter IX: Green Roofs

Each of these chapters provides a description of the practice and will generally have sections on the Benefits, Installation, Costs, Maintenance, Limitations, and Oklahoma Examples. Content of the chapters includes references and information on other resources that may prove useful for the reader.

Methods

Research methods included the use of a variety of sources. Peer-reviewed publications were used for the literature review as well as documentation of some of the benefits associated with LID. Other sources included use of the material from LID programs at major research universities including North Carolina State University and the University of Wisconsin. Federal and State agencies were also utilized in respect to current LID programs, practices and guidance.

CHAPTER II

INTRODUCTION TO MANUAL

Preface

Since 1990 stormwater management has been required for municipalities, industrial facilities and construction sites within the State of Oklahoma. In addition to meeting the regulatory requirements faced by these groups there is also a desire to protect water resource, and as a result, preserve aquatic habitats and the quality of life in Oklahoma communities. The following series of Low Impact Development (LID) fact sheets will help Oklahoma move forward with a comprehensive approach to stormwater management that integrates drainage design, stormwater quantity, and water quality considerations and views stormwater as an important resource and opportunity for our state. The goal of these fact sheets is to develop and promote a consistent and effective approach to the implementation of stormwater management.

Background

The protection of water quality has been an integral part of restoring our nation's water bodies since the Clean Water Act was first passed back in 1972. Today, water quality restoration and maintenance is more imperative than ever with increasing land development and population growth. With ongoing "water wars" in the western United States and non-point source pollution causing a large percentage of our water quality impairments, we continue to understand that water is a precious resource that must be both managed by professionals and valued by the citizens. Traditionally stormwater management has gone unnoticed in the media and therefore is less understood by the public. However, that doesn't mean that it is any less vital to our way of life. As the Environmental Protection Agency continues to develop new stormwater policies to improve our water resources, it is equally important for academia to embrace these new regulations and disperse the information to the public. With the forthcoming EPA stormwater rulemaking it is evident that stormwater management as we know it will change in a very significant way. Thus, adapting to these changes and leading by example is the most beneficial and progressive approach.

Audience

This series of fact sheets is primarily intended for developers, engineers, builders, contractors and homeowners who are interested in utilizing LID practices on land development and retrofit projects.

Scope

These fact sheets are intended to educate the user on the basic information about LID, with some in-depth information on Best Management Practices (BMPs) related to land use and development practices and pollution prevention. The user should be able to comprehend the purpose and function of LID practices and have a solid understanding of the steps to implement these types of practices on site. However, the manual design is intended to be used as guidelines for the construction, installation and maintenance of these practices. It is recommended that a Professional Engineer with experience in hydrology be utilized to prepare design specifications based on site soils, topography and water table depths, especially for larger installations. For further design guidelines, one can utilize the Oklahoma State University (OSU) Low Impact Development website (www.lid.okstate.edu) which has numerous useful documents that can be used in the preparation of site design, installation and maintenance of low impact development practices.

What is Stormwater Runoff?

Stormwater runoff is created when precipitation from rain and snowmelt flows over land or impervious surfaces and does not infiltrate into the ground. As the runoff flows over the land or impervious surfaces such as paved streets, parking lots, and rooftops, it accumulates debris, chemicals, sediment and other pollutants that can adversely affect water quality. In Oklahoma, the storm sewer system collects all stormwater runoff from rain and snowmelt events. The storm sewer system then discharges all the stormwater, and its accumulated pollutants, directly into our ponds, creeks, streams and lakes.

What is LID?

Low Impact Development (LID) is a stormwater management approach which seeks to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store and evaporate stormwater runoff at or close to its source. Unlike traditional stormwater infrastructure that solely conveys runoff through a large system of underground pipes, LID addresses stormwater runoff through a variety of landscape practices and designed systems which preserve natural drainage features and infiltrate or capture stormwater runoff. LID can be applied to new development, redevelopment, or as retrofits to existing development. LID has been adapted to a range of land uses from high density ultra-urban settings to low density development (U.S. EPA 2007).

The following are short descriptions of the practices discussed in this manual.

Rain Gardens and Bioretention Cells are essentially excavated areas in the landscape that are filled with compost amended sorted sand and planted with water and drought tolerant plants that allow infiltration of stormwater runoff into the subsoil.

Rainwater Harvesting is the practice of capturing stormwater runoff, often from rooftops, and storing the water for later use for such activities as irrigation, livestock watering, flushing toilets, or washing clothes.

Pervious Pavement utilizes pavers, pervious concrete, or pervious asphalt to allow water to infiltrate through the pavement instead of running off and washing off pollutants into surface waters.

Natural & Engineered Wetlands are similar to bioretention cells, but with poorer draining subsoil which causes more ponding and growth of plants capable of flourishing in wet conditions.

Green Roofs are vegetated layers that sit on top of the conventional waterproofed roof surfaces of a building.

The LID concept began in 1990 in Prince George's County, Maryland as an alternative to traditional stormwater best management practices installed at construction projects. Prince George's County Department of Environmental Resources (PGDER) found that traditional practices such as detention ponds and retention basins were not cost-effective and the results did not meet water quality goals (PGDER 1997). Today there are case studies available from across the country which reflect the acceptance and viability for using these types of practices.

Urbanization & Water Quality

As cities become more urbanized, the amount of impervious surface area increases. This occurs as cropland, pastureland and forests are converted to housing developments, shopping centers and business districts. The result is that natural surface cover such as trees, grass and plants is replaced by rooftops, roads and parking lots. Undeveloped areas allow stormwater to infiltrate the soil, while developed areas have far less trees and grass for the stormwater to infiltrate. Therefore, to prevent flooding, cities must provide a collection system for the increased stormwater runoff. Figure 1 is a general illustration of how land development, on average, can increase stormwater runoff 45%.

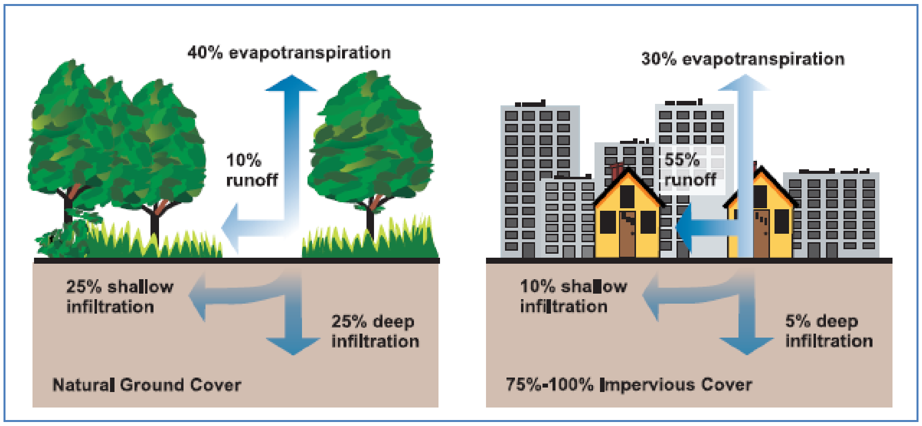

Figure 1: Runoff diagram comparing natural ground cover to 75-100% impervious cover
Source: (U.S. EPA 2010)

It should be noted that the percentages shown in Figure 1 are generalizations. In Oklahoma the climate and soils vary from West to East. As a result, the percentage of water that goes to each portion of the water budget varies as well. This is demonstrated in Table 1 using data adapted from the Water Atlas of Oklahoma for data from 1970-1979 (the most recent summary of its kind).

Table 1: Typical Oklahoma annual water balance

Texas County, OK		
Precipitation:	17 inches	
Runoff:	0.3 inches	2%
Evapotranspiration:	16.6 inches	97%
GW Recharge:	0.1 inches	1%
Oklahoma County, OK		
Precipitation:	33 inches	
Runoff:	4.5 inches	14%
Evapotranspiration:	27.7 inches	84%
GW Recharge:	0.8 inches	2%
McCurtain County, OK		
Precipitation:	54 inches	
Runoff:	18 inches	33%
Evapotranspiration:	28 inches	52%
GW Recharge:	8 inches	15%

Source: (Adapted from Pettyjohn 1983)

This information is useful for selecting the appropriate LID practice for different parts of the state. In the western part of Oklahoma where there is less rainfall, less runoff and high evapotranspiration rates, rainwater harvesting is an ideal practice to conserve water. However, in the east, there is a large amount of runoff that would indicate that rain gardens, pervious pavement, and other practices that encourage infiltration could further benefit groundwater recharge and reduce runoff. In central Oklahoma a combination of practices would be ideal, depending on site location. It should be noted, however, that that all LID practices can be beneficial in all areas of the state. Urban developments include impervious surfaces, disturbed soils, and managed turf grass which can have multiple impacts on water quality and aquatic life. Urban development also impacts the hydrograph of urban streams (Figure 2). Compared to the pre-development hydrograph, post-development stormwater discharges can increase the runoff volume, increase the peak discharge, and decrease the infiltration of stormwater, which thereby decreases base flow into streams and aquifers. These changes to stream hydrology result in negative impacts on water quality and quantity. Common problems associated with traditional development includes stream bank scouring and erosion, loss of wildlife habitat for macro invertebrates, fish, and other non-aquatic organisms, decreased storage in lakes due to sedimentation and lost recreational opportunities.

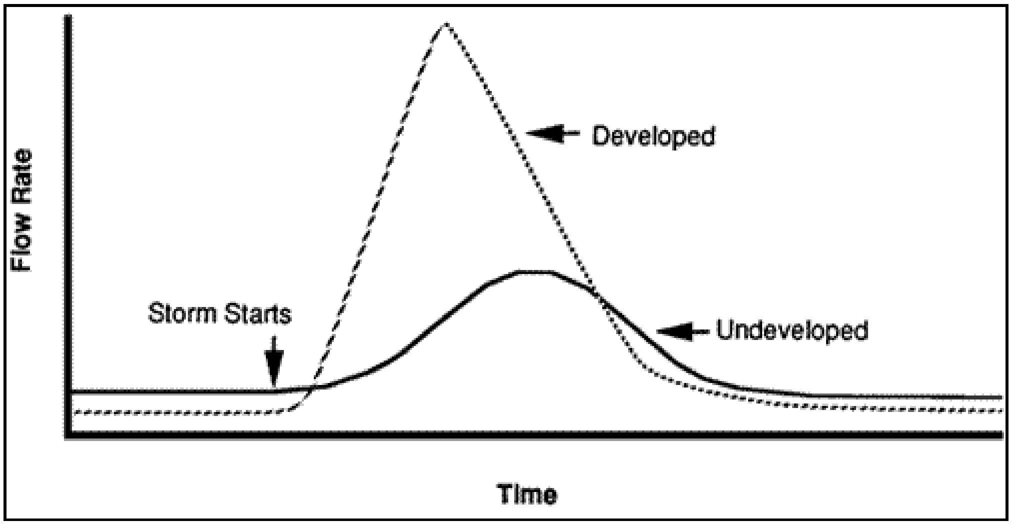

Figure 2: Typical hydrograph for an undeveloped and developed watershed
Source: (Annis Water Resources Institute, undated)

To deal with the harmful effects of stormwater runoff, the EPA began regulating certain groups. Polluted stormwater runoff is transported through Municipal Separate Storm Sewer Systems (MS4s), from which it is discharged untreated into local water bodies. The regulatory definition of an MS4 is "a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains owned or operated by a state, city, town, borough, county, parish, district, association, or other public body" (U.S. EPA 2007). In common terms, MS4s can include municipalities and local sewer districts, state and federal departments of transportation, universities, hospitals, military bases, and correctional facilities (U.S. EPA 2007). The Stormwater Phase II Rule added federal systems, such as military bases and correctional facilities by including them in the definition of small MS4s. Polluted stormwater can also be in agricultural areas or in small communities that are not designated as MS4's.

To prevent harmful pollutants from being washed or dumped into an MS4, operators must obtain a National Pollutant Discharge Elimination System (NPDES) permit and develop a stormwater management program. The NPDES program is a requirement under the Clean Water Act. The NPDES MS4 permits provide more detailed requirements that MS4s must meet. In response to these permit requirements; MS4s create Stormwater Management Plans that describe the measurable goals and activities that the MS4 must meet to stay in compliance with their permit. Some states also have developed post-construction standards and/or stormwater guidance manuals to implement the stormwater regulations. Within the program, there are currently two types of regulated communities, Phase I & Phase II communities.

- Phase I, issued in 1990, requires cities or certain counties with populations of 100,000 or more to obtain NPDES permit coverage for their stormwater discharges.
- Phase II, issued in 1999, requires regulated small MS4s in urbanized areas, as well as small MS4s outside the urbanized areas that are designated by the permitting authority, to obtain NPDES permit coverage for their stormwater discharges.

An urbanized area is a land area comprising one or more places, central place(s), and the adjacent densely settled surrounding area, urban fringe, that together have a residential population of at least 50,000 and an overall population density of at least 1,000 people per square mile (U.S. EPA 2007). The MS4 Program contains 6 required elements called Minimum Control Measures (MCMs) that, when implemented, should result in a significant reduction in pollutants discharged into receiving waters. MCM number 5 is relevant in the discussion of LID. These MCMs include:

- Public Education and Outreach
- Public Participation/Involvement
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-Construction Runoff Control
- Pollution Prevention/Good Housekeeping

Each of the MCMs except for illicit discharge detection and elimination have aspects that are relevant to LID implementation or education. Since the inception of the NPDES Program regulated communities across the country are increasingly viewing stormwater management as an opportunity to improve the environment, create attractive public and private spaces, engage the community in environmental stewardship, and remedy inadequate stormwater controls.

Oklahoma Climate

"Oklahoma lies entirely within the drainage basin of the Mississippi River. The two main rivers in the state are the Arkansas, which drains the northern two-thirds of the state, and the Red, which drains the southern third and serves as the state's southern border. Principal tributaries of the Arkansas are the Verdigris, Salt Fork, Grand (Neosho), Illinois, Cimarron, Canadian and North Canadian. The Washita and Kiamichi serve as the

Red's principal tributaries in Oklahoma, with the Little River flowing into the Red after it crosses into Arkansas." (Oklahoma Climatalogical Survey 2010).

The State of Oklahoma receives an average annual precipitation of 36 inches. Although precipitation is quite variable on a year-to-year basis, average annual precipitation ranges from about 17 inches in the far western panhandle to about 56 inches in the far southeast (Oklahoma Climatological Survey 2002). The rainfall distribution for Oklahoma is shown in Figure 3 below. As indicated by the data shown in Figures 3 and 4, the rainfall in Oklahoma is actually well spread out over the seasons and does not come in only one short period of the year. Figure 5 shows the spatial distribution of rainfall, which decreases from east to west. LID techniques are well suited to this type of rainfall distribution. However, depending on the duration and frequency of periods of drought, watering might be needed on certain vegetative practices.

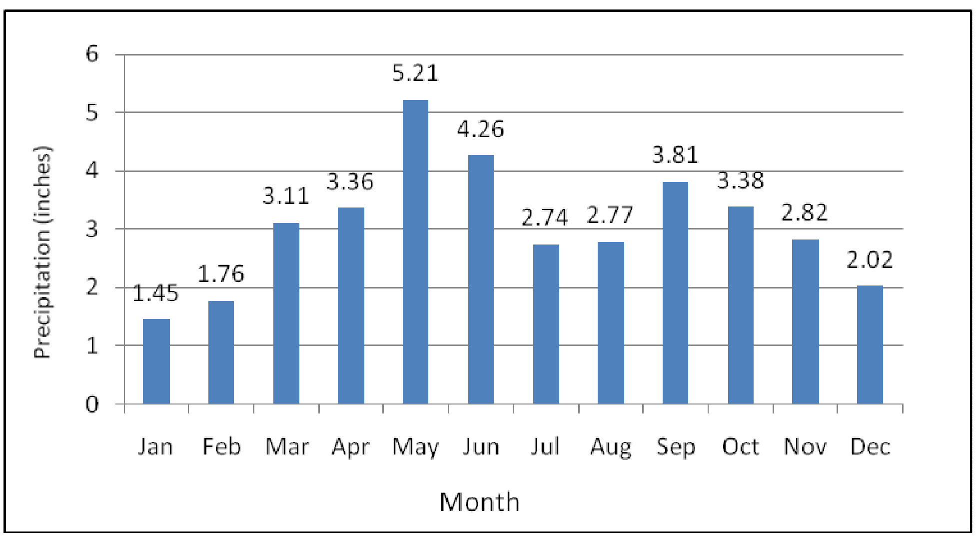

Figure 3: Oklahoma average precipitation by month
Source: (Oklahoma Climatological Survey 2004)

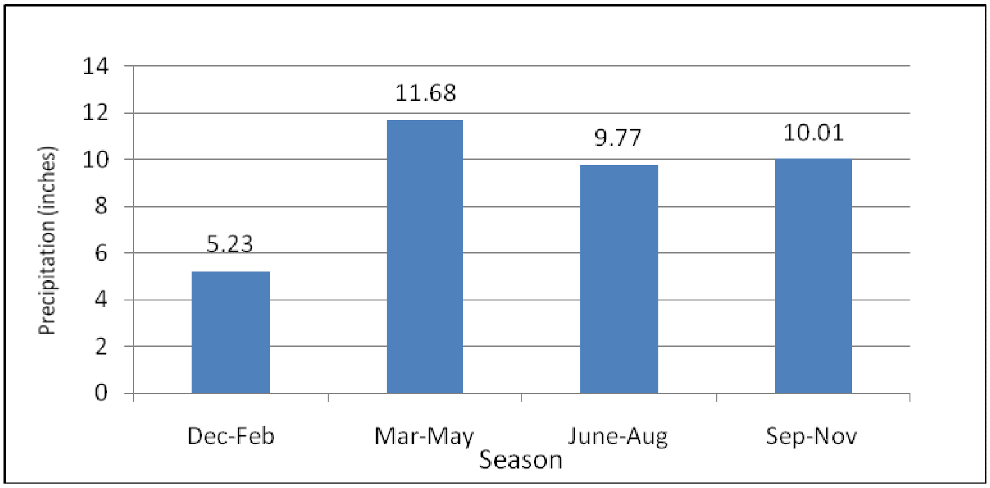

Figure 4: Oklahoma average rainfall by season
Source: (Oklahoma Climatological Survey 2004)

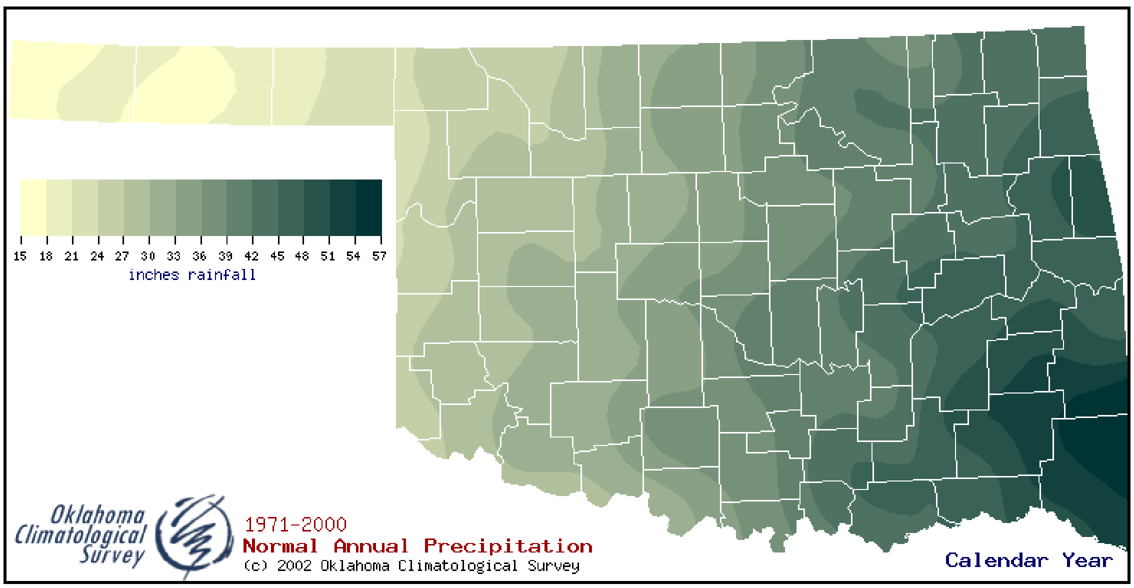

Figure 5: Oklahoma's average annual precipitation
Source: (Oklahoma Climatological Survey 2002)

How Does LID Help Oklahoma?

In recent years, many stormwater programs across the nation have become more sophisticated and environmentally friendly by incorporating streambank protection, groundwater recharge, protection of sensitive receiving waters, control of the overall volume of stormwater runoff, and use of natural systems and site design techniques to control runoff. Since Oklahoma is regulated under the NPDES program, LID can help communities meet challenging regulations to improve water quality that are very difficult to achieve using traditional methods for handling stormwater. Table 2 lists the current regulated MS4s in Oklahoma that may benefit from LID:

Table 2: List of regulated MS4s in Oklahoma

Altus	Noble	Spencer
Bartlesville	Norman	Stillwater
Bethany	Oklahoma City	Tahlequah
Bixby	Oklahoma County	The Village
Broken Arrow	OK Dept. of Transportation	Tinker Air Force Base
City of Catoosa	Oklahoma Turnpike Authority	Tulsa
Choctaw	Okmulgee	Tulsa County
Claremore, City of	Owasso	University of Oklahoma
Comanche County	Ponca City	Wagoner County
Coweta	Rogers County	Warr Acres
Creek County	Sand Springs	Yukon

Source: (ODEQ 2011)

More specifically, some of the benefits to adopting LID practices include:

Cost Savings- Cost savings can be achieved by using fewer materials, less labor and less land area.

Enhanced Groundwater Recharge - The natural infiltration capability of LID technologies can improve the rate at which groundwater is replenished. Allowing stormwater to infiltrate the soil and bedrock provides more water to private and public water wells (U.S. EPA undated).

Habitat Protection- conservation easements, riparian buffers, urban forests, wetlands and water quality improvements, achieved by decreased runoff, protects wildlife habitat (U.S. EPA undated).

