Low Impact Development and
Rain Garden Project Summary Report

Final Report

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Executive Summary

This Project Summary Report satisfies several output requirements from EPA water quality grants. In late 2007, INCOG began a grant funded project under Project 2 of the FY07-08 604(b) contract (C6-4000000-47) with the Office of Secretary of the Environment (OSE) to develop Low Impact Development (LID) information and resources for Oklahoma. This report represents Output 203 of this grant and summarizes the accomplishments of INCOG.

In mid 2009, INCOG began a special American Recovery and Reinvestment Act (ARRA) funded program under Project 6 of the FY09 604(b) ARRA (2P-966908-01) to perform sampling of many 303(d) listed streams in Northeast Oklahoma. Part of this program was required by EPA to fund a specific environmental project. With EPA approval, INCOG elected to construct several rain gardens within the 303(d) project area. The goal was to not only have structural Best Management Practices (BMPs) installed to help control pollution, but to develop information about how the rain gardens could be constructed for educational purposes.

Since the 604(b) program funds could not be used for purchasing materials to construct the rain gardens (plants, rock, soil, screening, mulch, etc.), OSE solicited an agreement with the Oklahoma Conservation Commission (OCC) to utilize sufficient funds from a FY05 319(h) grant (C9-996100-13) to purchase all rain garden materials. The 319(h) purchases were made prior to the end date of the 319(h) grant (June 2010), and all rain garden construction materials were stockpiled and used during the construction phase of the four rain gardens.

The rain garden for the City of Bixby was scheduled to be completed by the end of 2010, however because it was part of a larger city public works street improvement project, completion of the rain garden was rescheduled for fall 2011 due to delays in funding of the street project. Funding has now been secured, and all rain garden materials have been purchased and are being stockpiled for use within the next few months.

At the time of initiation of the FY07 604(b) grant for LID resources, Oklahoma lagged behind many states in basic knowledge of rain gardens and other LID concepts. There were few structural LID practices anywhere in the state, and most developers and municipalities did not have even fundamental knowledge of LID. During the past four years of implementing these grants, Oklahoma has seen an explosion of interest in LID and Green Infrastructure. INCOG’s grant funded LID program helped to stimulate awareness of the benefits of LID and develop a network of information and resources for LID practitioners.

Over the next few years, the accomplishments under these grants will lead to better LID information, showcased BMPs for education and research, and will open doors to help locate resources for future LID deployment in Oklahoma. Cities having to meet LID requirements in their stormwater permits can use the outputs from these grants for public education. Builders and developers can seek information to make informed decisions about using LID in new development and redevelopment projects. And the increased awareness of citizens will stimulate the desire and demand for LID within their residential areas and communities, one of the principal goals of INCOG’s grant funded programs.

An Introduction to the Principles of Low Impact Development and Stormwater Management

Introduction

As our population continues to grow and development consumes more and more of our landscape it has become apparent that the traditional approach to stormwater management can be improved to meet society's current needs and better protect our water resources. Numerous regulatory agencies, environmental groups and professionals agree on this. In urban settings, the historical approach has been to develop an extensive piping and drainage system that will quickly move stormwater and snowmelt from rooftops, roads, parking lots and lawns to holding basins, wetlands, ponds and streams. The intent was to get the water off the land and into a waterway as quickly as possible. This helped to reduce the flooding potential and minimize property damage in the vicinity of the rainfall or snowfall. As a nation we became very good at this.

In 1975, 74% of the United States population lived in urban areas. By 2000, 79% lived in urban areas and it is projected that by 2025, 86% will live in urbanized areas. In 1975 the urban population in the United States was 162.2 million. By the year 2000 it was 224.8 million and it is projected to be 300.9 million by the year 2025 (UN Population Division). By definition, urban areas are based on population density. The US census bureau defines an urban area as one having a core population density of at least 386 people per square kilometer and surrounding areas having an overall density of at least 193 people per square kilometer (Bernhardt and Palmer, 2007).