Improved Air Quality – LID facilitates the incorporation of trees and vegetation in urban landscapes, which can contribute to improved air quality. Trees and vegetation absorb certain pollutants from the air through leaf uptake and contact removal. If widely planted or preserved throughout a community, trees and plants can even cool the air and slow the reaction that forms smog (U.S. EPA undated).

Improved Human Health – A number of scientific studies conducted by faculty and graduate students at the University of Illinois at Urbana-Champaign suggest that vegetation and green space, two key components of LID, can have a positive impact on human health. Their research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders (University of Illinois at Urbana-Champaign 2010).

Increased Land Values –LID can increase surrounding property values. This is achieved by the fact that lots near a water feature, open space area or natural feature have higher values (MacMahon 2008).

Reduced Energy Demands – Trees and vegetation have a natural cooling effect. By providing increased amounts of urban green space and vegetation, LID can help mitigate the effect of urban heat islands and reduce energy demands. Trees, green roofs and other green infrastructure can also lower the demand for air conditioning energy, thereby decreasing emissions from power plants (U.S. EPA undated).

Reduction in Streambank Erosion - By using practices that infiltrate stormwater rather than pipe it to a creek, the runoff is reduced and therefore less stream erosion occurs. This is achieved by reducing the total water volume entering waterways.

Water Conservation – Rainwater harvesting through the use of rain barrels and cisterns can result in a decrease in municipal or well water usage.

Water Quality Improvements – When stormwater runoff is reduced, less water is available to transport pollutants in its path to nearby surface waters. Once runoff soaks into soils, plants and microbes can naturally filter and breakdown many common pollutants found in stormwater.

Table 3: Pollutant removal rates among low impact development practices

	Quantity Control	TSS Removal Efficiency	TN Removal Efficiency	TP Removal Efficiency	Fecal Removal Ability	High Temperature Concern
Bioretention	Possible	85%	35%	45%	High	Med
Stormwater wetlands	Yes	85%	40%	35%	Med	High
Wet detention basin	Yes	85%	25%	40%	Med	High
Sand filter	Possible	85%	35%	45%	High	Med
Filter strip	No	25-40%	20%	35%	Med	High
Grassed swale	No	35%	20%	20%	Low	Low
Restored riparian buffer	No	60%	30%	35%	Med	Low
Infiltration devices	Possible	85%	30%	35%	High	Low
Dry extended detention basin	Yes	50%	10%	10%	Med	Med

Source: (Glen 2008)

As Table 3 indicates, some LID practices can benefit Oklahoma through water-quantity control and by improving water quality.

Summary

As stormwater runoff occurs, pollutants are transported to our waterways resulting in impaired waterways. LID seeks to manage rainfall where it occurs instead of piping it away from sites. When stormwater is infiltrated it allows a variety of benefits to be achieved. Some of these benefits include groundwater recharge, aesthetic value, wildlife habitat, nutrient uptake and water conservation just to name a few. In Oklahoma, our climate and topography are ideal for all the implementation of all types of LID practices. As Federal, State and municipal stormwater regulations seek to improve water quality, LID is one part of the solution.

CHAPTER III

COST COMPARISON OF LOW IMPACT DEVELOPMENT TO CONVENTIONAL STORMWATER MANAGEMENT PRACTICES

Numerous benefits can be achieved through the installation of low impact development (LID) techniques for stormwater control during both new construction and retrofitting projects. The following is a comparison of LID to conventional development practices. Topics to be compared are cost, lot value, aesthetic appeal, water quality, compliance, and operations and maintenance. We will begin by first defining the two types of stormwater management practices:

Low Impact Development (LID) is a stormwater management approach that seeks to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store and evaporate stormwater runoff at or close to its source. This method addresses stormwater runoff through a variety of landscape practices and designed systems which preserve natural drainage features and infiltrate or capture stormwater runoff (U.S. EPA 2007).

Conventional Stormwater Infrastructure: is generally comprised of an underground system of pipes that solely conveys stormwater runoff to the nearest stream, river or lake. These systems are technically called storm sewer systems. However, unlike the sanitary sewer system which sends the water to a treatment plant, a storm sewer system does not convey the water to a treatment plant, but rather sends it directly to the nearest waterbody without treatment.

Changing Perceptions

For a developer or builder one of the most important factors in determining whether or not an LID design is right for a construction project is the overall cost of implementing this type of project. Many feel that LID is expensive and simply ineffective. This might have been true 20 years ago when stormwater was seen as a waste product and the top priority was moving it from the landscape to a stream as quickly as possible to prevent flooding. However, in the past two decades LID has been implemented on an increasingly widespread scale and projects have been completed in many states, major cities and small towns across the United States. In light of the United States Environmental Protection Agency's (EPA) current proposed stormwater rulemaking, LID will likely become the new way of doing business in the development industry.

As of March 2011, the EPA is considering establishing specific requirements to control stormwater discharges from new development and redevelopment (U.S. EPA 2010). In addition the EPA is looking at requiring communities with more that 10,000 residents and over 1,000 people per square mile (and some other urbanizing areas as sensitive watershed and state departments of transportation) to address stormwater discharges in areas of existing development through retrofitting the sewer system or drainage area with improved stormwater control measures (U.S. EPA 2010).

To accurately depict the true cost of LID vs. traditional development, all aspects of a project from planning through construction and into post construction should be considered. One of the most significant reductions in cost is achieved by using less traditional stormwater infrastructure such as pipe, curbs, gutters, storm drains and on-site detention. This is due to the fact that LID infrastructure has the ability to infiltrate, evaporate, or reuse stormwater, reducing the need for large amounts of traditional infrastructure. In most cases flood control will still require the construction of a detention pond, but the size will be reduced. The use of LID practices also often results in less labor cost and fewer heavy equipment expenses during construction. This is due to the fact that less and smaller infrastructure does not require as many heavy equipment operators and manual laborers.

Cost Comparisons

While the examples provided below are not specific to Oklahoma, they illustrate the typical cost difference between the two methods of development. While these locations differ from Oklahoma in geography and demographics they face the same obstacles with their implementation. Project costs will vary based on the soil, topography and existing vegetation among other factors specific to the site. Table 4 shows the range of costs for construction and maintenance for several LID practices. It also includes the lifespan range for these practices. This information can be used when deciding which practice to implement.

Table 4: Cost estimates for LID practice construction, maintenance and lifespan

LID Practice	Construction Cost Range	Maintenance Cost Range	Lifespan Range
Rain Gardens	\$5.15 to \$16.05/ ft^2	\$0.31 to \$0.61/ft^2	25 to 50 years
Bioretention Cells	\$5.50 to \$24.00/ ft^2	\$0.06 to \$0.21/ft^2	20 to 50 years
Rain Barrels	\$0.72 to \$2.54/ gallon	\$0.00 to \$0.00/gallon	20 years
Cisterns	\$0.61 to \$2.88/gallon	\$0.00 to \$.07/gallon	20 to 50 years
Pervious Concrete	\$5.50 to \$11.60/ft^2	\$0.09 to \$0.23/ft^2	20 to 40 years
Pervious Asphalt	\$5.50 to \$\$8.13/ft^2	\$0.09 to \$0.23/ft^2	20 to 40 years
Pervious Pavers	\$5.30 to \$12.00/ft^2	\$0.10 to \$0.23/ft^2	15 to 50 years
Green Roofs	\$8.75 to \$31.80/ft^2	\$0.20 to \$0.41/ft^2	25 to 50 years

Source: (Adapted from CNT 2009)

Table 5 shows the results of an EPA study comparing actual LID projects throughout the United States. In general, the study demonstrates that LID practices can reduce project costs and improve environmental performance. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with one exception in which LID project costs were higher than conventional stormwater management costs. In a few case studies, initial project costs were higher than those for conventional designs; but in most cases, significant savings were realized due to reduced costs for grading and preparation, stormwater infrastructure, paving, and landscaping.

Table 5: Cost comparison of conventional development to low impact development

Project	Location	Conventional Development Cost	LID Cost	Cost Difference	Percent Difference
Bioretention	Seattle, WA	$869,000	$652,000	$217,000	25%
Open space preservation, Wetlands	Southwestern WI	$2,360,000	$1,599,000	$761,000	32%
Rain Gardens	Bellingham, WA	$28,000	$6,000	$22,000	80%
Rain Gardens	Bellingham, WA	$53,000	$13,000	$40,000	76%
Open space preservation	Sherwood, AR	$4,621,000	$3,942,000	$679,000	15%
Wetland, Bioretention, Pervious pavement	Pierce County, WA	$324,000	$261,000	$64,000	20%
Wetlands, Pervious pavement, Rainwater harvesting	Pierce County, WA	$766,000	$1,503,000	$-737,000	-96%
Open space preservation, Bioretention	Jackson, WI	$1,654,000	$1,150,000	$504,000	30%
Open space preservation, Swales	Kane County, IL	$12,000	$9,000	$3,000	27%
Bioretention, wetlands	Germantown, WI	$1,004,000	$600,000	$405,000	40%
Bioretention	Prince George's County, MD	$2,457,000	$1,671,000	$785,000	32%
Bioretention, Wetlands	Naperville, IL	$3,162,000	$2,800,000	$462,000	15%

Source: (U.S. EPA 2007)

In all cases, LID provided other benefits that were not monetized and factored into the project bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales. The projects also provided other environmental benefits such as reduced runoff volumes and pollutant loadings to downstream waters, and reduced incidences of combined sewer overflows (U.S. EPA 2007).

In 2008 the Houston Land/ Water Sustainability Forum (http://www.houstonlwsforum.org/) conducted an LID design competition (HLWSF, 2008). The following objectives drove the competition:

- Leverage ongoing educational efforts into real world experience
- Attract the attention of wider audience
- Recognize those who are prepared to deliver new ideas and methods
- Resolve the ‘chicken or the egg’ syndrome
- Prevent more ‘missed opportunities’ in LEED projects

The results of the competition were phenomenal and in total there were 230 professionals from 42 design firms that competed. The following were the requirements for the competition.

- Used real properties with challenging conditions
- Allows reusable design and viable LID adaptations
- Required dramatic post-development runoff reduction
- Below pre-development curve (5 yr, 10 yr, 100 yr event)
- Required cost comparison of LID to Traditional
- Provides viable numbers for value comparison

The cost comparison for the residential design winner is shown below in Table 6. Note that the majority of savings came from reducing channel excavation, reducing paving and reducing detention excavation.

Table 6: Houston low impact development design competition winner cost estimate

	Acres	LID Design Costs	Conventional Design Costs
Residential Pods			
50 foot lots	43.6	$ 2,095,000	$ 2,180,000
60 foot lots	111.4	$ 5,403,000	$ 5,570,000
70 foot lots	45.7	$ 2,193,000	$ 2,285,000
Residential pods Sub Total		**$ 9,691,000**	**$10,035,000**
Trunk Facilities			
Clearing and Grubbing		$ 70,000	$ 70,000
Water Distribution System		$ 229,000	$ 229,000
Water Plant		$ 1,500,000	$ 1,500,000
Water Interconnect		$ 400,000	$ 400,000
Wastewater Treatment Plant		$ 2,000,000	$ 2,000,000
Wastewater Collection System		$ 559,000	$ 559,000
Stormwater Collection System		$ 152,000	$ 152,000
Drainage Channel Excavation		$ 704,000	$ 3,494,000
Excavation and Paving		$ 1,267,000	$ 2,731,000
Construction Staking Services (2.5%)		$ 154,000	$ 210,000
Trunk Facilities Sub Total		$ 7,035,000	$11,345,000
PRELIMINARY CONSTRUCTION COSTS TOTAL		**$16,726,000**	**$21,380,000**

Source: (HLWSF 2008)

In some circumstances LID techniques may result in higher costs due to more expensive plant material, site preparation, soil amendments, as well as increased project design costs. The cost of LID practices is often dependent on the experience of the project engineers, and installation contractors. However, materials are getting better and less expensive as the market for these products expands. It is also important to consider differences in maintenance requirements between LID and conventional development.

Economic Benefits of LID

Studies have shown that LID practices can provide a number of economic benefits that reduce the total development cost. From an economic standpoint, recent studies contradict the notion that LID is always more expensive than conventional development. In fact, case studies indicate a significant reduction in development costs may result when compared to conventional techniques. A study done by Ed MacMullen, a Senior Economist with EcoNorthwest shows the following:

- 10% to 15% increase in property value adjacent to an urban greenway.
- Increase in property value associated with more tree canopy coverage.
- 9% to 24% increase in property value adjacent to cleaner water bodies.

(MacMullen 2008)

A developer that used LID techniques in a residential subdivision sold lots for $3,000 more than lots in competing areas that did not use LID (Lehner and others, 1999). Research from Rhode Island shows conservation subdivisions can be more profitable to developers than conventional subdivisions. Results of the research (Mohamed 2006) show that lots that use LID can:

- be sold for 12-16% more per lot,
- cost an average of $7,400 less to develop,
- be sold in about half the time of conventional lots, and
- provide ecological benefits that translate into greater resident satisfaction.

LID provides important benefits to the municipality, the developer, and the general public. More concentrated (cluster) design, with less impervious area and smaller infrastructure (stormwater drainage and other utilities), means significant cost savings to developers and reduces maintenance costs for municipalities. Figure 6 below illustrates the concept of cluster design. This layout allows for the same number of lots, while providing up to 50% open space, a lower percentage of impervious surface and protection of water resources.

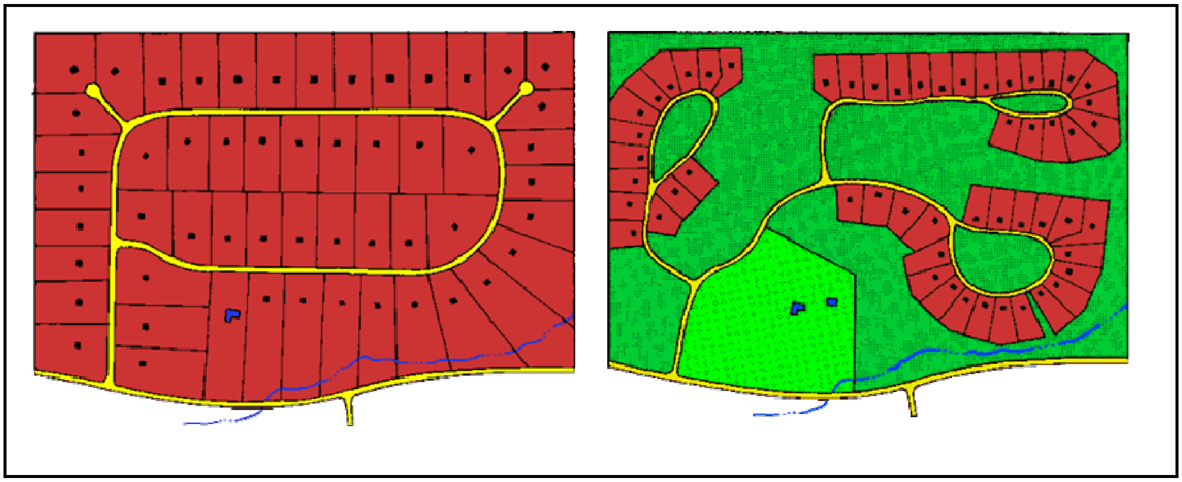

Figure 6: Different layout between conventional subdivision and conservation subdivision
Source: (Arendt 1996)

Water Quality Benefits of LID

Stormwater runoff can carry with it over-applied fertilizers, oil from leaking vehicles, sediment from construction sites, heavy metals from brake pads, and bacteria from sanitary sewer overflows and pet waste among many other pollutants from countless sources. This is due to the large amount of impervious surfaces that are present which prevents water from infiltrating and filtering out these pollutants. However, when stormwater runoff is able to infiltrate the soil, it allows these pollutants to be filtered out and prevented from entering our water bodies. With LID creating more permeable surfaces, this is an instant benefit to water quality.

LID practices can provide a variety of economic, social and ecological values. Ideally, the inherent value of these services will guide management and policy decisions regarding the use and preservation of ecosystems (Moore and Hunt 2011).

A good framework for calculating the monetary value of the water quality benefits provided by LID and other green infrastructure is provided in The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental, and Social Benefits by the Center for Neighborhood Technology (CNT 2010).

Operations and Maintenance

Maintenance of stormwater management practices can be classified into two categories: aesthetic/nuisance maintenance and functional maintenance. Functional maintenance is important for performance and safety reasons, while aesthetic maintenance is important primarily for public acceptance of LID practices, and because it may also reduce needed functional maintenance. Aesthetic maintenance is obviously more important for practices that are highly visible, such as ponds and bioretention facilities. In most studies, operation and maintenance costs have been estimated as a percentage of base construction costs. While some practices require infrequent, costly maintenance, others need more frequent but less costly maintenance. The selection of appropriate practices must consider maintenance costs to effective long-term performance of the system. (EOR, undated).

It is also important to recognize the fact that regular maintenance is vital to the success of these practices. In a residential setting, the maintenance will most likely be the responsibility of the homeowner. This can create problems when the property is sold and new owners take possession. It is for this reason that maintenance agreements are important to include from the onset of project development. In some locations the Homeowners Association is responsible for maintenance. Another option is for the municipality to be responsible, but the most common practice is for the homeowner to have a maintenance agreement with the city in which they live. For maintenance programs to be effective and complete, stakeholders must realize that there are several parties, such as real estate agents, homebuilders, developers, homeowners and landscape companies among others, that are crucial to the success of these practices. See Appendix

A for a sample maintenance agreement from the City of Kirkland, Washington or visit the following website:

http://www.kirklandwa.gov/Assets/Public+Works/Public+Works+PDFs/Pre Approved+Plans/D-7+Declaration+of+SW+Facility+Maintenance.pdf

This agreement can be customized to fit a variety of maintenance responsibility scenarios. Operations and Maintenance for specific BMPs are discussed in other fact sheets in the OSU LID fact sheet series.

Summary

The LID approach is very different than the traditional way of handling stormwater runoff. These differences are seen in the design, installation, maintenance, costs and benefits. LID is generally less expensive, provides more and a broader range of benefits and fewer maintenance activities. However, the design and installation of LID practices is still evolving and careful selection of the right practices for the right site is advised. The best approach to deciding whether LID is right for you is to look at the overall costs and benefits between conventional development and low impact development.

CHAPTER IV

POLLUTANT SOURCE REDUCTION

Many everyday substances that stormwater can come into contact with have the potential to cause harm when they are handled and disposed of carelessly or improperly. Runoff pollution upsets the delicate balance of aquatic communities, forces fish and wildlife to find new habitat to survive, and ruins recreational opportunities. It is imperative to minimize the contact of pollutants with stormwater to help prevent runoff pollution. This fact sheet presents source reduction on the following topics.

- Composting
- Household Hazardous Waste (HHW)
- Illegal Dumping & Littering
- Lawn & Gardening
- Pet Waste
- Sediment Pollution

Composting

Yard trimmings and food residuals together constitute 23% of the U.S. municipal solid waste stream (U.S. EPA 2010). If these items were utilized in composting there would definitely be fewer trips to take out the trash. Composting is the controlled decay of food scraps and yard clippings to provide a useable product with a variety of environmental benefits. The number one benefit is the

Compost has the ability to help enrich nutrient starved soils and is a virtually free alternative to expensive soil amendments. "The composting process encourages the production of beneficial micro-organisms, mainly bacteria and fungi, which in turn break down organic matter to create humus. Humus, a rich nutrient-filled material, increases the nutrient content in soils and helps soils to retain moisture. Compost has also been shown to suppress plant diseases and pests, reduce the need for chemical fertilizers, and promote higher yields of agricultural crops (U.S. EPA 2010)."

Composting can also prevent harmful stormwater runoff pollution and flooding. Collecting leaves and grass clippings for composting prevents them from entering our storm sewer system. By using compost, the need for additives like fertilizers and pesticides may be reduced. By composting, fewer leaves and grass clippings are present to clog the storm drains and pipes.

Composting is easy to do. Common materials like chicken wire, bricks and buckets are the materials needed to begin composting, which can be done either indoors or outdoors. Maintenance doesn't have to be difficult either; the regular mixing or turning of the compost pile and a little water will ensure success. For more information on composting, see the following Extension Publications: BAE 1742, BAE 1744, HLA 6402, PSS 2911, L 252

Household Hazardous Waste (HHW)

Thanks to today's chemical advances, chores around the house have never been easier. Not all, but many household cleaning and home improvement products can be very toxic if used or stored improperly. To keep our homes and environment safe, it is important that we use and dispose of these products in a responsible manner. Some products in your home (certain paints, stains and varnishes, cleaners, polishes, automotive products, pesticides and herbicides) can contain hazardous components. The unused or leftover portions of these products are known as "Household Hazardous Waste" or HHW.

If simply thrown in the trash, these items can contaminate our environment. This pollution can affect streams, lakes, wildlife and even our drinking water. Dumping hazardous products in the street or creek, down a storm drain or behind your fence can contaminate our soil and drinking water. Disposing of household chemicals in your trash is also dangerous. When these items are compacted in the garbage truck, chemical containers can break and their contents can mix. Depending on the chemicals involved, the resulting reaction may create toxic smoke, fumes, and fires, injuring those nearby and harming the environment.

Fortunately, many Oklahoma communities have recognized the dangers that these wastes pose to humans and the environment. Many cities or counties have disposal options available for residents by way of curbside service, drop off centers or annual collection events. Check with your local government to see what options are available to you. For more information on managing Household Hazardous products see the Oklahoma*A*Syst Assessment Worksheet # 5.

Illegal Dumping & Littering

You've seen it before…an old refrigerator or sofa lying on the side of the road (Figure 7). Unfortunately, open dumping occurs every day in Oklahoma. But what exactly is open dumping? It is the disposal of solid waste at any location other than a Department of Environmental Quality (DEQ) permitted facility. Solid waste includes but is not limited to trash, grass clippings, used motor oil, household items, furniture, building materials and demolition debris. Once something is dumped, people tend to forget that chemicals and other contaminants found in solid waste can be carried by stormwater to creeks and rivers that provide essential wildlife habitat. These contaminants can also seep into our groundwater, rivers and lakes which are all sources of drinking water. Our waterways are a valuable resource for drinking water, recreation and wildlife habitat. Once a waterbody becomes polluted by litter, it can affect wildlife like birds, fish and other animals. What many people don't realize is that wildlife can mistake litter for food and can choke on it or become tangled in it, resulting in death. But

Figure 7: Illegal roadside dumping in Oklahoma

animals are not the only concern with trash pollution. Litter can carry germs and diseases that affect humans.

Not only is litter unattractive, it also stays around for a very long time. A cigarette butt takes 10 years to decompose, while aluminum cans take anywhere from 200 to 500 years (ODEQ 2004). There are several things that you can do to prevent littering. These tips include:

- Avoid discarding trash in truck beds as it can easily blow out
- Close the lid on your garbage containers
- Dispose of cigarette butts by using an ash receptacle, not the ground
- Hold onto your litter until you can put it in a trash container
- Keep a litter bag in your vehicle
- Never dump anything into a stormdrain
- Secure truck beds with a tarp or tie materials down
- Set an example - don’t litter and teach your children the importance of respecting our environment

Did you know that The State of Oklahoma spends 3.3 million dollars annually on picking up litter on the highway system (ODOT undated) If you would like to become a solution to this problem contact your local government to find out what type of events and volunteer programs are available. Many local governments offer Adopt-A-Street programs that involve picking up trash on the volunteers’ choice of street at a certain annual frequency. The Oklahoma Department of Transportation also offers similar

Adopt-A- Highway programs and the Annual Trash Off event in April. It is only with the cooperation of all Oklahomans that this difficult problem can be solved**.**

Lawn and Gardening

A picture perfect lawn is something almost every homeowner desires, each for their own purposes. But did you know that your lawn and how you take care of it can also help the environment? To have a beautiful lawn and productive garden, sometimes it is necessary to use inputs like fertilizer and pesticide. However, putting fertilizer or pesticide on your driveway will not help it grow (Figure 8). It will however, contribute to water quality pollution in the stormwater coming from your property.

All plants need 16 essential nutrients to grow and most of them come from the soil. When lawns and gardens do not receive the nutrients needed, they never achieve the quality or productivity anticipated. However, when too much fertilizer is applied, nutrients are wasted and pose a threat to the environment. A soil test is needed to identify the necessary fertilizer requirements for proper lawn care. A soil test is a chemical analysis that estimates a soil's ability to supply nutrients. The results from a soil test allow you to monitor soil chemical conditions, tap existing nutrient supplies, identify nutrient deficiencies, and apply optimum fertilizer amounts. In Oklahoma, the Oklahoma Cooperative Extension Service

Figure 8: Example of careless fertilizer application

offers soil testing for a fee. Based on results from your soil sample, your County Extension Office educator will provide you with the following information:

- How much fertilizer should be applied for each application
- The appropriate timing of each application
- Which fertilizer is best for your lawn or garden

While adding more of a nutrient than a lawn or garden needs can cost extra money and harm the plants, it also may degrade water quality. As stormwater flows over driveways, lawns, and sidewalks, it picks up fertilizers, pesticides, dirt, and other pollutants before entering our waterways. This type of runoff can be harmful to aquatic life, so it is important to only use the needed amounts of chemicals on your lawn. By taking this simple step before you apply fertilizer you will save money and prevent harmful runoff pollution. For more information on how to take a soil sample and where to send the sample visit: www.soiltesting.okstate.edu

Pesticides can help control many lawn pests, but pesticides have risks as well as benefits and it is important to use them properly. The chemicals we call pesticides include insecticides, herbicides and fungicides. These products are designed to kill or control pest insects, weeds, and fungal diseases.

Pesticides can be very effective, but don't be tempted to rely solely on pesticides as a quick fix solution to any lawn problem. Serious, ongoing pest problems are often a sign that your lawn is not getting everything it needs. In other words, the pests may be a symptom of an underlying problem. You'll want to correct the underlying problem to reduce the chance that the pest will reappear.

All pesticides are toxic to some degree. People and pets can become unintended victims if these chemicals are overused or applied carelessly. Try nontoxic or the least toxic methods and products first, including pruning and hand picking and setting baits and traps. If a pesticide must be used, spot treat the affected areas instead of widespread application, which can kill beneficial insects. When applying pesticides it is important to read the entire label and use only as directed. The old adage “more is better” doesn’t apply to pesticide application. In fact, your lawn and living creatures can only assimilate so much poison and the rest is simply wasted. For flea or tick infestation, it is a good idea is to use prescription flea drops for pets instead of treating an entire lawn.

Here are some options that can help you have a healthy lawn while also protecting the environment:

- Collect grass clippings and leaves for composting. Use the compost in your garden and flower beds.
- If you have a mulching mower, you can chop the leaves and grass into small pieces that will decompose directly into your lawn. If you have a bagger on your mower, you can use the chopped leaves in flowerbeds and around shrubs.
- Leaves can be tilled directly into a garden, contributing valuable organic matter.
- Sweep or blow excess fertilizer, grass clippings and soil back onto your lawn. Hosing down your driveway sends these pollutants directly into stormdrains that lead to our lakes and streams.

These are simple things that you can do to assure that your lawn is healthy and green while protecting the environment at the same time.

Pet Waste

Is your neighbor a lazy pet owner who pretends it isn't their dog that routinely leaves your lawn blemished with pet waste? Perhaps you are, in fact, guilty of walking the dog in the park and not wanting to be bothered with taking care of the dog's business because it's "gross". Either way, many Oklahoma cities have ordinances that require the removal of an animal's solid waste on public and private properties and provide pet waste bags for your use (Figure 9). Contrary to what many people believe, pet waste is not a fertilizer. Pet waste should not be left on lawns, streets or sidewalks. Every time it rains, there is potential for pet waste to wash down stormdrains and into streams, rivers and lakes.

Figure 9: Pet waste bag dispenser

In Oklahoma, excessive nutrients are a major cause of water quality decline. Pet waste contains nutrients that cause excessive weed and algae growth. Once in waterways, the decay of both the pet waste and the algae depletes oxygen in the water. Low oxygen levels kill fish and other aquatic life. Floating mats of algae make the water cloudy and green which is unattractive for recreational activities such as swimming and fishing. Harmful bacteria in pet waste can also threaten the health of people. Those most susceptible to infection are gardening adults and children who play outside a lot. Some of the diseases that can be transmitted from pet waste to humans are the following:

Cryptosporidiosis: Caused by a single-celled, microscopic parasite that lives in the intestines and can be present in high numbers in the stool of infected animals or people. People infected with *Cryptosporidium* may develop stomach cramps, diarrhea, vomiting and fever (AVMA 2009).

Salmonellosis: People with salmonellosis usually have diarrhea, stomach pain/cramps and a fever. They are usually ill for 4-7 days (AVMA 2009).

Hookworms and Roundworms: Roundworm infection in people can cause serious, even life-threatening, illness when the parasites enter the organs. Lung, liver or brain damage can occur. If they are eaten, they can cause intestinal problems (AVMA 2009).

Toxoplasmosis: Ingestion of infectious oocysts from soil or water contaminated with feline feces. Signs of illness include mild flulike symptoms such as fever, mild aches and pains, and enlarged lymph nodes for a short period of time (AVMA 2009).

Here are some general guidelines for handling pet waste properly:

- ❖ Always carry a plastic baggy to pick up your pet's waste when walking your pet.
- ❖ Dispose of pet waste by placing it in a garbage can or flushing it down a toilet.
- ❖ Never dispose of pet waste in a stormdrain or use it in a compost pile.
- ❖ Encourage your neighbors and other pet owners to be responsible.

Good neighbors care about keeping their environment healthy. Help keep Oklahoma's water clean by picking up after your pet.

Sediment Pollution

According to the EPA, sediment is the number one pollutant in the United States. Sediment and nutrients cause many of the problems we see in our waterways. Sediment is soil particles eroded from construction sites, lawns, streambanks (Figure 10) and cropland. When these particles are carried by stormwater to lakes and streams they cause the water to have increased turbidity which makes it difficult for fish to see and feed properly. The abrasiveness of sediment particles can also damage fish gills and

Figure 10: Streambank erosion in Oklahoma creek

cause fin rot, which ultimately leads to death. Aquatic insects can also have impaired feeding and breathing which ultimately interrupts the food chain.

Many fish and aquatic insects lay their eggs on gravel beds. When sediment is deposited on these beds, spawning habitat can be destroyed. Sediment clouds the water and covers plant leaves, reducing the amount of sunlight reaching desirable aquatic plants. Sediment can also create soft, unstable beds for plant roots that result in a decrease in food for other wildlife. In moving water abrasive particles can scour aquatic plants and animals, physically removing them from their habitat. The deposition of sediment into Oklahoma’s ponds, rivers and lakes can also decrease the storage capacity which is important for flood protection and navigation. Eventually, these waterbodies have to be dredged to restore their original capacity. Dredging is very costly and also has associated environmental concerns. The shallow water is also heated more efficiently by the sun, causing water temperatures to rise. Over time, cold water fish are replaced by warm water fish. Fertilizers, pesticides and oils can also become attached to sediment particles which increase the toxicity and detrimental effects of sediment pollution.

Signs of Erosion Include:

- Buildup of sediment in low areas
- Exposed tree roots, stones and rocks
- Formation of gullies
- Widening or deepening of stream channels

What You Can Do to Prevent Erosion:

- Choose plant and tree species that are appropriate for your climate and soil type. Native plants have deep root systems that protect soil from erosion.
- Do not garden on areas with steep slopes.
- Install erosion and sediment controls during construction projects.
- Sod or seed any bare soil on your property. Vegetative cover protects soil from rain drops and prevents erosion.
- Stabilize hills with trees or other plants.
- Use a rainwater harvesting system to collect water from downspouts

To prevent sediment deposition it is important to prevent erosion from occurring wherever possible. Erosion from agricultural fields and construction sites constitute the largest culprits, but fortunately it can be prevented if certain actions are taken (U.S. EPA

2005). Agricultural and range lands can employ no till technologies, terracing and crop rotation methods to prevent erosion. The USDA Natural Resources Conservation Service even provides cost-share incentives for producers to implement certain technologies that prevent erosion on private lands. The construction industry is currently regulated by the EPA and is required to implement certain Best Management Practices on site to prevent erosion and sediment deposition. For more information on preventing erosion on construction sites see Extension Fact Sheet BAE 1514. Homeowners are an integral part of the solution to improving our waterways and everyday actions by individuals can result in noticeable results. Since stormwater runoff is largely a problem in urban areas and urban creeks have been drastically changed due to the increased runoff rates and volumes one might find the following agencies helpful with grants and recommendations for the restoration of urban streams:

Oklahoma Conservation Commission

Oklahoma Department of Agriculture, Food & Forestry

Oklahoma Department of Environmental Quality

Oklahoma Department of Wildlife Conservation

Oklahoma Water Resources Board

US Corps of Engineers

US Environmental Protection Agency

USDA Natural Resources Conservation Service

For Additional Resources on Pollution Source Reduction, visit us on the web at:

http://lid.okstate.edu/source-reduction

CHAPTER V

RAIN GARDENS AND BIORETENTION CELLS

What is the difference between a bioretention cell and a rain garden? In general it is generally considered an issue of scale. If you need a machine to excavate it, it is a bioretention cell.

Rain gardens and bioretention cells are landscape features designed to capture stormwater runoff from impervious areas such as roofs, driveways and parking lots and allow it to slowly seep into the ground. This helps to filter out pollutants including fertilizers, pesticides, oils, heavy metals and other chemicals that are carried with the rainwater that flows across lawns, rooftops, driveways, and streets. Rain gardens and bioretention cells also reduce peak storm flows, helping to reduce flooding and prevent stream bank erosion. These systems create an attractive landscape with less watering while providing habitat for wildlife such as hummingbirds and butterflies. They also generally require less maintenance and fewer chemicals than lawns.

Fortunately, rain gardens can be a do-it-yourself project or if preferred landscape professionals can install these attractive features in your yard in just a matter of a day or two. The following is a guide to constructing both rain gardens and bioretention cells. The topics below will be covered:

- Installation
- Use of Native Plants
- Oklahoma Examples
- Costs
- Maintenance
- Limitations

Figure 11: Bioretention cell in Grove, Oklahoma

Rain Garden Installation

Rain garden installation on the landscape is dependent on a number of variables including soil infiltration capacity, slope, size and characteristics of the contributing drainage, expected local benefit, depth to ground water, and aesthetic considerations.

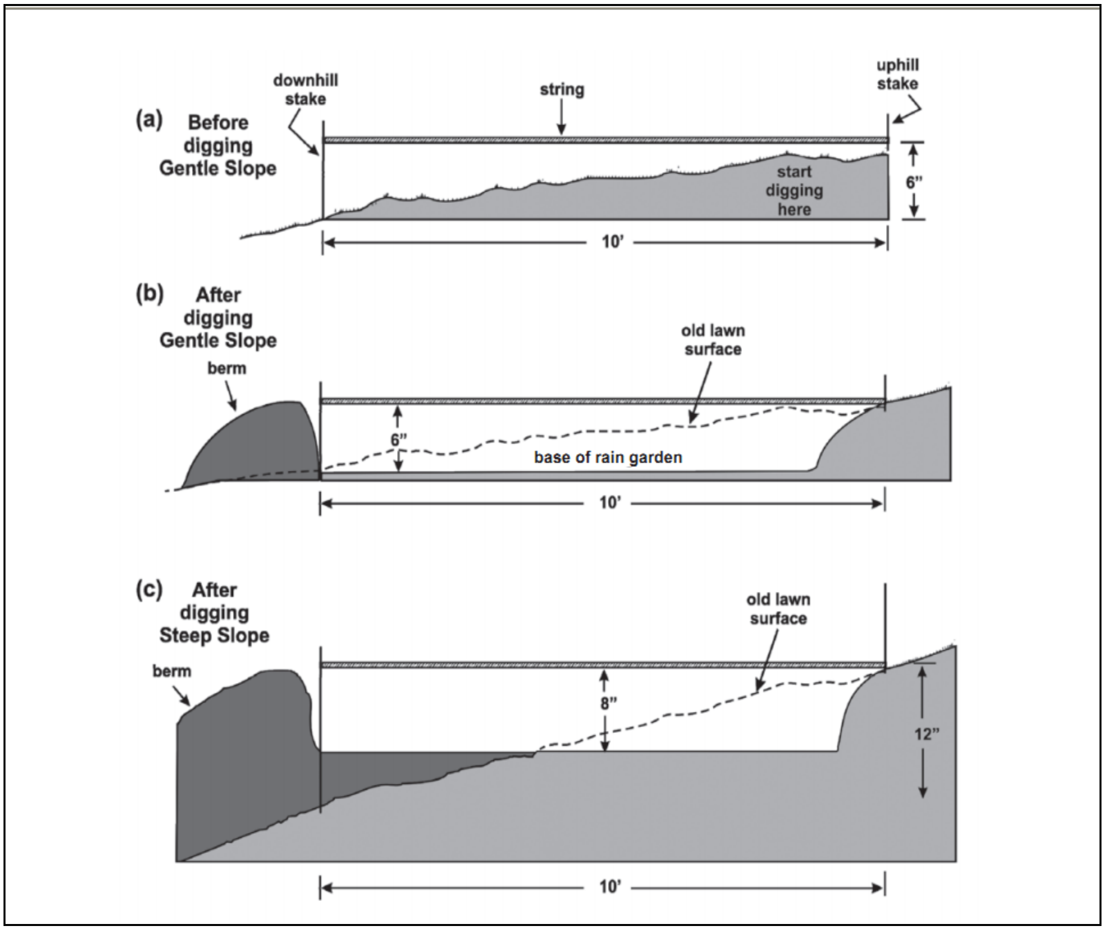

Figure 12: Rain garden slope diagram
Source: (Bannerman and Considine 2003)

Figure 12 illustrates how the slope of a lawn plays a role in the ultimate depth of a rain garden. This can be used as a general guide when constructing a rain garden. The first step before construction begins is to call OKIE to check for buried cables, pipes, or other public infrastructure. In Oklahoma, dial 811, or 800-522-6543.

Next, determine the size and depth of your rain garden. This can be achieved by using the following procedure:

The slope of the lawn should determine the depth of the rain garden. Find the slope of your lawn by following these steps.

A. Pound one stake in at the uphill end of your rain garden site and pound the other stake in at the downhill end. The stakes should be about 15 feet apart.

B. Tie a string to the bottom of the uphill stake and run the string to the downhill stake.

C. Using a string level or a carpenter's level, make the string horizontal and tie the string to the downhill stake at that height.

D. Measure the width (in inches) between the two stakes.

E. Now measure the height (in inches) on the downhill stake between the ground and string.

F. Divide the height by the width and multiply the result by 100 to find the lawn's percent slope.

If the slope is more than 12%, it's best to find another site or talk to a professional landscaper. Using the slope of the lawn, select the depth of the rain garden from the following options:

• If the slope is less than 4%, it is easiest to build a 3 to 5-inch deep rain garden.

• If the slope is between 5 and 7%, it is easiest to build one 6 to 7 inches deep.

• If the slope is between 8 and 12%, it is easiest to build one about 8 inches deep.

Having estimated the drainage area, soil type, and depth for your rain garden use the sizing factors in Table 7 below to determine the rain garden's surface area (Bannerman and Considine, 2003).

Table 7: Rain garden sizing factor chart

Rain gardens less than 30 feet from downspout.	3-5 in. deep	6-7 in. deep	8 in. deep
Sandy soil	0.19	0.15	0.08
Silty soil	0.34	0.25	0.16
Clayey soil	0.43	0.32	0.20

Rain gardens more than 30 feet from downspout.	Size Factor, for all depths
Sandy soil	0.03
Silty soil	0.06
Clayey soil	0.10

Source: (Bannerman and Considine 2003)

1. Find the ***size factor*** for the soil type and rain garden depth.

2. Multiply the ***size factor*** by the drainage area. This number is the recommended rain garden area.

3. If the recommended rain garden area is much more than 300 square feet, divide it into smaller rain gardens. If a rain garden is larger than 300 square feet it takes a lot more time to dig, is more difficult to make level, and could be hard on your budget.

4. If you would prefer to have more storage volume in the rain garden, more excavation and fill can be done.

Locate a spot that is a depressed area in your yard and at least 10 feet from your home's foundation and perform a percolation test to determine how much water will infiltrate in 24 hours. This can be done by following the steps below:

1. Dig a 12" deep hole.

2. Fill the hole with water and allow it to saturate for 24 hours.

3. Determine how many inches will infiltrate in 24 hours.

If the rain garden construction is being done for a new home construction, generally the same principles apply with the exception of sediment control. Before construction starts on the home, the area for the rain garden should be determined and sediment controls like silt fence should be installed. Sediment controls will act to prevent sediment from entering the area that will later be the rain garden. It is best to hold off construction on the rain garden until the yard is graded and completely stabilized with vegetation. Taking these precautions will prevent the rain garden from becoming clogged with sediment.

An adequate infiltration rate for a rain garden without supplemental drainage is .5” per hour. If the composition of your soil does not allow for proper infiltration (see percolation test above), you may need to amend the soil. A good soil amendment mixture is 50% sand, 25% topsoil and 25% compost. These items can be found at your local lawn and garden store. You are now ready to mix these amendments in the bottom of the excavated area and continue the construction of your rain garden.

Excavate the area by using shovels or an excavation device depending on the size of the application. Dig a shallow, flat-bottomed hole with gradually sloping sides. Have a spot located in your landscape for excavated materials or build a berm with it on the lower side of your rain garden. Fill the excavated area with water and observe where the excess water flows. If necessary, dig a shallow channel to direct water away from buildings and toward the street or creek. If needed, direct your gutter downspout to your rain garden by digging a shallow channel. Underdrains can be used in rain gardens if the soil conditions are unfavorable for moderate drainage. The underdrain will typically consist of a perforated PVC pipe and gravel as a base to support the pipe. Elbow drains can also be used to reduce nitrogen through the denitrification process.

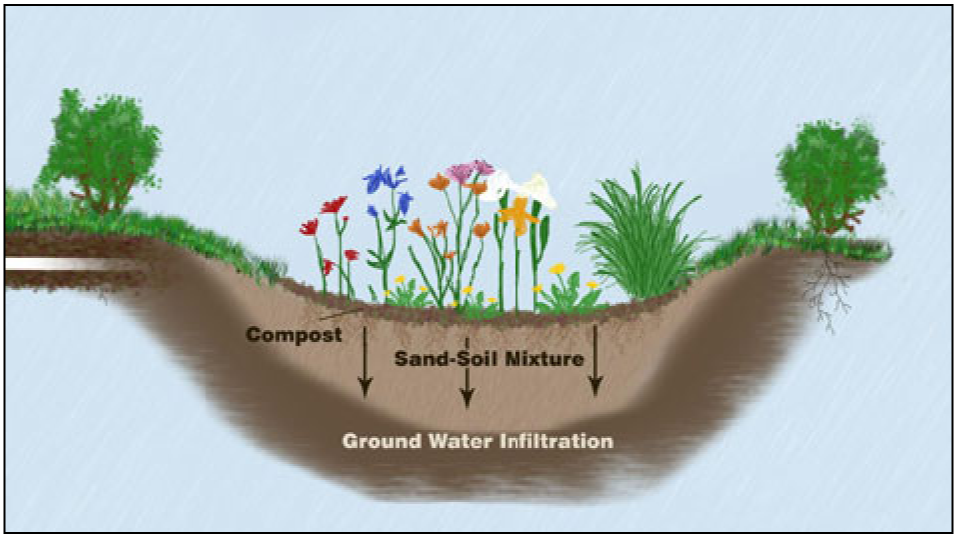

Figure 13: Rain garden cross section
Source: (Water Resources Education Network 2009)

Use of Native Plants

To determine the number of plants you will need in your garden, simply take your garden size in square feet divided by 2.25 (City of Springfield 2010). This will be a good estimate for plants spaced 18" apart. Once planted, put a 3" layer of untreated shredded hardwood mulch around the plants to conserve moisture and deter weeds.

Roots of native plants are generally longer than those of non-natives, so they can filter more rain water and absorb more water than a typical lawn of the same size. Table 8 lists examples of some native Oklahoma plants that can be used in your rain garden. Native plants are also adapted to the soils, climate and pests in the area as well. For a more complete list see visit OSU's LID website to view the OSU resource, Plants for Rain Gardens.

Table 8: Oklahoma native plants suitable for rain gardens

SHRUBS
American Beautyberry – *Callicarpa Americana*
Elderberry – *Sambucus canadensis*
Possumhaw – *Viburnum nudum*
Red Chokeberry – *Aronia arbutifolia*
Yaupon – *Ilex vomitoria*
ORNAMENTAL GRASSES
River Oats – *Chasmanthium latifolium*
Muhly Grass – *Muhlenbergia capillaries*
Sweetgrass – *Muhlenbergia filipes*
Switch Grass – *Panicum virgatum*
SEDGES AND RUSHES
Lurid Sedge – *Carex lurida*
Fringed Sedge – *Carex crinita*
Southern Waxy Sedge – *Carex glaucescens*
White-topped Sedge – *Rhynchospora latifolia*
Woolgrass - *Scirpus cyperinus*
PERENNIALS
Black-eyed Susan– *Rudbeckia fulgida*
Columbine --*Aquilegia canadensis*
Homestead Purple Verbena – *Verbena Canadensis*
Joe Pye Weed – *Eupatorium fistulosum*
Prairie Blazing Star --*Liatris pycnostachya*
Showy Goldenrod --*Solidago speciosa*
Tickseed – *Coreopsis angustifolia*
FERNS
Southern Lady Fern— *Athyrium aplenoides*
Cinnamon Fern – *Osmunda cinnamomea*
Royal Fern—*Osmunda regalis*

Source: (OSU 2009)

Bioretention Cells

Bioretention cells are different from rain gardens primarily in the size and methods of construction. Some applications that often incorporate bioretention cells are: parking lots and street drainage. Bioretention cells are much larger in scale and are designed differently to handle larger amounts of water. They typically consist of a series of cells, and usually have an underdrain system. In general, bioretention cells should be designed by an engineer with experience in hydrology. A set of engineering plans should be made available to the contractor, city inspector and client among any other relevant parties. A set of engineering plans requires the contractor to install the feature as it was designed instead of just digging a hole in the ground and hoping that it works. Due to their larger scale and use of heavy equipment they should also be constructed by a contractor who has experience with these applications. If the city the bioretention cell is built in does not require inspection, it is always a good idea to hire an independent inspector to verify the bioretention cell is built as designed. Not following these basic rules can result in wasted time, money and drainage problems.

Design and installation of bioretention cells will not be discussed here, as there are numerous methods and scales utilized when designing these features. However, some things to consider when deciding if a bioretention cell might be right for your project are outlined below.

Key Points for Success

- Stabilize all surrounding surfaces before construction begins. Install sediment control devices. Prevention of sediment deposition during construction is important to prevent the cell from becoming clogged.
- Scarify the existing soil surfaces, taking care not to compact the on- site soils. Scarify means to scratch the surface, in this application scarifying can be done with a hand rake, hoe or a backhoe. Compaction of soils can cause poor drainage and defeat the purpose of the bioretention cell.
- Install underdrain system to handle large rain events. While these features can typically handle light rain events, it is a common practice for underdrains or overflow structures to be installed to prevent flooding.

Guidelines and Inspection Points

- Grading of any catchment area draining to the bioretention cell should be done sparingly and stabilized immediately (within 14 days).
- A bioretention cell should not be placed in service until all of the contributing drainage area has been stabilized and approved by the inspector.
- Soil materials should not be delivered until the bioretention site has been excavated or graded and the underdrain systems are in place. Planting materials should not be delivered until after the soil medium has had time to settle to the proper grade and elevation.

- Prior to covering the underdrain system, the inspector must observe the underdrain itself, the connections, gravel bedding, and any filter fabric. Manufacturer's tickets are required for the gravel, pipe and filter fabric material.
- If placing gravel over the underdrain, avoid dropping it from high levels with a backhoe or front-end loader bucket. Spill directly over the underdrain and spread manually.
- Avoid over-compaction of the soil material by allowing time for natural compaction and settlement. No additional manual compaction of soil is necessary. To speed up the natural compaction process, presoaking the placed soil may be performed.
- Overfill above the proposed surface invert to accommodate natural settlement to the proper grade. Depending upon the soil material, up to 20% natural compaction may occur. If construction scheduling permits, it is preferable to allow natural settlement to occur with the help of rain events.
- The mulch layer surface should approximate the final elevation as shown on the design plans.
- All plant materials should be tagged for identification in accordance with the American Standard for Nursery Stock.
- The landscaping work and materials shall be guaranteed for a minimum of 1 growing season and a maximum of 2 years from the date of installation. The warranty period begins when the as-built construction plan is approved

Source: (Hunt and Lord 2006)

Use of Compost

Compost is recommended as a fill media in both rain gardens and bioretention cells. This is due to the fact that compost is high in organic matter which will increase the water holding capacity of your soil which contributes to desired infiltration rates. Compost also contains valuable nutrients that are quite beneficial when establishing plants in a rain garden or bioretention cell. However, if the area that drains to the rain garden has high nutrient loading, compost is less desirable since the garden is getting other nutrient inputs. Compost has also been shown to suppress plant diseases and pests. A good soil amendment mixture is 75% sand, 15% topsoil and 10% compost.

Costs

In the summer of 2007, researchers from Oklahoma State University designed and installed eight bioretention cells in Grove, Oklahoma, as part of a technology demonstration and evaluation project. Cell design focused on phosphorus and nitrate attenuation by utilizing fly ash as an additive to the filter medium and incorporating a biozone or anaerobic zone, respectively. Sites included two commercial properties, four public or municipal properties, and two residential properties. Construction was professionally contracted as an official state project with a formal Plans, Specifications, and Estimates package. Two additional cells were constructed by Oklahoma State University in the Spring of 2008 at the Oklahoma State University Botanical Gardens. The costs associated with this project are listed in Table 9 below. While it is important to realize that these bioretention cells had a specialized media installed for research purposes, the general methodologies are similar to other bioretention cells installed throughout the state of Oklahoma. It is also important to note that these costs include labor, which can be quite high when hiring landscape professionals and may be more expensive than similar structures in more urban areas where plants and other materials, and contractors for installation, are more readily available.

Table 9: Area, volume and cost of bioretention cells in Grove, Oklahoma

Location	Area (ft2)	Volume (ft3)	Total Cost	Cost/Area (ft2)
Elm Creek Plaza	678	4520	$12,496	$18.43
Lendonwood Gardens	247	670	$8,847	$35.81
Grove High School	1604	5685	$17,071	$10.64
Grand Lake Association	1851	15361	$29,173	$15.76
Cherokee Queen Riverboats	1248	3813	$13,796	$11.05
Early Childhood Development Center	516	2472	$10,715	$20.76
Spicer Residence	1087	3284	$13,271	$12.20
Clark Residence	322	953	$7,368	$22.88

Source: (Chavez, et. al. 2008)

In addition to these Oklahoma cost examples, Table 10 shows the varying costs that can be associated with different scales and features of rain gardens and bioretention cells. These costs are from 2001 and have decreased somewhat. In addition, the Sustainable Cities Institute provides calculators for users to determine rain garden and bioretention cell costs based on their specific inputs. This tool is available at www.sustainablecitiesinstitute.org by simply clicking on the Planning Center tab.

Table 10: Cost estimates for residential and commercial rain gardens

Residential Lot in a Subdivision
This is applicable if the project is a shallow rain garden incorporating in-situ soils and no underdrain system. Homeowner, garden group, or volunteers provide the labor, and no heavy construction equipment is used (most of the labor is done by hand). The disturbed area is small enough to avoid permits and fees, and the rain garden is seen as a homeowner landscaping project. • planning phase $25 • design phase $100 • construction phase $950 TOTAL ESTIMATED COST: **$1,075**
Residential Rain Garden
The cost information is the average cost per facility installed, assuming a 100 lot subdivision. All of the facilities have an underdrain system, and many of the facilities will be constructed simultaneously. Planning, designing, and construction costs are all pro-rated as a portion of the overall site cost work, and sediment control, permits, fees, and technical plan approval are required. • planning phase $95 • design phase $340 • construction phase $3225 • closeout phase $130 TOTAL ESTIMATED COST: **$3,790**
Residential Single Lot
Costs are increased substantially due to the small scale of the project, and closeout is higher due to as-built requirements. • planning phase $200 • design phase $875 • construction phase $5750 • closeout phase $950 TOT AL ESTIMATED COST: **$7,775**
Commercial - New
The facility construction costs are lower than that for a single residential lot because of the increase in related site work. The storm drainage discharge system is not included as part of the bioretention costs since it is treated as a general site expense. • planning phase $845 • design phase $3600 • construction phase $5237 • closeout phase $675 TOTAL ESTIMATED COST: **$10,357**

Commercial - Retrofit
Total retrofit costs are higher than those for new construction due to economies of scale. Design costs are lower because the drainage conveyance system is already in place. • planning phase $350 • design phase $2410 • construction phase $7943 • closeout phase $1652 TOTAL ESTIMATED COST: **$12,355**

Source: (PGDER 2001)

Benefits

As a whole there are numerous benefits to the installation of rain gardens including improved water quality, lower development costs, improved aesthetics, wildlife habitat and improved air quality. One rain garden alone will not make a noticeable difference in terms of managing stormwater. However, many rain gardens can result in substantial improvements. A recent project and study done by the City of Burnsville, Minnesota installed 17 rain gardens in a watershed and used another watershed without rain gardens as a control. As a result, the city saw an 82% reduction in stormwater runoff from the watershed with the rain gardens compared to its previous performance (Landers 2006). The overall appearance of a property can be improved by adding rain gardens or bioretention cells. This can translate to increased property values and health benefits (University of Illinois at Urbana-Champaign 2010). In addition, butterflies, birds and helpful insects are attracted to native plants for nesting and feeding. Designed to drain water within a day, rain gardens will not breed mosquitoes since mosquito larvae need more than 48 hours to grow into adults. Rain gardens also attract dragonflies which are a natural predator of mosquitoes.

Table 11 summarizes current knowledge of pollutant removal effectiveness by bioretention systems for the following parameters; total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), heavy metals including copper (Cu), lead (Pb) and Zinc (Zn); oil and grease, and bacteria (Prince George's County 2006). Several of the parameters show a high percentage removal. Rain gardens are important not only to help absorb rainwater but also to allow pollutants like those listed below, to infiltrate and be utilized by the plants. Rain gardens are most effective at the removing nutrients from stormwater runoff. This is due to the fact that plants need 16 essential nutrients to survive. Many of these nutrients are found in stormwater runoff and can be utilized by plants by way of nutrient uptake.

Table 11: Reported pollutant removal performance of bioretention systems

Parameter	% Removal	Source(s)
TSS	97	Hsieh and Davis 2005b; UNHSC 2006; Ermilio & Traver 2006
TP	35-65	Davis et al. 2006; Hunt et al.; 2006 Ermilio 2005
TN	33-66	UNHSC 2006; Hunt et al. 2006 Sharkey 2006; Davis et al. 2006
Cu	36-93	Ermilio 2005; Davis et al. 2006
Pb	24-99	Ermilio 2005; Davis et al. 2006
Zn	31-99	UNHSC 2006; Ermilio 2005
Oil & Grease	99	UNHSC 2006; Hong et al. 2006
Bacteria	70	Hunt et al. 2007

Source: (Prince George's County 2006)

Maintenance

The maintenance of a rain garden or bioretention cell is as important as the installation. Just like regular plant and lawn care duties, these features should be inspected periodically. This inspection can be brief and should address disease, insect infestation, hardwood mulch condition, presence of invasive species and overall appearance and species survival. Annually, the rain garden or bioretention cell should be inspected more thoroughly and maintenance completed as needed. The annual inspection should cover all of the items listed above as well as removal of any accumulated leaf and plant litter and sediment deposition. Hardwood mulch should also be replaced if it has degraded and is not providing adequate cover. If at some point the feature is not draining properly one might need to do some re-grading of the surrounding area to redirect the water or minor excavation of the rain garden if accumulated sediment and debris have somewhat "clogged" the garden. To prevent this from occurring try to prevent runoff from bare soil areas from transporting sediment to the rain garden or bioretention cell. This can be achieved by utilizing a sediment barrier such as silt fencing.

Limitations

As with all lawn maintenance, problems can arise if a rain garden is not property installed or maintained. By following the guidelines below, potential issues can be avoided:

- Determine the appropriate placement for the garden: Do not place the garden on the top of a hill. The garden must be placed at the sump position or a converging portion of the lawn that is not a main channel. This allows the water to concentrate and not just flow past the garden, thus providing the most water quality benefits.

- The rain garden should not be placed where there is a lot of foot or pet traffic, as this could compact the soil in and around the garden. When soil becomes compacted water infiltration decreases and plants can have difficulty growing.

- While constructing the garden it is crucial to ensure the area has good soil that will infiltrate the stormwater. If not, a soil amendment will be needed. If the proper soils are not present and the garden is planted anyway, it will not drain properly and the plants will drown.

- Plant selection is also crucial to creating a thriving rain garden. Native plants are generally the best choice for the garden because they require less input such as water and fertilizer to stay alive. It is important to use native plants because some non-native plants are not tolerant to extreme conditions such as long wet and dry periods. Remember the garden does not need to be and should not be watered on a regular basis like one might with non-native plants. The plants in the garden are specific to Oklahoma's climate and can withstand long periods of dry weather.

Oklahoma Examples

In Oklahoma, there are several examples of rain gardens throughout the state. Table 12 shows a partial list of rain gardens and their addresses in Oklahoma.

Table 12: Location of rain gardens in Oklahoma

CITY	FACILITY	ADDRESS
Bixby	Center Island Roundabout	148th & Riverview
Broken Arrow	Ray Harral Nature Park	7101 S 3rd Street
Edmond	Edmond Soccer Field Expansion	1520 W. Danforth
Edmond	Xeriscape Demonstration Garden	Rankin & 33rd
Grove	Elm Creek Plaza	1625 S Main St
Grove	Lendonwood Gardens	1308 West 13th Street
Grove	Grove High School	300 Ford Road
Grove	Grand Lake Association	9630 Hwy 59N Ste B
Grove	Cherokee Queen Riverboats	11368 US Hwy 59
Grove	Early Childhood Development Center	901 W 10th St
Sapulpa	Sapulpa Aquatics Facility	1400 E. Haskell Street
Tulsa	Remington Elementary School	2524 West 53rd Street
Tulsa	Eisenhower International Elementary School	2819 South New Haven Avenue

The Xeriscape Demonstration Garden at the Bickham-Rudkin Park in Edmond, features a rain garden in conjunction with several other water conservation and LID techniques implemented at the park. The rain garden is placed adjacent to the structure and utilizes rain chains to transfer the water from the roof to the garden. The rain garden was constructed at an existing low spot in the landscape that was well drained. The soil was amended to a depth of 8 inches. The cost of this project including the soil amendments, stone for weir structure and outflow, and two rain chains was approximately $2500.00. The Xeriscape Demonstration Garden was completed in 2009.

Figure 14: Rain garden at Xeriscape Demonstration Garden in Edmond

For Additional Resources on Rain Gardens & Bioretention Cells, visit us on the web at: http://lid.okstate.edu/bioretention-cells-and-rain-gardens

CHAPTER VI

RAINWATER HARVESTING

Introduction

Rainwater harvesting is the process of capturing, channeling, and storing stormwater runoff for later use. Keeping in mind the inherent duties of routine maintenance and operation, rainwater harvesting systems can easily be implemented at the home, commercial, and community level. This method of collection and storage can be advantageous in that it augments municipal and well-water supplies, reduces flooding and erosion, improves water quality, and reduces water bills. There are two basic types of rainwater harvesting collection systems that essentially differ because of the volume of water to be collected: cisterns and rain barrels.

Ideas and technologies of harvesting rain date back over 4,000 years ago in areas such as Rome, the Middle East, and China. Ancient societies left evidence of agricultural dams and runoff control methods, as well as reservoir or cistern construction in urbanized areas. Today, an estimated 100,000 residential rainwater harvesting systems are in use in the United States and its territories (TWDB 2005).

Uses of harvested rainwater include irrigation, washing cars, flushing toilets, and use as a potable source. Due to atmospheric contaminants, vegetation overhang, infrequent rains, dust accumulation, roof material, and bird and rodent droppings, rainwater can pick up a number of impurities throughout the hydrologic cycle and system of collection. It is worthy to note that if used for drinking water or flushing toilets, the water must be treated in accordance with state and federal drinking water regulations; this includes but is not limited to, debris filtration and various purification methods such as chlorination or UV Treatment to achieve disinfection.

Design and Sizing

There are five main components in a rainwater harvesting system: conveyance system, storage, overflow pipe, outlet pipe, delivery system, and first-flush diverter (optional). Before implementing a rainwater harvesting system, it is important to understand and consider the function of these components, as well as familiarizing oneself with local plumbing, building, neighborhood, and environmental codes. The limiting factors in most rainwater harvesting applications are the space available for storage, cost and aesthetics. Several factors must be considered when installing a system, including contributing rooftop area, rainfall patterns, and anticipated usage.

Different approaches to rainwater harvesting are taken in different parts of the country. To begin a rainwater harvesting project, consider the following:

- What will the harvested rainfall be used for?
- How reliable will you need the system to be?
- What is the size of the catchment area that you have or need?

- Where is the catchment area located relative to the intended use?
- What size and type of storage do you have/need to purchase for the harvested rainfall?

Catchment area should be calculated based on the footprint created by the roof and not by the square footage of the roof surface. Be sure to use roof surfaces as near as possible to the planned cistern location, to shorten pipe runs. Because precipitation and water demand are very uneven over the course of the year (except for in home demand), the cistern cannot be sized on the basis of annual precipitation and demand. Monthly average precipitation values are needed for this exercise; these can be obtained from Table 13 by multiplying your average annual precipitation at your location by the percentage of rain during the identified period desired for using the system.

The pertinent catchment area is calculated by the following;

$G = 0.4 \times R \times A \times .90$

Where G is the gallons of water harvested, R is the precipitation in inches, A is the roof area in square feet, 0.4 is a conversion factor that converts among inches, feet and gallons and .90 is the efficiency of the system. Efficiency is important to include in a system because not all of the water that falls on a rooftop will be captured due to leakage, impact splash, first flush diverters and evaporation. Catchment area should be calculated based on the footprint created by the roof and not by the square footage of the roof surface. An excessively steep catchment area or a dramatic rainfall event may further decrease capture estimates due to gutter overflow.

Example: Designing a System

Joe Homeowner wishes to collect precipitation to water a vegetable garden that covers 1500 square feet. The OSU county extension agent tells him he should apply an inch of water to the garden each week between June 15 and Sept. 15, and that the average rainfall during that time is two inches. Joe calculates that he will need to collect 9,350 gallons (see example calculation below) to water the garden each summer. After pricing cistern options, he decides he only wishes to buy 6000 gallons of storage capacity, and will use well water for the rest of his irrigation water. For a catchment area, he will need at least:

$$A = 2.5 \times 6000 \text{ gallons} / R\text{-annual}$$

where R-annual is the total average annual precipitation, in inches, A is the area and 2.5 is a conversion factor that converts among inches, feet and gallons. The average annual precipitation on the Homeowner place is 15 inches, so Joe will need to collect from a roof area with a horizontal projection of at least 1000 square feet (2.5 x 6000/15). He decides to collect from the south side of his barn, which has 1200 square feet of roof area and is just above where he wishes to install his cistern. (Adapted from Rupp 2006).

Table 13: Oklahoma average monthly rainfall distribution

Month Percentage of Annual Rainfall	
January	4%
February	5%
March	8%
April	9%
May	14%
June	12%
July	8%
August	8%
September	11%
October	9%
November	7%
December	5%

Source: (Oklahoma Climatological Survey 2002)

Storage Tank

The storage tank, which is sometimes called a cistern, is the primary storage component of the system and is usually the most expensive component of the rainwater harvesting system. Material, size, and location of storage tanks are dependent upon the anticipated purposes of the collected rainwater. In order to enhance the effectiveness of potential collection, the storage tank must be sized accordingly. The capacity of the tank should be in proportion to the purpose and demand, the location of later use, the annual rainfall in inches per year, and the size of the collection area.

Whether to have the storage tank below or above ground is a function of surrounding landscape, existing downspouts, cost, structural support of the surrounding foundation of soil, and aesthetic preference of the landowner. Below ground storage tanks should have manhole covers to ensure safety, yet maintain their accessibility for cleaning and upkeep. Below grade fixtures should be sealed in order to prevent inadvertent entrance of surface or groundwater. Keep in mind the likelihood of buoyancy of an underground storage tank when empty. Observe the structural support of the adjacent foundation for an above ground storage tank. The ground should be flat and able to withstand the weight of the storage tank at full capacity.

In order to prevent algae growth and the degradation due to UV rays, above grade storage tanks should be opaque, heavily tinted, or have sun barriers. Storage tanks are available in a variety of materials, including plastic, fiberglass, and galvanized metal. Storage tanks are sturdy, watertight, with a smooth interior surface, as well as sealed with non-toxic, waterproof materials. Special storage tank materials are required when the harvested rainwater is to be used to supply drinking water due to the possibility of leaching from materials. Figure 15 is a general diagram of an above ground storage tank.

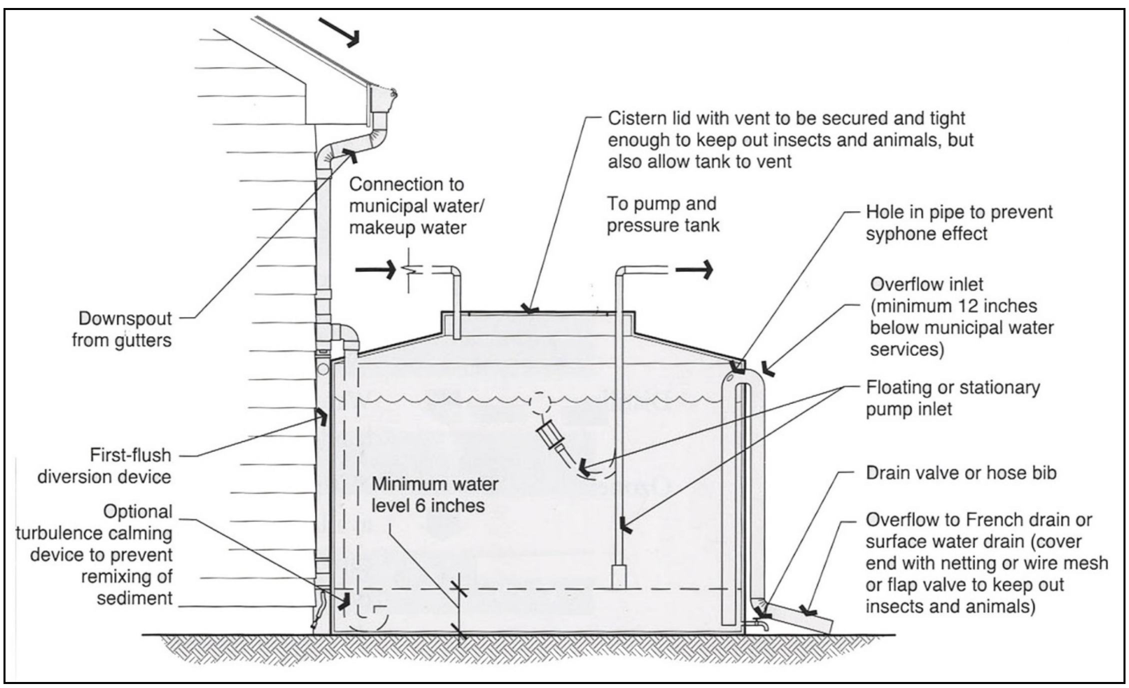

Figure 15: Above ground water harvesting system diagram
Source: (Kinkade-Lavario 2004)

Cistern storage tanks come in various sizes. Table 14 shows the capacity of round cisterns with varying dimensions. In general, cisterns should be opaque to inhibit algae growth. To achieve this, they can be purchased opaque or painted. Cisterns come in a variety of materials including: fiberglass, wood, polypropylene, concrete and metal. There are different benefits to each type of material depending on your aesthetic needs, climate and location of the tank. It is important to consider the placement of your cistern to prevent settling resulting from improper foundation preparation. Remember, one gallon of water weighs 8.34 pounds so even with a small system that is 6 x 6, when full the total weight is more than 5 tons. This fact necessitates a proper foundation be installed before the cistern is put in place. To discourage mosquito breeding, the cistern should also have screened vents installed.

Table 14: Round cistern storage capacity (gallons)

Height	6-Foot Diameter	12-Foot Diameter	18-Foot Diameter
6	1269	5076	11421
8	1692	6768	15227
10	2115	8460	19034
12	2538	10152	22841
14	2961	11844	26648
16	3384	13535	30455
18	3807	15227	34262
20	4230	16919	38069

Source: (TWDB 2005)

First Flush Diverters

Varying degrees of contaminant removal may be required depending on the water's use. For most situations, a screen filter at the gutter inlet can be used to remove large debris such as leaves, sticks or pieces of roofing material from the roof runoff. Dust and bird droppings also accumulate on roof surfaces between rainstorms. Generally, the inflow of rain enters the gutters and downspouts from the collection area; the first flush of higher contaminated rainwater may be diverted and the rest flows to the cistern. In order to improve the water quality that is actually stored, first flush diverters divert those first portions of rooftop runoff away from the cistern.

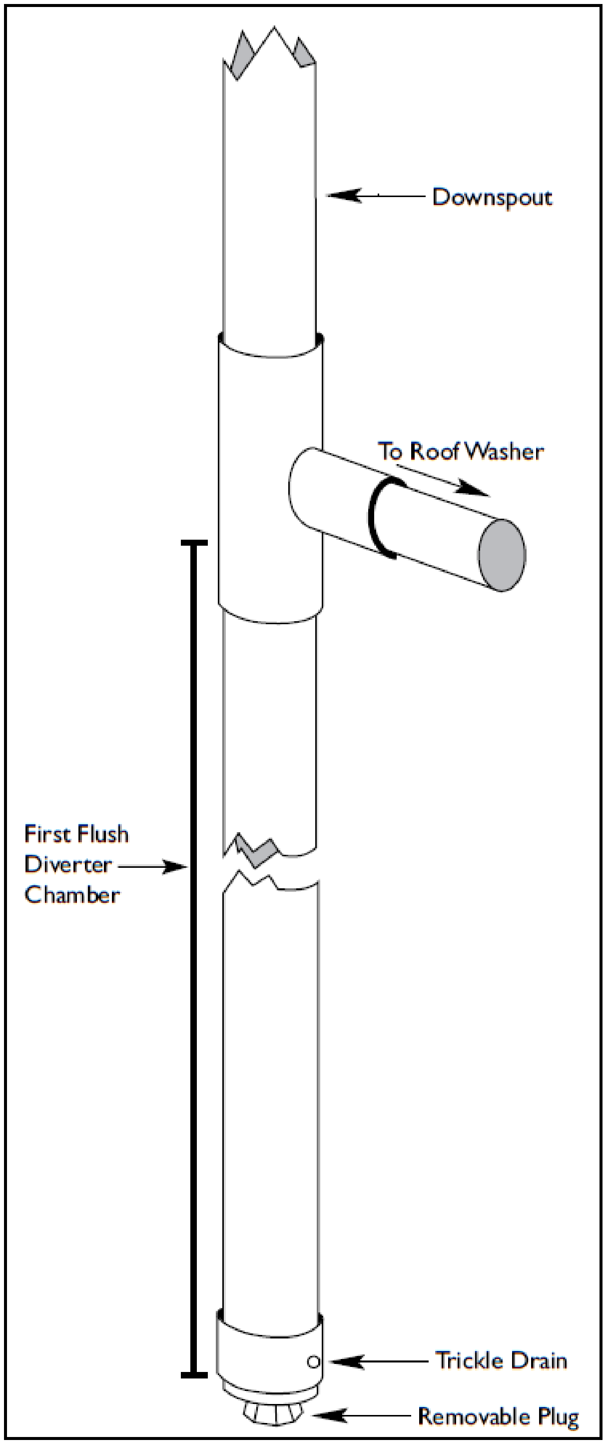

Figure 16: First flush diverter system
Source: (Rupp 2006)

A common first flush diverter is shown in Figure 16. Water will not begin to flow into the cistern until the diverter has filled completely. A trickle drain or clean out valve ensures an empty chamber for subsequent rainfall events. A general rule of thumb is to divert at least 10 gallons per 1000 square feet of catchment area. Gutter screens, filters, and roof-washers are often used in addition to first-flush diverters facilitating the prevention of mosquito breeding and to prevent sediment buildup in the cistern. Figure 17 shows a roof washing system.

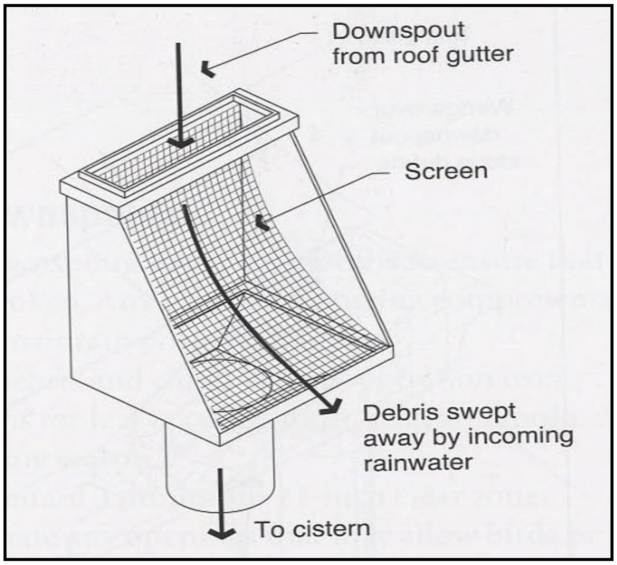

Figure 17: Roof washing system for rainwater harvesting
Source: (Kinkade-Lavario 2004)

Effectively, the contaminated water is sealed off or siphoned from the next flow of rains that will enter the cistern. The proper placement for a roof washer is between the first flush diverter and the cistern. The roof washer contains a screen that will filter out large debris such as twigs and leaves. Various devices can be constructed by the homeowner or purchased commercially for this purpose. Characteristics of precipitation can affect collection such as frequency, volume, duration and intensity. Recommendations for minimum first flush diverter lengths are shown in Table 15.

Table 15: Rainwater harvesting first flush diverter length (Rupp 2006)

Pipe Diameter (Inches)	Chamber Length (Inches/Gallon)
3"	32.75"
4"	18.5"
6"	8.25"
8"	4.63"

A turbulence calming device, or calming inlet, may be used to minimize bottom sediment disturbance where the rainwater enters the tank. It is another safeguard to ensure an appropriate quality of water. This device can be seen in Figure 15.

The Conveyance System

The gutter conveyance system is composed of a series of gutters, downspouts and pipes that conveys precipitation from the roof through the piping and to the cistern. The Uniform Plumbing Code (UPC) recommends that a gutter system be able to carry the runoff of the 100 year-1 hour rain event (Pushard undated). Existing gutters can be easily retrofitted to distribute more rainwater through various fixtures and to the cistern; this may require additional structural support from the building to the gutter system. The most common materials used for the gutter and piping system are PVC, seamless aluminum, and galvanized steel. The following are some general guidelines to keep in mind when designing and installing your guttering and pipe system:

- Slope gutters 0.5% (1 in/16 ft)
- Place gutter hangers 3 ft on center
- Use expansion joints in gutters 60 ft or longer
- 1 downspout per 50 ft of gutter length

- Slope horizontal conveyance pipes 2% (1 in/4 ft)
- Horizontal conveyance pipes should have cleanouts every 100 feet
- Limit horizontal conveyance pipe bends to 45°

Source: (Sustainable Building Sourcebook 2000)

The Overflow Pipe

When the cistern has reached capacity, a bypass or overflow pipe is necessary to direct continuing water flows away from the full cistern, while also protecting the area from erosion. The overflow pipe, installed near the top of the cistern, allows this excess water to leave the cistern when needed. It is required to handle the same flow as the gutter system in order to be effective. Be sure that overflow is diverted away from any building foundations, but not directly to impervious areas.

The Outlet Pipe

The outlet pipe, installed at least 6 inches above the bottom of the cistern, is used to draw water from the bottom of the cistern to the delivery system that ultimately delivers the captured rainwater to its desired location. A pump may be necessary to provide adequate pressure to draw water for some applications. Solar pumps are also available for locations without electricity.

Economics of Rainwater Harvesting

The economic savings potential of installing a system depends upon the amount of rainfall stored, the value of water at a particular location, and the intrinsic value associated by the user with using rainwater for a particular use. For instance, harvested rainwater may have an added value over tap water when used for urban irrigation because of actual or perceived benefits of using harvested rainfall to grow their plants. Installing a system will reduce utility bills depending on how much and to what use the water is allocated.

The single largest expense is generally the storage tank, and the cost of the tank is based upon the size and the material. Costs range from a low of about $0.50 per gallon for large fiberglass tanks up to $4.00 per gallon for welded steel tanks. For those desiring professionally installed materials, costs range from $3.50 to $12 per foot of gutter, including materials and installation, in 2004. The range for pump costs runs from $385 for the low end tankless pump, to more than $1,000 for the combined price of a high-end pump and pressure tank (TWDB 2005). Cisterns are more expensive due to the larger size and multiple "moving parts." Installation of buried cisterns can also be expensive. A common cistern shared by multiple properties may result in considerable economies of scale because there is only one excavation, one tank or set of tanks, and one pump (TWDB 2005). Over time, routine maintenance and replacement of filters or other parts will be required as well.

As of March 2011, Oklahoma does not provide tax incentives concerning rainwater harvesting. However, the neighboring local and state governments of Texas and New Mexico offer various tax exemptions, rebate programs, and other financial incentives to individuals that install rainwater harvesting systems.

Rain Barrels

For residential lots, rain barrels are a simple and lower cost way for homeowners to conserve water for later use. The most common size of residential rain barrels is a 55 gallon barrel, but barrels can range from 40 to 300 gallons. Rain barrels have become more popular among the general public and as of March 2011 pre-constructed systems are available at lawn and garden stores for between $100.00 to $200.00. If you would like to build your own there are also online companies that will sell you a do-it-yourself kit. However, with a little time and effort you can build your own system just as easily as buying one. Oklahoma Gardening features two episodes on “How to Build a Rain Barrel” that can be viewed at the following websites. These short episodes show the step by step instructions on how to build a residential rain barrel.

http://www.youtube.com/oklahomagardening#p/search/1/FeRO2MnH79M

http://www.youtube.com/oklahomagardening#p/search/0/u7joBFwn338

It is important to remember to utilize mosquito screens to prevent mosquitoes from breeding within the rain barrel. This can be done by installing a 1 mm or smaller screen at any point where standing water could be exposed to the outside environment. Rain barrels can also be painted to reflect the homeowners’ sense of style (Figure 18).

Figure 18: Residential rain barrel, Stillwater, OK

Maintenance

Rainwater collection and storage facilities require a variety of routine maintenance. These activities should be completed in mild weather at the end of the summer and the end of winter. Since Oklahoma has very hot summers and cold winters it is important to inspect the system to ensure that no damage has occurred due to extreme temperatures during these seasons. At least once a year the following routine activities will need to be completed:

- Inspection and repair of vent screens
- Removing debris from the roof, leaf guard, gutter, gutter screen, roof washer and first-flush diverter
- The storage tank will need to be drained and emptied of accumulated sediment every few years
- Inspection and service of pumps
- Empty the rain barrel during the winter season to prevent damage from freezing.
- The tank can be cleaned out by letting it soak in a 5% bleach solution and then rinsing the tank out afterwards.

Figure 19: Rainwater harvesting system capable of capturing 2,200 gallons at the Xeriscape Gardens in Edmond, Oklahoma

Oklahoma Example

The rainwater harvesting system shown in Figure 19 is located at the Xeriscape Demonstration Garden in Edmond. The Xeriscape Garden at Bickham-Rudkin Park located at 33rd St. & Rankin was designed to demonstrate effective water management strategies within a residential landscape. Those strategies include water conservation (Xeriscape), rain water capture for use in the landscape, reduced volume and rate of stormwater runoff, and improved water quality.

Though Edmond, which is located in Oklahoma County, receives on average 36 inches of annual precipitation, it doesn’t always fall during the hot summer months when many plants need it. During the summer months, as much as 50% of the total treated water supply in Edmond is used to irrigate landscapes, and on hot, dry days that figure can reach 80%. This cistern system is able to capture the runoff from a rainfall event of up to 3.6 inches or 2200 gallons total. The total catchment area of this system is 1100 square feet of rooftop runoff. This water is then stored for later irrigation needs. This system utilizes the rain in the cistern first and then switches to municipal water for the remainder of the water needs. The items required for the systems are listed below in Table 16 along with the total cost.

Table 16: Material costs for water harvesting system at the Xeriscape Demonstration Garden in Edmond, Oklahoma

1-½ HP submersible pump
2- 1200 gal. storage tanks
1-floating filter intake
1-pump controller with run dry protection
1-Overflow siphon
1-calming inlet
1-backup inlet valve for alternate source water
1-Tank level indicator
1-first flush diverter
1-down spout debris diverter
1-Vent cap
4-4” bulkhead fittings
4-1 ¼ bulkhead fittings
1-1 1/4 “ wye strainer
2-1 ¼” brass ball valves
2-3/4” brass ball valves
All necessary pipe and fittings
Total Material Cost: $ 4400
Total Labor Cost: $ 4600
Total Costs: $9000

In Summary, whether you're going all the way with a large cistern system or simply disconnecting your downspout onto your grass, these actions translate into water conservation, dollar savings and increases in property value. Installing a rainwater harvesting system is also a great way to reduce stormwater pollution.

For Additional Resources on Rainwater Harvesting, visit us on the web at: http://lid.okstate.edu/rainfall-harvesting

Acknowledgements

I wish to recognize Kelly Nash and Jessica Lay as contributing authors to this chapter.

CHAPTER VII

PERVIOUS PAVEMENT

Pervious pavement, also called permeable pavement, is a Low Impact Development (LID) best management practice (BMP) that is capable of reducing both the peak and total runoff from paved surfaces.

IS IT PERMEABLE, PERVIOUS, OR POROUS PAVEMENT?

All three of these terms are used interchangeably to describe pavement that allows water to flow through it rather than shedding water. Only two of these words, however, are synonymous: permeable and pervious. Both mean that water can flow through the material via a series of connected holes or pores.

The term porous simply means that there are holes in the substance, but do not necessarily mean that these holes are connected. For example, pumice is a porous rock, yet it is not permeable because many of its holes do not connect.

The more technically specific terms are, therefore, permeable and pervious. However, much of the pavement and design industry uses porous instead.

-- Adapted from the North Carolina State University Cooperative Extension

Pervious pavement works by allowing water to drain directly through the pavement. The water is then either allowed to flow into the soil or is piped to a stormwater discharge.

The use of pervious pavement mitigates many of the disadvantages of conventional concrete and asphalt pavement, such as increased runoff, erosion and pollution while recharging the groundwater. It can also be beneficial during the winter by increasing the rate at which snow thaws and reducing the melt and freeze cycle that is dangerous and damaging to normal pavement. Pervious pavement can also be a cost saving method by reducing the need for storm sewers and detention ponds.

There are three types of pervious pavement that will be the focus of this fact sheet: permeable pavers, pervious concrete, and pervious asphalt. All three have different properties and functions that are outlined in the following sections. Other types of pervious pavement not discussed in this fact sheet are concrete grid pavers, plastic reinforcing grids filled with gravel, and plastic reinforcing grids with grass.

Permeable Pavers

Permeable pavers usually consist of an alternating grid of permeable and non-permeable materials that allows water to pass through. There are a variety of different patterns that can be used with permeable pavers. From the standard square bricks, to interlocking pavers that form patterns. The impermeable material can consist of brick, concrete, stone, plastic, or several other options. The permeable material is often made of crushed aggregate, sand, or soil. The opening in installed permeable pavers generally account for 8 to 20 percent of the surface area, are typically filled with pea gravel aggregate, but can also contain top soil and grass. ASTM C936 specifications (200 1b) state that the pavers be at least 60 mm (2.36 in) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and gravel fill, 38 to 76 mm (1.5 – 3.0 in) fine gravel bedding layer, and a gravel base-course storage layer (Figure 20). A drainage pipe may also be installed in sub base layer. Permeable pavers are mostly used in residential applications and are generally easy to install, maintain and repair.

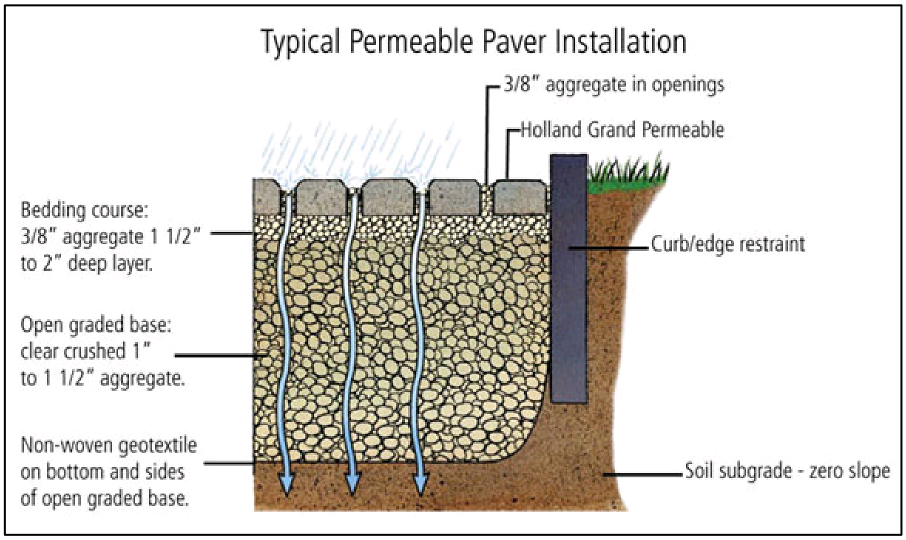

Figure 20: Cross section of permeable paver installation (mypavedriveway.com)

Pervious Concrete

In pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content. Typically, between 15% and 25% voids are achieved in the hardened concrete, and flow rates for water through pervious concrete are typically around 480 in./hr (0.34 cm/s, which is 5 gal/ft^2/ min or 200 L/m^2/min), although they can be much higher. These pavements are typically laid with a 10 to 20 cm (4 – 8 in) thickness and may contain a gravel base course for additional storage or infiltration. Compressive strength can range from 2.8 to 28 MPa (400 to 4,000 psi) or more. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for many applications is readily achieved (NRMCA 2010). Figure 21 shows a cross section of pervious pavement.

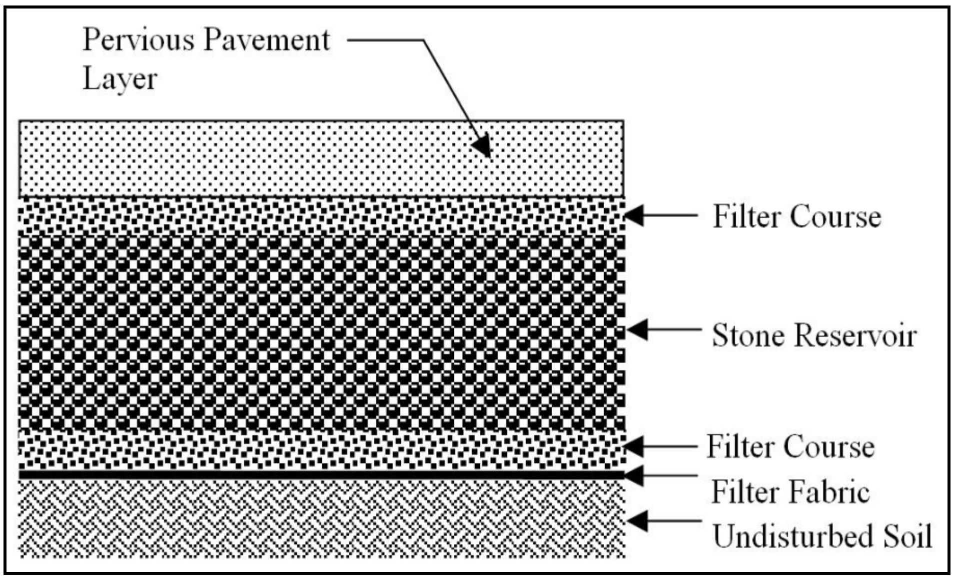

Figure 21: Cross section of pervious pavement installation
Source: (Georgia Stormwater Management Manual 2002)

Pervious Asphalt

Pervious asphalt, also called permeable asphalt or porous asphalt, is made of the same material as its non-permeable counterpart. The difference is in how the material is mixed. Most of the fine particles are removed creating more spaces for water to flow through. As with permeable pavers and pervious concrete, pervious asphalt is built on top of a subbase layer of gravel and crushed stone. There are also applications of pervious asphalt made largely from recycled tires. Figure 22 illustrates a cross section of pervious pavement.

This asphalt maintains the rubbery feel of the tires, making it a great shock absorber and is less likely to crack than other types of asphalt. The amount of fine aggregate is reduced to allow for a larger void space of typically 15 to 20 percent. Thickness of the asphalt depends on the traffic load, but usually ranges from 7.5 to 18 cm (3 – 7 in). A required underlying base course increases storage and adds strength.

Construction

Construction of a pervious pavement is fairly similar to that of conventional pavement, but requires care to ensure the system will function properly. The following describes the installation of pervious concrete and breaks it into seven steps:

1. **Sub grade and sub base preparation:** The ground must be excavated to the desired depth, then smoothed and sloped as necessary. An optional geotextile may then be added to prevent fines from the soil moving into the base layer. After excavation the sub base layer is added. This layer is made of gravel or large aggregates and generally is about 30% void spaces. It can be between 1 to 3 feet deep or more depending on the amount of runoff expected and soil infiltration rates. Uniformity of sub grade support is a key criterion for placing pervious pavement. Compaction to a minimum density of 90% to 95% of theoretical density is often recommended for consistent sub grade support; however, increasing the sub grade density decreases its permeability. For pervious concrete and asphalt, the sub grade must be moist (without free-standing water) prior to placement in order to prevent water from being removed from the lower portion of the pavement too soon. From here the installation practices vary depending on the system being built.

2. **Batching and mixing:** The mixing of the concrete is vital to the success of the system. Table 17 provides general guidelines for the composition of the concrete. In particular, the water content of pervious concrete is limited to a narrow range to provide adequate strength and permeability, and prevent the paste from flowing off the aggregate and closing the open structure. It has been suggested that the best water: cement ratio is 0.32 (Indiana Ready-mixed Concrete Association) and that an aggregate: cement ratio of 4.5:1 to 8:1 be used. Fine aggregate content is limited in pervious concrete and coarse aggregate is kept to a narrow gradation. Commonly used gradations of coarse aggregate include ASTM C 33 No. 67 (3⁄4 in. to No. 4), No. 8 (3⁄8 in. to No. 16), or No. 89 (3⁄8 in. to No. 50) sieves [in metric units: No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), or No. 89 (9.5 to 1.18 mm), respectively]. Single-sized aggregate up to 1 in. (25 mm) also has been used. Aggregate moisture level should be monitored carefully and accounted for, as both water absorbed by the aggregate and excess moisture supplied with the aggregate can be detrimental. Contractors and producers must work together to ensure a proper mixture prior to delivery at the job site. The National Ready-mixed Concrete Association has an online database of certified contractors for installing pervious concrete. On some occasions, slight adjustments to the water content may be necessary at the job site to achieve proper consistency; however, this should be done with care because jobsite additions of water can be difficult to control. Aggregate and cement proportions will be established by testing and by experience with locally available materials, as variations in material characteristics (for example, cement setting times, strength development rates,

aggregate shape, gradation, and density) will limit the usefulness of “cook book” or prescriptive mix designs. Similar equipment can be used for pervious and conventional concrete, including the same mixing and form devices. Almost certainly, the mixtures will be stiff. Conventional concrete mixing equipment is used, although mixing times may be extended compared to conventional concrete.

Table 17: Mixing guidelines for pervious concrete

Ingredient	**Amount per yd^3**
Cement	450 to 700 lb
Course Aggregate	2000 to 2500 lb
Fine Aggregate	0 lb
Water/Cement Ratio	0.27 to 0.34

3. **Transportation:** Because pervious concrete has a low water content, special attention is required during transportation and placement. It’s very low slump may make discharge from transit mixers slower than for conventional concrete; transit mixers with large discharge openings or paving mixers tend to provide a faster unloading time. A pervious pavement mixture should be discharged completely within one hour after initial mixing. High ambient temperatures and windy conditions will have more pronounced effects relative to conventional pavements, and should be taken into account.
4. **Placement and consolidation:** A variety of placement techniques can be used for constructing pervious concrete pavements; as with conventional concrete, placement techniques are developed to fit the specific jobsite conditions. Each load of concrete should be inspected visually for consistency and aggregate

coating. The stiff consistency of pervious concrete means that slump testing is not a useful method of quality control. Placement should be continuous, and spreading and strike off should be rapid. Conventional formwork is used. Mechanical (vibrating) and manual screeds are commonly used, although manual screeds can cause tears in the surface if the mixture is too stiff. Other devices, such as laser screeds, could also be used. For pavements, it is recommended to strike off about ½ to ¾ in. (15 to 20 mm) above the forms to allow for compaction. One technique for accomplishing this is to attach a temporary wood strip above the top form to bring it to the desired height. After strike off, the strips are removed and the concrete is consolidated to the height of the form. Consolidation is generally accomplished by rolling over the concrete with a steel roller which compacts the concrete to the height of the forms. Because of rapid hardening and high evaporation rates, delays in consolidation can cause problems; generally, it is recommended that consolidation be completed within 15 minutes of placement.

5. **Joint placement:** Control joints should be placed if prevention of random cracking of the pavement is desired, although the joint spacing is usually larger than for conventional concrete pavements because pervious concrete tends to shrink much less. Recommended joint spacing of 20 ft (6 m) has been suggested, although some installations have had joint spacing of 45 ft (13.5 m) or more without uncontrolled cracking. Because setting time and shrinkage are accelerated in pervious concrete construction, joint installation should be soon after consolidation, with a rolling joint tool.

6. **Finishing:** Typically, pervious concrete pavements are not finished in the same way as conventional concrete pavements. Normal floating and troweling operations tend to close up the top surface of the voids, which defeats the purpose (for most applications) of pervious concrete. For the majority of pervious pavements, the "finishing" step is the compaction. This leaves a rougher surface, but can improve traction.
7. **Curing and Protection:** The open structure and relatively rough surface of pervious concrete exposes more surface area of the cement paste to evaporation, making curing even more essential than in conventional concreting. Water is needed for the chemical reactions of the cement, and it is critical for pervious concrete to be cured promptly. Because pervious concrete pavements do not bleed, they can have a high propensity for plastic shrinkage cracking. In fact, "curing" for pervious slabs and pavements begins before the concrete is placed--the sub grade must be moistened to prevent it from absorbing moisture from the concrete. After placement, fog misting followed by plastic sheeting is the recommended curing procedure, and sheeting should remain in place for at least seven days. Using sand or dirt to hold plastic sheeting in place is not recommended because clogging of the voids could result from spillage on removal. Instead, it is recommended to secure plastic sheeting with lumber, rebar, stakes, or other methods. Curing should be started as soon as practical after placing, compacting, and jointing. Best practice calls for curing to begin within a maximum of 20 minutes after these procedures. High ambient temperatures and

windy conditions will have more pronounced effects relative to conventional pavements, and should be taken into account.

(National Ready Mix Concrete Association 2010)

For permeable pavers, a similar sub base is used, but a layer of sand or small aggregate conforming to ASTM C33 is placed over the base layer, called the bed layer (Figure 20). The spaces between the layers are filled with crushed aggregate or sand. Pervious asphalt is installed similar to regular asphalt, but uses no fines (similar to pervious concrete).

Drainage

When constructing pervious pavement in soils with low permeability it may be necessary to install a drain system to convey excess water that builds up under the pavement (Figure 22).

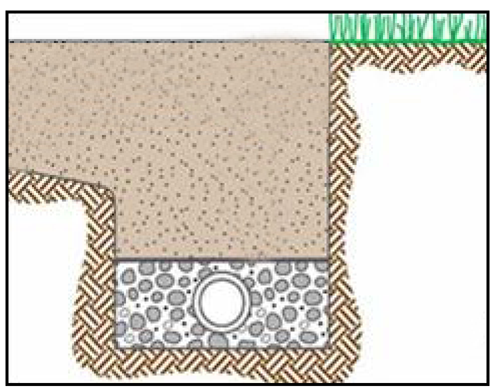

Figure 22: Cross section of pervious pavement with an underdrain.

This is necessary primarily in soils with high clay content, a common feature across Oklahoma. A good rule of thumb is that soils with less than ½ inch per hour of infiltration will need additional drainage. There are many different options for creating the required drainage, including drainage pipes and channels. The drainage system may also require a thicker sub base to provide additional storage.

Application

Pervious pavement can be employed in a wide variety of areas, but has several important limitations. It should not be used in areas that will experience heavy loads, such as major roads and highways. It also should not be placed in areas that experience heavy erosion or are sanded in the winter, as this can clog the concrete. Areas where hazardous materials are present are not suitable. The ideal locations for the placement of pervious concrete are neighborhood streets, walking paths, patios, or parking areas. The permeability of the soil is also important to consider. Soils with low permeability may require the use of under drains as they will not be able to adequately absorb the incoming rainfall.

Figure 23. Comparison of standard concrete (left) with pervious concrete (right) after snow plowing (http://www.go-explore-trans.org).

It was previously believed that pervious pavement, with its lower strength and rigidity, would not be well suited for the more strenuous winter conditions. However, permeable pavement has in fact been in use since the 1970’s and was first installed in New England. In addition, recent studies in New Hampshire suggest that pervious pavement might actually perform *better* than typical concrete. When snow melts on the pervious pavement, it infiltrates through, leaving a dry surface that won’t refreeze and lead to dangerous black ice conditions. The void spaces also allow increased air flow which increases snow melt from the surface of the pavement. In addition, the need for sand or salt is reduced since the pervious pavement already provides a surface with more traction than traditional concrete (Gunderson 2008).

Water-quality Benefits

Pervious pavement has a wide range of water quality benefits. While impermeable pavement causes higher runoff loads and peak flows, pervious pavement can in many situations completely eliminate not only the negative effects of the increased runoff, but runoff entirely. Pervious pavement can also reduce the pollutant loads from paved surfaces. By directing stormwater into the soil it prevents the water from entering the surface drainage systems and allows it to be filtered by the soil. Studies have shown that pervious pavement is effective at filtering suspended solids, heavy metal and other pollutants such as phosphorus and nitrogen. Pervious pavement accomplishes this without the installation of expensive, land consuming ponds and treatment plants. While removal rates of nutrients, heavy metals and other pollutants are widely varied, results have shown that significant achievements can be made throughout the country.

Table 18: Selected water quality removal data from pervious pavement

		Percent Removal		
Application	Location	TSS	Metals	Nutrients
Permeable Pavers				
Driveways	Jordan Cove, CT	67	Cu: 67 Pb: 67 Zn: 71	TP: 34 NO_3-N: 67 NH_3-N: 72
Parking lot	Goldsboro, NC	71	Zn: 88	TP: 65 TN: 35
Parking lot	Renton, WA	--	Cu: 79 Zn: 83	--
Parking lot	King College, ON	81	Cu: 13 Zn: 72	TP: 53 TKN: 53
Pervious Concrete				
Parking lot	Durham, NH	91	75-92	--
Pervious Asphalt				
Parking lot	Durham, NH	99	Zn: 97	TP: 42

[TSS, total suspended solids; CT, Connecticut; %, percent; Cu, copper; Pb, lead; Zn, zinc; TP, total phosphorus; NO_3-N, nitrate as nitrogen; NH_3-N, ammonia as nitrogen; NC, North Carolina; TN, total nitrogen; WA, Washington; --, not available; ON, Ontario; TX, Texas; NH, New Hampshire]

Sources: (Rushton, 2001; Bean et al., 2007, Clausen and Gilbert, 2006; Van Seters/TRCA, 2007; Barret et al., 2006; UNHSC, 2007)

Maintenance

As with traditional pavement, proper maintenance is vital to the longevity and infiltration efficiency of pervious pavement. Clogging is a serious concern for pervious pavement systems. Clogged pavement leads to reduced benefits, and can completely negate the original benefits. The pavement should be checked after each major storm to ensure that it is still functioning properly. It should also be vacuumed (recommended) or horizontally air jetted at least once a year to ensure that the system doesn’t clog. Some sources also recommend power washing to remove sediment, but this may compromise the structural integrity of the pervious pavement surface and entrain particles deeper within the pavement. Debris should be cleared from the surface of the pavement. Pervious pavement should not be built in an area that is prone to high sediment loads. If properly maintained, pervious pavement can last significant periods of time. Systems installed 20 years ago in North Carolina are still working nearly as well as the day they were first built. It is estimated that infiltration rates generally drop 10-20% throughout the life of the system. “Permeable pavements will function for up to 20 years if they are constructed in areas free of disturbed soil and regularly maintained (Hunt 2006)”. Traditional permeable pavers may lose their color in a relatively short time because of efflorescence. Efflorescence is a hardened crystalline deposit of salts that migrate from the interior of concrete pavers to the surface. Over time efflorescence can affect the appearance of the surface (appears white, gray, or black) and may cause the surface to become slippery when exposed to moisture. Calcium and lime efflorescence can be removed chemically without damaging the integrity of the paving surface.

Limitations

Pervious pavement systems do have limitations and these should be considered when contemplating the use of a pervious system. Generally, the system is not designed for use in high traffic areas such as highways, interstates and arterials streets. In addition, it is not a good idea to place the system in areas where there is the potential for large amount of sediment or other debris that could clog the system. Also, the pervious pavement systems are not ideal in locations where there are high water tables.

Economic Benefits and Cost

Pervious pavement often results in lower overall construction costs due to elimination of the need for large detention ponds and other stormwater drainage infrastructure, since the pavement itself acts as a detention area. Specifically, parking lot owners that use pervious concrete will spend less on labor, construction, and maintenance of detention ponds, skimmers, pumps, drainage pipes. There is also the potential to gain land that can be developed for a more profitable use. In some locales, pervious concrete can reduce stormwater fees for the property owner by helping to minimize demands upon sewer systems. Pervious concrete can also benefit local economies because it uses local products (course aggregates) for construction.

Pervious asphalt costs approximately 10-15% more than conventional asphalt, while pervious concrete costs about 25% more than regular concrete. Structural pavers can be three or four times more expensive than conventional pavement. Maintenance for a pervious parking lot costs on average $200 per acre per year (Sustainable Cities Institute 2011). In Oklahoma, the authors received a quote in July 2010 that indicated that pervious concrete was approximately 50% more than conventional concrete at that time. However, we expect this price difference to decrease as demand increases and more contractors become familiar with methods for installing pervious concrete.

Oklahoma Examples

Pervious pavement is not yet in wide use in Oklahoma. However, there are some examples if you go looking for them. The following are known locations of permeable pavement systems in Oklahoma.

- Agricultural Resource Center on the OSU-Oklahoma City campus (permeable pavers)
- OSU Botanical Gardens-Stillwater (permeable pavers)
- Federal Building – Oklahoma City (pervious concrete)
- Riverwind Casino- Norman (pervious asphalt)
- Silver Tree Interiors – Edmond (permeable geogrid system)

Figure 24: Permeable geogrid system at Silver Tree Interiors in Edmond, OK

Figure 25: Oklahoma Federal Building pervious parking lot

For more information on this topic in Oklahoma, go to the following websites and watch three Oklahoma Gardening shows dedicated to pervious pavement:

Part 1 http://www.youtube.com/oklahomagardening#p/a/u/2/wvuAXhAfFLs

Part 2 http://www.youtube.com/oklahomagardening#p/a/u/0/PzcQlSjsKa0

Part 3 http://www.youtube.com/oklahomagardening#p/a/u/1/56ne6SLYyUs

For Additional Resources on Permeable Pavement, visit us on the web at:

http://lid.okstate.edu/pervious-pavement

Acknowledgements

I wish to recognize Kevin Stunkel as a contributing author to this chapter.

CHAPTER VIII

NATURAL AND ENGINEERED WETLANDS

In Oklahoma wetlands can take many forms and afford a variety of benefits. Over the years, many wetlands have been lost to agricultural production and urban development. The importance of wetlands has only more recently been realized. Due to the ability of wetlands to act as a filter for pollutants, habitat for wildlife and infiltrate stormwater runoff, among many other benefits, the preservation of natural wetlands and the construction of engineered wetlands are gaining in popularity. The following information will discuss the uses of wetlands, environmental benefits of wetlands, construction of engineered wetlands, and the required maintenance activities associated with these features.

Wetlands are areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for existence in saturated soil conditions (OCC 2010). Wetlands are identified by have each of the following three characteristics during some portion of the growing season:

1. *Hydrology*: Refers to the presence of flooding or soil saturation for a sufficient duration of time during the growing season.

2. *Soil*: Hydric soils have characteristics that indicate they were developed in conditions where soil oxygen is limited by the presence of saturated soil for long periods during the growing season. If the soil in your area is listed as hydric by the Natural Resources Conservation Service, the area might be a wetland (U.S. Army Corp of Engineers 2011).

3. *Vegetation*: Wetlands can contain certain vegetation like cattails, but can also have trees, annual and perennial herbaceous plants, shrubs, vines and grasses. This is called hydrophytic vegetation.

Riparian wetlands are located adjacent to streams or lakes. Generally, there is direct hydrologic interaction (the wetland is connected directly to the water body) between wetland soils and biota in laminar flow regimes (slow moving flow regimes). Nutrient and pollutant removal can occur through a variety of biological and physical processes, which improves water quality of the stream or lake (Water Encyclopedia 2010).

Figure 26: Engineered wetlands in Stillwater, Oklahoma
Source: (Nutley 2010)

Functional Uses of Wetlands

Historically, wetlands were considered to be wastelands that should be drained as soon as possible for farming, residential or industrial development. Wetlands were not considered valuable resources, and their complex ecological and hydrological functions were, for the most part, unrecognized. Only recently have wetlands been recognized as valuable natural resources that, if maintained and properly managed, can provide important benefits to the public and the environment. For example, wetlands can protect or enhance water supplies, improve water quality, reduce flooding, provide valuable habitat for wildlife, and contribute to the biological diversity and stability of the ecosystems upon which we all depend.

Wetland Value and Benefits

Wetlands are often described as "nature's kidneys" because they are able to filter out pollutants and other impurities from the water (Ohio EPA 2007). Particles can settle in the wetlands, while other impurities bind to plant surfaces or are degraded by microbes, improving the quality of water. Wetlands are beneficial to the environment by providing a home for endangered plants which are found only in wetlands. They also provide important habitat for fish, birds, and other types of wildlife. Wetlands also help with preventing flooding and controlling shoreline erosion, while improving recreation such as fishing, floating and swimming (Ohio EPA 2007). The degree to which a wetland performs a function is related to, and defined by, a complex web of interrelations among the wetland's characteristics and its landscape setting, upstream contributors, downstream receivers, and biotic interactions. The functions associated with Oklahoma wetlands are:

Water Quality Enhancement -Wetlands have a capacity to enhance the physical and chemical condition of water from a base condition by:

Sediment/Toxic Substance Retention. Reducing the concentration of suspended and bed-load sediment, and attendant toxicant load, through energy dissipation, precipitation, ionization, and/or biotic bonding.

Nutrient Removal/Transformation. Reducing the concentration or modifying the form of nitrogen, phosphorus, and potassium ions through oxidation, reduction, assimilation, or other biochemical processes. A study conducted in North Carolina by Glen (2008) found that stormwater wetlands had an 85% total suspended sediment (TSS) removal rate. This is very important since sediment is the number one pollutant in the United States. The wetlands were also shown to have a fairly good removal rate for total nitrogen (TN) and total phosphorus (TP).

Reduction of Flood Impacts -Wetlands reduce the volume and physical energy of water below a base condition, through:

Flood Peak Reduction: Wetlands influence regional water-flow regimes by intercepting stormwater runoff and temporarily storing excess surface waters, thereby reducing stormwater runoff peak discharges by storing and slowly releasing runoff over a longer period of time.

Erosion Potential Reduction: Wetlands in the natural state are usually vegetated. This vegetation reduces the velocity of flood waters and wave action, thereby lessening the potential for erosion of shorelines and floodplain areas. The root systems of wetlands vegetation bind the floodplain and shoreline soils to further resist erosive forces.

Biological Productivity - Wetlands provide habitat, including food, water, cover, and reproductive features, that supports a diverse array of wetland-dependent or indicative species and populations.

Vegetation: Species of plants typically adapted to periodically anaerobic soil conditions.

Food Chain Support: Providing primary and secondary productivity that support faunal communities within the wetland and in adjacent and downstream waterbodies.

Groundwater Influences - Wetlands significantly influence shallow water aquifers within their vicinity by:

Groundwater Recharge: Retaining water and allowing for its percolation into the underlying aquifer.

Low Flow Augmentation: Releasing water to adjacent streams or water bodies during dry periods of the year and during drought.

Groundwater Discharge Buffering: Enhancing the quality of groundwater discharge by providing a biochemical water treatment system.

Direct Human Benefits - In addition to the societal benefits provided by normal wetlands functions, several direct human benefits can be derived from wetlands and their functions through managed use. Opportunities for human uses compatible with sustained wetlands conditions include:

Recreation: Use for play, amusement, relaxation, and/or physical and mental refreshment.

Education: Use for training and developing knowledge and skills.

Timber Production: Providing the potential for profitable production of wetland endemic trees through management that is compatible with sustained wetland conditions.

Agricultural Production: Providing the potential for agricultural resource management consistent with sustained wetland conditions. (OCC 1996)

Natural Wetlands in Oklahoma

In Oklahoma, wetlands conservation and management are shared responsibilities among federal, state, and local agencies as well as conservation organizations, private corporations, landowners, and other interest groups. Individually, no agency or group has either the mandate or the resources to adequately protect wetlands. Wetlands conservation and management are accomplished only through cooperative and continued efforts of these groups and individuals (OCC 1996).

About 950,000 acres of Oklahoma are covered by wetlands, approximately 2 percent of the state. Most wetlands are found in eastern Oklahoma where precipitation is high and evaporation is low. Oklahoma wetlands include “bottom-land hardwood forests and swamps; marshes and wet meadows; aquatic-bed wetlands.” About two-thirds of

Oklahoma's wetlands have disappeared from changes in "agricultural conversions, channelization, impoundment, stream flow regulation and other causes (Yuhas 1996)." Voluntary programs such as the United States Fish and Wildlife Service Partners for Wildlife Program and the USDA Wetland Reserve Program need to be expanded in Oklahoma, and could serve as models for conservation of wetlands on private lands. (OCC 1996)

Engineered Wetlands

Since natural wetlands have such a positive benefit to the environment, many scientists and engineers create wetlands systems that function just like a natural wetlands (U.S. EPA 2004). These engineered wetlands are sometimes called "treatment wetlands," because they are treating stormwater runoff or river water for such pollutants as nitrogen and phosphorus. These treatment wetlands can be a more cost efficient way of treating pollutants and add beauty to an environment while also reducing unwanted odors (U.S. EPA 2004). Treatment or engineered wetlands are mostly built in areas outside flooded land to avoid damage to the natural environment or aquatic life (U.S. EPA 2004). They are made with natural plant life in soil and constructed to establish a "desired hydraulic flow" so pollutants can be lowered while flowing through the wetland. Recent research at OSU and other places across the country have also indicated that injecting alum or other coagulants at the wetland inflow may remove a significant portion of the phosphorus and sediment load compared to traditional engineered wetlands without alum addition (Dr. Dan Storm, OSU BAE, personal communication)

Advantages and Disadvantages of an Engineered Wetland

There are several advantages to engineered wetlands. They cost less than many other alternatives to lowering pollutants. They provide a habitat for both aquatic species and non-aquatic wildlife, and provide hunting. Wetlands also protect against floods and make the environment more appealing as a whole. There are some disadvantages to a constructed wetland system. During high water flow events water is difficult to control, without building structures within the system, and can potentially damage the wetland. They also require more space, and the removal rates vary from season to season. Constructed wetlands vary in cost according to the "number and sizes of treatment cells required." They can range from $35,000 to $150,000 per acre (Brookhaven National Laboratory 2001).

Wetland Zones

Figure 27 shows the five different zones of the interior areas of a wetland. The first zone consists of deep pools, which can dissipate "flow energy, trap sediment coming in with stormwater and provide an anaerobic environment for enhanced nitrate treatment." Zone II is deep to shallow water transitions and the average depth is 18 to 30 inches for deep pools and 2 to 4 inches for shallow water. This zone has slight slopes that connect to the deep pool. Zone III is shallow water zones that "retain water following a storm event." When flows are low, water entering the wetland should go through the shallow water zone. The depth is approximately 6 to 12 inches. Zone IV is the temporary inundation which is an internal flood area. It "surrounds the channel of shallow water and extends to the wetland's lower bank. It is designed for inundation or overflow when a storm larger than the design "water quality event" occurs. Zone V is "the upper bank" which is the upper area of the wetland. This is the part of the wetland that ties back to the surrounding area (Hunt et al. 2007).

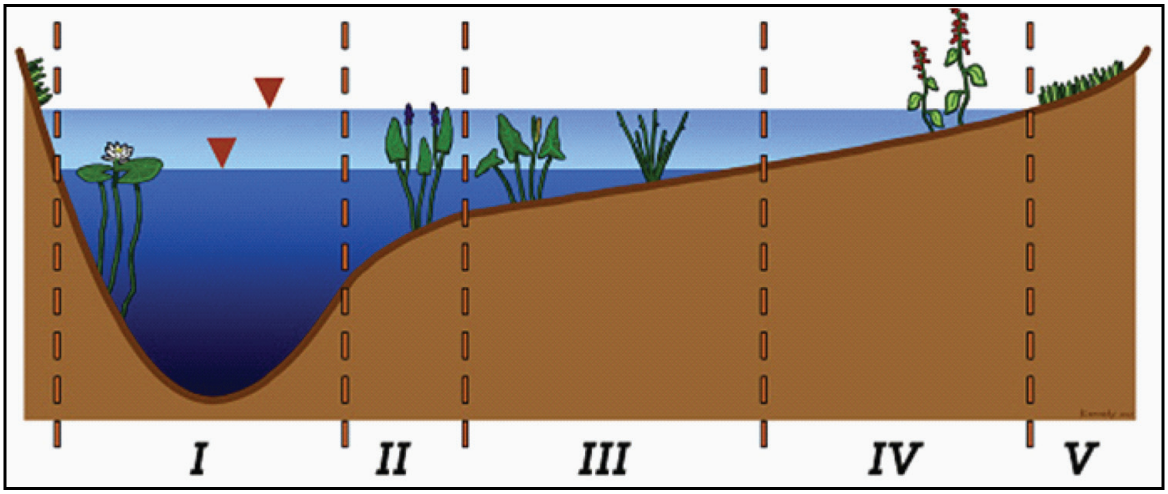

Figure 27: Zones of a Wetland
Source: (Hunt et al. 2007)

Wetland Construction

A plan that outlines the most efficient sequence for constructing the stormwater wetland can save both time and money. In general, a wetlands construction sequence involves the following steps (Burchell, et al., 2010):

1. **Site Layout**

   This involves staking out the important features of a wetland on the site based on design drawings. More complex wetlands may require site surveying to establish grade stakes, a wetland perimeter, and the location of internal wetland features (such as pools and shallow water). Large wetlands that involve deep excavations may require multiple stakeouts throughout construction. All existing utilities at the site must be identified and marked *before* any construction activities occur.

2. **Erosion Control Measures**

   In Oklahoma, sites that disturb less than 1 acre are not required to have a sediment and erosion control plan. However, site managers are still required to take measures that will prevent soil from leaving the site, such as installing silt fences and rock check dams at appropriate locations. If you are required to follow an erosion and sediment control plan, put the measures in place at the beginning of the project prior to excavation. Erosion control measures may need to be installed in phases, and a detailed installation schedule will be a part of an erosion control plan. In general, all erosion control measures must be inspected and maintained regularly and after each rainfall.

3. **Outlet Construction**

   If inflows can be diverted around the proposed wetland during construction, outlets can be installed at any time. If the proposed wetland has been designed to be "in-line" with stormwater flow, outlet structures should be installed before any other major excavation. Establishing the outlet will give the structure more time to stabilize, and contractors will be able to control site drainage if groundwater seepage or rainfall occurs during construction.

4. **Excavation and Wetland Soil Preparation**

   After the site layout has been staked, erosion control measures put in place, and the outlet installed, excavation of the site can commence. Excavation of the stormwater wetland should begin near the outlet and progress towards the proposed inlet(s) (generally from downstream to upstream). Many stormwater wetlands will require preparation of subsurface soils by compaction or soil additions (such as bentonite) to reduce infiltration. In addition, most sites will require at least topsoil addition, while others may require the incorporation of organic matter to improve vegetation growth.

5. **Bank Stabilization**

   As excavation of the site progresses, the banks should be stabilized by seeding with fast-germinating grasses native to your location. Installing lightweight erosion control fabric at the end of each day will reduce bank erosion after rainfall events.

6. **Inlet Stabilization**

   After site excavation and stabilization, the areas surrounding the inlet and the forebay should be armored to dissipate the stormwater's energy as it enters the wetland. Energy can be dissipated in several ways. The most popular, effective method is to stabilize the inlet with riprap underlain with geotextile fabric. Some stormwater wetlands may have multiple inlets, so be sure to stabilize all of the inlets appropriately.

7. **Final Surface Preparation**

   If the wetland surface becomes compacted through unavoidable construction traffic or crusted during extended hot, dry weather, tilling or scarifying the surface prior to planting will encourage plant growth. It is important to avoid compaction of the surface while still maintaining proposed grades, so lightweight equipment will be needed to till or scarify. Strict oversight of grading in this phase is critical to successful wetland development.

8. **Planting**

   Wetland plants should be planted at the end of construction (ideally in an appropriate season) in the recommended internal wetland zones. Shrubs for wetland banks also are often planted at this time. A procedure to help determine the number of wetland plants needed for your project is shown in the callout box. Table 2 also lists some of the wetland plant species common to Oklahoma wetlands.

9. **Water Management**

   The adjustable outlet should be set to maintain an appropriate water level for early vegetation establishment within the wetland. By adjusting the outlet, a source of water can also be provided during extended droughts. In some areas a supplemental water source may be needed to maintain saturation during extended droughts.

A procedure to help determine the number of wetland plants needed for your project is shown in Figure 28. Table 19 also lists some of the wetland plant species common to Oklahoma wetlands.

Estimating the Number of Wetland Plants

The number of plants needed for a project can be easily estimated based on the wetlands surface area and the required spacing that your budget will allow. Numerous plant spacing calculators are available via the internet. Most use a simple calculation based on the following relationship:

Number of plants = Planting area (ft^2) ÷ (Plant spacing (ft))^2

You can use the following formulas derived from this relationship to calculate the number of plants required:

12-inch spacing:

No. plants = ft^2 of wetland area

No. plants = 43,560 x acres of wetland

24-inch spacing:

No. plants = 0.25 x ft^2 of wetland area

No. plants = 10,890 x acres of wetland

36-inch spacing:

No. plants = 0.11 x ft^2 of wetland area

No. plants = 4,841 x acres of wetland

Planting on 12-inch centers will ensure widespread vegetation coverage within 1 year; 24 and 36-inch centers tend to be adequate for coverage in 2 and 3 years, respectively.

At least 6 months before construction notify any local nurseries that will provide plants of the varieties and numbers you will need for your project to make sure the plants will be available (particularly if your project is sizeable).

Figure 28: Method to Estimate Number of Wetland Plants Needed (Burchell et. al 2010)

Table 19: Wetland plants for Oklahoma

Common Name	Latin Name
Alder	*Alnus spp.*
Arrowhead	*Sagittaria latifolia*
Bald Cypress	*Taxodium distichum*
Barnyard Grass	*Echinochloa crusgalli*
Blue Beech	*Carpinus caroliniana*
Bladderwort	*Utricularia vulgaris*
Buttonbush	*Cephalanthus occidentalis*
Common Cattail	*Typha latifolia*
Cocklebur	*Xanthium spp.*
Cottonwood	*Populus deltoides*
Pale Dock	*Rumex altissimus*
Elm	*Ulmus spp.*
Ferns	*Osmunda spp.*
Frog Fruit	*Phyla ianceolata*
Hibiscus	*Hibiscus spp.*
Lizard's Tail	*Saururus cernuus*
Mud Plantain	*Heteranthera dubia*
Pecan	*Carya illinoensis*
Rushes	*Juncus spp.*
Spikerush	*Eleocharis spp.*
Green Spangletop	*Leptochloa dubia*
Stinkweed	*Pluchea camphorata*
Sumpweed	*Iva spp.*
Tamarisk	*Tamarix chinensis*
Tearthumb	*Polygonum sagittatum*
Water Hyssop	*Bacopa spp.*
Water Primrose	*Ludwigia hexapetala*
Black Willow	*Salix nigra*

Source: (OCC 2000)

Maintenance

If the wetland is “front and center” on a site it needs to be more attractive and therefore specific planting plans should be followed. Maintenance becomes more important. In addition to design, stormwater wetlands must be maintained to keep mosquitoes from becoming a problem. Some common maintenance requirements include (Glen 2008):

a. Removing unwanted trees and shrubs: An abundance of woody species was found to provide a safe harbor for mosquitoes. It is reasonable to have a limited number of woody species (one recommendation is 1 tree per 3,000 square feet of wetland) but others will volunteer.
b. Removing cattails: Cattails are very aggressive and can crowd out other vegetation if given enough time. Removing cattails as they become established in the wetland is an annual to semi-annual process which should not be time consuming.
c. Removing trash and other floatables: wetlands, like all BMPs, receive water from a larger watershed meaning that not only water comes to the wetland, but everything in or carried by the water, as well. Trash will inevitably collect in a wetland if there is a human population in or adjacent to the wetland’s drainage catchment. Floating trash provides mosquitoes an area free of many predators.
d. Trash removal from outlet: In addition to being unsightly, trash can also clog a wetland’s outlet. A clogged outlet will necessarily raise the elevation of the water inside the wetland, which may cause desirable vegetation to die. Into these voids of dead vegetation the hardier species (like cattails) will take over.

Source: (Glen 2008)

Limitations

There are also limiting factors to consider when deciding to build an engineered wetland. First, care must be taken to ensure that the defined wetland area will receive enough stormwater runoff to support wetland plants. Depending on the size of wetland desired, space might also be a limiting factor. Public perception of wetlands is also something to think about. Unfortunately, the public often perceives wetlands as mosquito breeding swamps that harbor snakes and rats. To deal with this misconception, education and interaction with the community about the proposed wetland is a great way to prevent negative perceptions.

Oklahoma Example

Figure 29: Natural wetland in Edmond, Oklahoma

Bridgewater, Edmond

In the residential development Bridgewater, in Edmond, a small natural wetland provides several benefits in the middle of a suburban neighborhood. The wetland acts as a filter for stormwater runoff from an adjacent neighborhood before it enters a large series of ponds.

Since the wetland is natural to the area, there were no costs associated with it. However, the cost of building a man-made wetland can vary greatly depending on the size, location, and plant species. Notice in Figure 29 that the wetland is not saturated with water. This particular area was identified by a private consultant as a wetland due to its hydrology, vegetation and soils. However, benefits can be realized under a variety of conditions that are characterized as a wetland. This example in particular provides both an aesthetic and water quality benefits to the residents in the neighborhood.

For Additional Resources on Wetlands, visit us on the web at:

http://lid.okstate.edu/wetlands

Acknowledgements

I wish to recognize Mattie Nutley as a contributing author to this chapter.

CHAPTER IX

GREEN ROOFS

Introduction

Green roofs are vegetative systems that include different types and forms of vegetation that are installed on rooftops. The terms green roof, living roof and vegetative roof are used interchangeably and describe the same system. When stormwater falls on a green roof it is absorbed by the soil and vegetation and then transpired back into the atmosphere, thereby reducing rooftop runoff. Green roofs have been widely used in Europe since the 1970's and have recently started to gain in popularity and acceptance in the United States. Green roofs are appropriate when reducing the overall amount of stormwater runoff is a desired goal. They are an effective practice to use in dense urban areas, in areas where infiltration is difficult due to soil or bedrock limitations, or on sites where infiltration is undesirable due to existing soil contamination. (MAPC 2005)

Green roof projects may fall under two categories: retrofits and new construction. Since green roofs require structural support it is very important to consult a Professional

Engineer to determine if the existing structure can support the extra weight. With new construction it is equally important to consult an engineer to design the appropriate system. A landscape architect should also be consulted to prepare a planting scheme. Before construction, research should also be done to identify a qualified contractor with experience in green roof installation.

Benefits

Green roofs can confer a variety of benefits to both the owner of the property and the environment. These benefits can be economical, aesthetic and social. The following are some of the known benefits of green roofs:

- Green roofs effectively reduce stormwater runoff. Researchers at North Carolina State have found that a 3" green roof can retain approximately 0.6" of rain for each rainfall event, even when storms come on consecutive days (Moran et al. 2004). The Center for Green Roof Research at Penn State University reports that a 4" green roof can retain 50% of total rainfall over a series of storm events (PSU 2005). Green roofs retain rainfall from small, frequently-occurring storms by storing rainfall in the soil. In turn, this water is lost to evaporation or transpiration by plants. For larger storms, the runoff volume and peak flow rate is reduced because of percolation and temporary storage in the soil. Green roofs improve water quality through a variety of physical, biological and chemical processes in the soil (Glen 2008).

- Green roofs reduce peak discharge rates by retaining runoff and creating longer flow paths. Research indicates that average peak flow reduction can range from 78% to 87% (Moran et al. 2004).
- The presence of a green roof helps to reduce air temperatures around the building, reducing the “heat island” effect and reducing the production of smog and ozone that can form in the intense heat (175 degrees) over large conventional roofs. The vegetation on green roofs also consumes carbon dioxide and increases the local levels of oxygen and humidity.
- Green roofs have demonstrated aesthetic benefits that can increase community acceptance of a high-visibility project; they may also add value to the property if marketed effectively.
- Because green roofs shield roof membranes from intense heat and direct sunlight, the entire roofing system has a longer lifespan than conventional roofs.
- Urban wildlife habitat is provided for pollinators like birds and bees. This can contribute to biodiversity in urban areas.
- Green roofs are becoming more popular to grow vegetable and herb gardens.
- Green roofs can provide recreation and improved well being through walking trails the availability of outdoor space.
- Green roofs lower heating and cooling costs because the trapped air in the underdrain layer and in the root layer help to insulate the roof of the building. During the summer, sunlight drives evaporation and plant

growth, instead of heating the roof surface. During the winter, a green roof can reduce heat loss by 25% or more. (MAPC 2005)

General Design

Green roof design can be customized to optimize for each of the benefits shown above, but most of these benefits can be realized with a little creativity. In general, green roofs typically consist of a number of layers: structural support, a waterproofing membrane, a drainage system, root protection, growing media and vegetation (Figure 30) and may cover all or part of a building's roof.

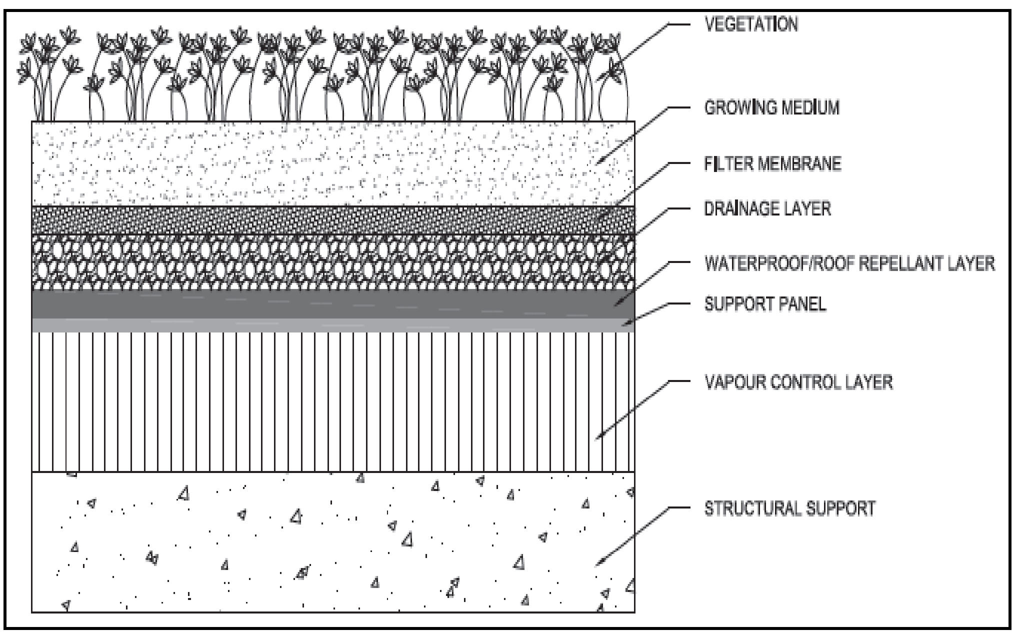

Figure 30: General diagram of green roof layer
Source: (Charles River Watershed Association 2008)

Other general design considerations including access routes and safety harness hooks for inspection and maintenance personnel should be identified during the design phase (MAPC 2005).

Types of Green Roofs

Extensive. Extensive green roofs are lightweight vegetated roofs consisting of 4-8 inches of growth media (or soil), planted with hardy species to minimize irrigation, maintenance, cost and weight. The vegetation on extensive green roofs usually consists of hardy, low-growing, drought resistant plants that create a dense cover and are able to withstand heat, cold, and high winds. Plant varieties most often used are succulents such as *Sedum* and *Delosperma*.

During dry periods, these plants wilt but do not die back. When it rains, they absorb large amounts of water which quickly restores their vigor. Grasses and herbs are less common on green roofs because to survive dry periods they require either irrigation or deeper substrate that retains more water (MAPC 2005). However, if grass is desired for a green roof in Oklahoma Buffalo Grass is a good native species to consider. This is due to its resistance to heat, drought and cold conditions. Extensive roofs are well-suited to both retrofit projects and new construction. An extensive green roof and a planting tray are shown in Figures 31 and 32.

Figure 31: Extensive green roof in Minneapolis, MN
Source: (www.greensroofs.com)

Figure 32: Planting tray for extensive green roof

Extensive green roof systems are composed of several layers. The roof systems may be modular interlocking components or each layer may be installed separately. Either way an extensive green roof is constructed with the following basic layers (starting at the bottom): structural support, a waterproof roofing membrane (including flashing), a root barrier, drainage, a filter fabric (for fine soils), growing medium (soil) and plant materials and mulch. Material for the growing medium must be weed-seed free and the proper material and depth for the particular roof style. Generally, a building's structure must be able to support an additional 10-25 pounds per square foot of weight, depending on the growth media and vegetation used. For new construction, the load requirement of the green roof can be addressed as part of the building's design process. Additional structural support may be necessary for a retrofit project; however, many existing buildings are constructed with adequate structural support to accommodate a green roof (Glen 2008).

Intensive. Intensive green roofs, sometimes called roof gardens, may support lawns, trees, and even gardens. They are designed as a complete soil/plant system on the roof and are not modular like the extensive systems. Intensive green roofs can provide the same environmental benefits of extensive green roofs, but do require extra structural support, greater depth of media, cost, and have functional goals in addition to stormwater management objectives. Depending on the additional objectives of the green roof, this cost can be offset by extra benefits such as outdoor recreation, aesthetic beauty, and production of fruits and vegetables. They also typically require supplemental irrigation systems. Figure 33 shows an intensive green roof in Boston, Massachusetts.

Figure 33: Intensive green roof in Boston, MA
Source: (www.greenroofs.com)

When deciding between an intensive or extensive roof the property owner should consider objectives of installing the roof, the desired maintenance requirements, the structural capacity of the roof, and accessibility of the roof. Soil depth is another critical design variable that strongly influences the rainfall retention capacity. Though several other site factors will need to be considered, such as the aspect of the roof, the microclimate of the site, prevailing winds and the building's functions – most factors can be accommodated in an appropriate green roof design (Glen 2008)

Plant Selection

Plant selection for a green roof depends on a variety of factors, including climate, type and depth of growing medium, loading capacity, height and slope of the roof, maintenance expectations, and the presence or absence of an irrigation system. Successful extensive green roof plants must exhibit characteristics such as easy propagation, rapid establishment, and high ground cover density (White 2003). Succulent plants have often been indentified as well adapted to extensive green roof conditions. The genus *Sedum* is a popular choice for green roofs in many locations. Other succulents such as *Delosperma*, *Euphorbia*, and *Sempervivum* have also been utilized on green roofs, and there is good argument to limit the monoculture of Sedum-based roofs and include more native species (Getter 2006 and Monterusso, et al. 2005). A list of plants that have been successful on green roofs in both the Midwest and Oklahoma is shown in Table 20. Further research is needed to determine more plants that can be used on green roofs in Oklahoma.

Table 20: Green roof species for Oklahoma

Scientific Name	Common Name
Allium cernuum	Nodding Wild Onion
Dalea purpurea	Purple Prairie Clover
Fragaria virginiana	Wild Strawberry
Koeleria macrantha	Prairie Junegrass
Opuntia humifusa	Prickly Pear
Potentilla anserma	Cinquefoil
Schizachyrium scoparium	Little Bluestem
Sedum acre	Biting Stonecrop
Sedum album	White Stonecrop
Sedum cauticola	Stonecrop
Sporobolus heterolepsis	Prairie Dropseed
Gaura lindheimeri	Beeblossum
Gaillardia Aristata	Arizona Sun
Verbena Canadensis	Rock Moss Vervain
Nassella Tenuissima	Mexican Feather Grass
Oenothera Macrocarpa	Evening Primrose

Source: (Adapted from Getter 2008 and Rowe 1998)

Costs

The cost of a green roof varies considerably depending on the type and factors such as the depth of growing medium, selected plants, size of installation, use of irrigation, and whether they are accessible or inaccessible as well as intensive or extensive. Intensive green roofs typically require greater investment but confer the benefits of accessibility. Estimated costs of installing a green roof start at $10 per square foot for extensive roofing, and $25 per square foot for intensive roofs (Peck and Kuhn 2003). Annual maintenance costs for either type of roof may range from $0.75 - $1.50 per square foot (Peck and Kuhn 2003). While green roofs typically require a greater initial investment, it is important to keep in mind that they can extend the life of the roof membrane and reduce the heating and cooling costs of the building. It is important to speak to a qualified green roof professional about the range of costs and benefits for different green roof systems and designs (Green Roofs for Healthy Cities undated).

Inspection and Maintenance

As with any structure inspection and routine maintenance are vital to ensuring longevity and functionality of the system and green roofs are no exception. By following scheduled inspections, this allows the owner to notice and remediate any issues before they get out of control and become costly repairs. Keep in mind the guidelines listed below and maintenance activities should be minimized. (Glen 2008).

- Upon installation, the green roof system should be inspected monthly for the first year and after each large storm event for erosion, plant survival, proper drainage and water proofing.

- Check for leaks on the roof prior to the green roof installation and have a leak detection system installed.

- Inspections can be reduced to a quarterly schedule once the green roof system has proven to work properly and vegetation is established.

- If necessary, irrigate in short bursts (3-5 minutes) to prevent runoff. Irrigation frequencies should be established by the designer using an automated system.

- Inspect and clean out drain inlets as needed.

- Weeding and mulching may be necessary during the establishment period, depending on the planting design.

• Replace or fill in vegetation as needed.

• Inspect soil levels semi-annually to ensure plant survival and rainfall absorption.

Limitations

While there are many benefits to installing green roofs, it is important to recognize that there are limitations to this practice. Every roof and building is different and it is important to recognize that a green roof might not be appropriate for certain structures. By contacting professionals in the green roof industry and having them assess the potential for a green roof on your project you can make an informed decision about whether a green roof is the right choice.

Some limitations to green roof usage include (MAPC 2005):

- Because green roofs return rainwater to the atmosphere, they should not be used in situations where groundwater recharge is a priority, such as in stressed basins with chronic low-flow conditions. In these circumstances, roof runoff should be infiltrated or reused whenever feasible.
- Load restrictions are usually the main limitation for green roofs in retrofit applications. A professional engineer must assess the necessary load reserves and design a roof structure that meets state and local codes.
- Slopes greater than 15% require a wooden lath grid or other retention system to hold substrate in place until plants form a thick vegetation mat.
- The initial construction cost is higher than conventional roofs.

Oklahoma Examples

National Weather Center Green Roof, Norman

An experimental green roof has been installed on the roof of the National Weather Center in Norman by the Oklahoma Conservation Commission worked with The University of Oklahoma's College of Architecture and its Landscape Architecture Division. The systems consist of two-foot square plant containers with four to six inches of growing media placed together in paddocks to create contiguous areas of green roof. *Sedum* plants were used, and the area was overseeded with native grasses and perennials including blue grama and purple coneflower. The project is split between two areas on the multi-roof building — the service roof and the classroom roof, using two different manufacturers' systems for comparison. The area over the classroom roof comprises 1,280 square feet and consists of 160 planted green roof trays. The area of the service green roof is 220 square feet. The classroom roof is used for study, teaching of students and officials and as an exhibit for visitors (OCC, 2010). The service roof is utilized for long-term collaborative research between the University of Oklahoma and Oklahoma State University.

Figure 34: Experimental green roof on the National Weather Center in Norman, Oklahoma (Reid Coffman, University of Oklahoma)

Tulsa Lofts Project

Figure 35. Green roof at Tulsa Lofts in Tulsa, Oklahoma (http:coolcounter.wordpress.com).

This project was designed by Shelby Navarro, a Landscape Architect based in Tulsa. It features a green roof as well as many other environmentally friendly concepts. The project was also able to achieve LEED platinum certification. “A ladder leads to the deck and buffalo-grass roof, where Navarro installed the Garland Green Shield layered roof system. At its base is multi-ply, modified bitumen waterproofing membrane. Specially engineered layers on top prevent roots from penetrating the membrane, draw moisture away from the roof’s surface, and keep soil from clogging the drainage system.” (Weber 2008)

CHAPTER X

CONCLUSION

The Development of comprehensive fact sheets on several LID practices for use in a future LID Manual has been completed. The identification of various LID projects in Oklahoma has also been discussed. These fact sheets will provide a resource for users to expand their knowledge on low impact development practices. As this knowledge increases, the hope is to see a higher implementation rate of LID in Oklahoma.

Lessons Learned

While this experience has been a valuable learning opportunity, there have also been challenges and lessons learned along the way. Some have been professional and some personal, but in any case I have grown from the task. The first lesson I learned is that utilizing existing resources can be both helpful but frustrating. While my research included perusing hundreds of Low Impact Development, green infrastructure and water quality websites and literature I found only a small percent to actually be useful material for my intentions. More specifically, a lot of the material published or available on websites is either too technical or too broad to utilize. I believe my fact sheets are a happy medium that do not overwhelm or underwhelm the average citizen.

Sections of the fact sheets that were easy to generate were the design drawings and benefits. This is due to the fact that the benefits and various design options are widely known for most practices. Obtaining cost estimates was more difficult due to the fact that costs vary widely among regions of the country due to product availability and locating professionals with experience in these practices. Finding examples on each practice in Oklahoma also proved difficult. Due to lack of cooperation, information on some of the Oklahoma examples is limited.

In addition, working for the City of Edmond I have become very well versed in stormwater quality. As the years have passed I have been involved in numerous projects that involve stormwater quality, some of which were discussed in the fact sheets. I've also met a diverse group of professionals and maintained working relationships with these individuals which I utilized to seek information about certain practices, projects or policies for which they are aware. Simply put, I believe my position as a Water Quality Specialist with the City of Edmond has given me an advantage over the typical graduate student not working in the field. Working full time has also proved difficult on a time management level, but nonetheless, possible.

Summary

Each of the LID practices discussed is an important part of the solution to improving the water quality in our nations waterbodies. In general, each chapter includes an Introduction, Benefits, Design and Installation, Costs, Maintenance and Limitations section. Pollutant Source Reduction is a combination of everyday preventative measures which minimizes the potential for rainwater to come into contact with pollution. The

Comparison of LID to Conventional Development breaks down the differences in benefits, costs and maintenance between the two types of development. Rain Gardens and Bioretention Cells are a great way for residential or commercial sites to incorporate stormwater infiltration while at the same time providing aesthetic appeal. Rainwater Harvesting Systems collect rainfall from rooftop runoff which can be stored and used at a later time for watering landscapes. Pervious Pavement allows water to infiltrate the pavement and there are several types of systems including pervious asphalt, pervious concrete and pervious pavers. Natural and Engineered Wetlands filter stormwater runoff and can thrive in urban environments and provide many benefits. Green Roofs are engineered, vegetative systems that are installed on rooftops, they also provide stormwater retention among other health and ecological benefits. In sum, there are many different types of LID practices, each having different design, installation, benefits and costs associated with them.

CHAPTER XI

RECOMMENDATIONS

There are several actions that I believe should be taken to further implement Low Impact Development in the State of Oklahoma. Whether the actions are likely or not, I merely believe they must occur. The first thing that must occur is to continue to educate the public, private and most of all government sectors. This can be achieved through multiple media outlets such as these fact sheets, statewide workshops, videos, stakeholder meetings and statewide conferences on LID. Once the education campaign has been initiated, legislators and policy makers should be pressured to adopt these practices into law and city ordinance.

In addition, I believe more research should be done to substantiate the effectiveness of these practices in Oklahoma. It would also be of value to conduct a survey to document attitudes and willingness to adopt LID practices. While much research has been done around the country it will likely be more accepted by the public and skeptics if the research is done within Oklahoma. This is due to the fact that the non-scientific public often mistakenly assumes that scientific studies done in other states or regions of the world are unable to be readily applied to Oklahoma or are unaware of the effectiveness of LID. I think all types of LID practices should be researched, however with some practices further down on the list. More specifically, personal interaction and discussion among individuals across Oklahoma indicate that green roofs, while very popular among major U.S. cities, are seen in a very poor light in Oklahoma. I don't believe the idea should be abandoned, but certainly not the first on the list since there seems to be large opposition to the practice. I believe the research should focus first and foremost on the most simple, inexpensive practices such as rain gardens, pollution reduction, and rainwater harvesting systems.

I also suggest that more fact sheets be developed over time. For example, streambank restoration is a necessary practice in many municipalities but also among private landowners who are losing land to erosion. A fact sheet on different restoration options would be beneficial to Oklahomans. In addition, riparian buffers are an essential tool in providing water quality benefits but are either being developed or cleared for agriculture all too often. A fact sheet on the benefits, establishment and maintenance of riparian buffers would also be a good tool for our citizens. It might also be of interest to develop a fact sheet that compares detention to infiltration to counter the famous argument that detention doesn't increase the flow of water and therefore is somehow an adequate solution. While detention does maintain flow rates and prevents flooding, it also increases the overall volume of water historically sent to a waterway. This results in excessive erosion due to the increase in water volume. This fundamental argument is the basis for all LID and should be recognized as such. It would also be beneficial to have the fact sheets bound together in a booklet. If done so in this fashion, someone interested in LID can get most of what they need in one booklet instead of having to search for separate sheets. If the materials are presented in this manner it will also look more professional.

A collaboration between Oklahoma State University and the ODEQ would also be beneficial. Since the next MS4 OKR04 General Permit is currently being developed now would be a great time to have meetings with the permit writers to discuss the need and viability of incorporating LID requirements into the permit. After all, the ball lies in ODEQs court since EPA openly supports and encourages LID implementation. At this point, I personally believe several people within the Water Quality Division at DEQ welcome LID, but are pressured by regulated municipalities who complain that requiring LID would be “impossible and politically opposed” among a host of other unsubstantiated claims.

To gain further understanding about the low rate of LID implementation in Oklahoma a survey among engineers, developers, homebuilders, scientists, academia and homeowners should be completed. The goal of the survey should be to obtain information about these individuals knowledge, attitude, experiences and intentions related to the use of Low Impact Development. More specific objectives could include the following:

- Ascertain stakeholder knowledge of LID concepts and issues
- Establish participants’ familiarity with LID
- Determine stakeholders willingness to adopt LID
- Identify barriers to using LID
- Learn the crucial topics to include in LID Fact Sheets
- Discover the LID practices most likely to be utilized

The information from a survey of this nature would likely show an educational need that can be met by the university in the way of extension through education and outreach on Low Impact Development. More fact sheets, public workshops, demonstration areas and other means can be utilized to meet this need in our state.

The true implementation of LID in Oklahoma will occur when policy makers and regulators muster the political will to stand up for something that will benefit Oklahoma's environment and economy. While opponents will argue that it is unproven, too costly and unnecessary those most familiar with the subject know the reality and should continue to stand up for the practice. I have personally stood up for the practice in the face of engineers, policy makers and the general public and it is not always been an easy task, nor did I always "win". In those moments of defeat I realize that eventually the pessimists will exit the work force and my generation will begin to make exponential progress. In closing, it is important to realize that we as a society must protect the environment and restore the degradation that we have caused, as after all it is the environment that sustains us.

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APPENDIX A

LID MAINTENANCE AGREEMENT

CITY OF KIRKLAND

123 FIFTH AVENUE KIRKLAND, WASHINGTON 98033-6189 (425) 587-3800

DEPARTMENT OF PUBLIC WORKS
PRE-APPROVED PLANS POLICY
Policy D-7: PRIVATE MAINTENANCE AGREEMENT FOR A STORMWATER FACILITY INCLUDING LOW IMPACT DEVELOPMENT (LID) FACILITY

The attached Private Maintenance Agreement for a stormwater and/or LID facility may be used in the following cases:

1. Where runoff from public right-of-way enters a stormwater and/or LID facility and the facility will be privately maintained.

2. Where runoff from private property enters a stormwater and/or LID facility and the facility will be privately maintained.

The applicant must provide the City with a signed copy of the attached maintenance agreement prior to issuance of a Building or Land Surface Modification permit.

PRIVATE MAINTENANCE AGREEMENT FOR A STORMWATER FACILITY INCLUDING LOW IMPACT DEVELOPMENT (LID) FACILITY

Parcel Number(s)

Permit Number(s)

The undersigned are owner(s) of the real property located in Kirkland, Washington (the "Owner"), which property is legally described as follows:

(the "Property");

and As a condition to the City of Kirkland's approval of the referenced permit, the Owner hereby declares and agrees as follows:

1. Ingress and Egress. The City of Kirkland (the "City") shall have the right to ingress and egress the Property for inspection of and to reasonably monitor the performance, operational flows, or defects of the stormwater and/or low impact development (LID) facility in accordance with Kirkland Municipal Code (KMC) 15.52.130.

2. Maintenance of Stormwater Facility (SWF). The SWF within the Property shall be owned, operated and maintained by Owner, pursuant to standards in **Exhibit A** and in KMC 15.52.120. If the City determines related maintenance or repair work of the SWF is required, the City shall give notice to the Owner of the specific maintenance and/or repair work required, and shall also set a reasonable time in which such work is to be completed by the Owner. If the above required maintenance or repair is not completed within the time set by the City, the City may perform the required maintenance or repair, or contract with a private company capable of

performing SWF maintenance or repair. All other SWFs in the public rights-of-way, except for storm drain lines 6- inches in diameter or smaller and rain garden facilities, shall be owned, operated, and maintained by the City.

3. Cost of Maintenance. The Owner shall assume all responsibility for the cost of any maintenance and for repairs to the SWF. Such responsibility shall include reimbursement to the City within thirty (30) days of receipt of the invoice for any such work performed. Overdue payments will require payment of interest at the rate of 12% per year. If legal action ensues, the prevailing party is entitled to recover its costs and reasonable attorney fees.

4. Flow of Stormwater. The Owner acknowledges that stormwater from public rights-of-way may and/or will flow into the SWF. The Owner agrees and covenants with the City to indemnify and hold the City, its officers, officials, employees and volunteers harmless from any and all claims, injuries, damages, losses or suits including attorney fees, arising out of or in connection with this Private Maintenance Agreement, except for injuries and damages caused by the sole negligence of the City.

5. Alterations or Modifications to SWF. The Owner is hereby required to obtain written approval from the City prior to filling, piping, cutting, or removing vegetation (except in routine landscape maintenance) in the SWF, or performing any alterations or modifications to the SWF, pursuant to KMC 15.52.120.

6. Covenants Run with the Land. The terms and covenants of this Agreement shall be covenants running with the land and shall inure to the benefit of and be binding upon any party having any right, title or interest in the Property. This Agreement constitutes the entire agreement between the parties, and supersedes all prior discussions, negotiations, and all agreements whatsoever whether oral or written.

(Sign in blue ink)

(Individuals Only)

OWNER(S) OF REAL PROPERTY (INCLUDING SPOUSE)

____

____

____

(Individuals Only)

STATE OF WASHINGTON)

) SS.

County of King)

On this _____ day of _____________, _____, before me, the undersigned, a Notary Public in and for the State of Washington, duly commissioned and sworn, personally appeared ____ and ____ to me known to be the individual(s) described herein and who executed the Private Maintenance Agreement for a Stormwater Facility Including Low Impact Development (LID) Facility and acknowledged that ____ signed the same as ____ free and voluntary act and deed, for the uses and purposes therein mentioned. WITNESS my hand and official seal hereto affixed the day and year first above written.

____

Notary's Signature

____

Print Notary's Name

Notary Public in and for the State of Washington,
Residing at: ____
My commission expires: ________________________

(Partnerships Only)

OWNER(S) OF REAL PROPERTY

(Name of Partnership or Joint Venture)

By General Partner
By General Partner
By General Partner

(Partnerships Only)

STATE OF WASHINGTON)

) SS.

County of King)

On this _____ day of ____________, _____, before me, the undersigned, a Notary Public in and for the State of Washington, duly commissioned and sworn, personally appeared

____

and ____

to me, known to be general partners of

____, the partnership that executed the Stormwater Facility Including Low Impact Development (LID) Facility and acknowledged the said instrument to be the free and voluntary act and deed of each personally and of said partnership, for the uses and purposes therein set forth, and on oath stated that they were authorized to sign said instrument.

WITNESS my hand and official seal hereto affixed the day and year first above written.

____

Notary's Signature

____

Print Notary's Name

Notary Public in and for the State of Washington,

Residing at: ____

My commission expires: ________________

(Corporations Only)

OWNER(S) OF REAL PROPERTY

(Name of Corporation)
By President
By Secretary

(Corporations Only)

STATE OF WASHINGTON)

) SS.

County of King)

On this _____ day of ____________, _____, before me, the undersigned, a Notary Public in and for the State of Washington, duly commissioned and sworn, personally appeared

____

and ____

to me, known to be the President and Secretary, respectively, of

____, the

corporation that executed the Stormwater Facility Including Low Impact Development (LID) Facility and acknowledged the said instrument to be the free and voluntary act and deed of said corporation, for the uses and purposes therein set forth, and on oath stated that they were authorized to sign said instrument and that the seal affixed is the corporate seal of said corporation. WITNESS my hand and official seal hereto affixed the day and year first above written.

____

Notary's Signature

____

Print Notary's Name
Notary Public in and for the State of Washington,
Residing at: ____
My commission expires: ________________

VITA

Ashley Faye Stringer

Candidate for the Degree of

Master of Science

Thesis: DESIGN GUIDANCE ON LOW IMPACT DEVELOPMENT PRACTICES FOR STORMWATER MANAGEMENT AND CONTROL IN OKLAHOMA

Major Field: Environmental Science

Biographical:

Education:

Completed the requirements for the Master of Science in Agricultural Sciences and Natural Resources at Oklahoma State University, Stillwater, Oklahoma in May 2011.

Completed the requirements for the Bachelor of Science in Agricultural Sciences and Natural Resources at Oklahoma State University, Stillwater, Oklahoma in December 2005.

Experience:

Currently employed with the City of Edmond as a Water Quality Specialist with the following responsibilities

- Ensuring compliance with ODEQ stormwater permit
- Documenting and reporting NPDES permit activities
- Conducting erosion and sediment control inspections
- Reviewing civil engineering plans and SWPPPs
- Performing water quality testing and analysis
- Use of GIS for plan review, reports and citizen data requests
- Developing public education and outreach materials
- Investigating illicit discharge complaints

Professional Memberships:

International Erosion Control Association
Certified Professional in Erosion and Sediment Control (CPESC), #4722
Certified Professional in Storm Water Quality (CPSWQ), #539

Name: Ashley F. Stringer Date of Degree: May, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: DESIGN GUIDANCE ON LOW IMPACT DEVELOPMENT PRACTICES FOR STORMWATER MANAGEMENT AND CONTROL IN OKLAHOMA

Pages in Study: 154 Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study: Evaluating the existing research and guidelines available on the design, installation, benefits, costs, maintenance and limitations of Low Impact Development practice for the State of Oklahoma. Method of study including researching peer-reviewed journal articles, searching for and utilizing manuals from Federal and State agencies as well as using research from universities to develop chapters for each practice.

Findings and Conclusions: Low Impact Development is more prevalent on the East and West coast. However, several LID projects are in place in Oklahoma. There are both benefits and limitation to LID practices and before implementation one should consider all of the factors before making a decision. LID can be very beneficial to Oklahoma and these chapters will be utilized in a forthcoming LID Manual for the public to utilize.

Since the National Pollutant Discharge Elimination System regulations were first implemented in Oklahoma in 1990 stormwater management has evolved in many ways. One of these evolutions has came by the way of the EPA encouraging communities to utilize Low Impact Development (LID) to deal with both stormwater quantity and achieve water quality benefits. In the last 5 years the installation of LID practices in the United States have grown tremendously. The purpose of this Thesis is to research the existing technology and implementation surrounding LID and document the findings to educate a variety of groups such as engineers, homebuilders, developers, homeowners, and scientists. Objectives of the research include indentifying LID practices appropriate for Oklahoma, developing comprehensive fact sheets on each practice for use in a future LID Manual, and identifying examples of LID practices currently in place in Oklahoma. Each chapter includes information on benefits, design, installation, cost, maintenance, and limitations of the following practices: rain gardens and bioretention cells, rainwater harvesting, pervious pavement, natural and engineered wetlands, and green roofs. Other chapters included are a comparison of traditional development to LID and pollutant source reduction. This series of fact sheets will provide a resource for the citizens of Oklahoma to utilize to determine if LID practices could be valuable to implement.

ADVISER'S APPROVAL: Dr. Jason Vogel