This increase in population density has had a profound impact on the volume of runoff from urban areas. Runoff from an acre of pavement is 10 to 25 times greater than the runoff from an acre of grass. In urban areas 30 to 40 percent of the rainfall drains directly into the nearest stream. In central business districts and heavily urbanized areas the runoff can be greater than 50 percent. In comparison, woodland runoff is frequently less than 5 percent. (Christopher J. Estes, 2009)

The shift from a rural to an urban setting concentrates development activities and has a profound impact on the rivers, streams and creeks which naturally flow through the lowest points in the landscape. Streambeds tend to get straightened, flow becomes channeled (or piped) and stream-side vegetation is lost. The floodplain becomes disconnected or is lost to development and in general, the overall complexity of the stream is lost. This ecological simplification results in a loss of biodiversity and the stream ecosystem can no longer function the way nature intended it to. Once this has occurred, restoring an urban stream to a pre-urbanization state is difficult if not impossible.

The end result can be a non-functional, unattractive stream with little recreational or societal value. It can have little or no aesthetic value, provide minimal aquatic habitat and the increased flooding potential threatens local residences and businesses. The Environmental Protection Agency's Wadeable Streams Assessment report states that 42 percent of the wadeable streams in this nation are in poor biological condition compared to reference sites. (Wadeable Streams Assessment, National Stream Report, EPA, 2006)

It is time to reconsider the way we think about stormwater runoff and how we develop the land. Stormwater programs must encompass more than just flood control. Rainwater isn’t a waste product and runoff should not be thought of as a disposal problem. The majority of homes and businesses in the United States use potable water for non-potable purposes because they have no other source of water. Collecting rainwater for landscape irrigation and other activities not requiring potable water reduces the demand for treated water, lowers operational costs at water treatment facilities and preserves water supplies for future use. Capturing, filtering and storing rainwater for non-potable use is relatively simple and very practical.

To help avoid future water quality and quantity problems runoff should be viewed as the valuable resource it is. By properly managing stormwater in the upper reaches of a watershed we can avoid damaging the lower portion of the watershed. The lack of planning in one area can become a significant problem in another. Nobody wants to hear that their house has been placed in a 100 year floodplain because of recent developments around and upstream of them. The fear of flooding and higher insurance rates can rally a neighborhood to action. Learning to contend with water quantity *and* quality problems simultaneously has taken some time and has resulted in the development and understanding of Low Impact Development (LID) practices which are used to enhance stormwater management programs.

The general public, city managers, engineers, developers and builders will need to work together to incorporate these LID practices if a difference is going to be realized. Education is the key. When the community understands that these changes will result in a more aesthetically pleasing environment, will reduce the potential for flooding and associated damages and improve the quality and quantity of water available to them they will band together and support this idea. It is happening all across the country as community leaders see the benefits and provide the necessary guidance.

When the Los Angeles (CA) City Council passed its Low Impact Development Ordinance by unanimous consent its Board of Public Works Commissioner stated “With this ordinance, we will be officially recognizing that rainwater is too precious a resource to waste.” (Los Angeles Board of Public Works Closer to Implementing LID Ordinance)

Local governments have the authority to implement stormwater programs and are held accountable for them. Stormwater guidelines and city codes and ordinances should be flexible enough to incorporate as many of these ideas as possible. City managers and leaders can promote the benefits of LID and encourage the implementation of these practices. To meet long term water management goals, it will be easier and less expensive to prevent or minimize the degradation of our water resources than trying to fix problems that could have been avoided. Restoration, stabilization and clean-up efforts can be expensive and are not always successful.

If post construction conditions could duplicate the preconstruction site hydrology there would be no net difference in infiltration rates, onsite water stores and evaporation and transpiration losses. Although this is not always possible, it would be ideal. The intent is to properly manage precipitation and pollutants as close to the source as possible thereby minimizing the amount of runoff.

Challenging, yet achievable goals should be set. It is often unrealistic to try to restore an urban stream to an unknown historical condition or its pre-urban state. Too many irrevocable changes may have occurred in the watershed or catchment basin to make this feasible. Instead, one can take protective measures to prevent further degradation of this resource and try to reverse as much of the past damage as possible. By implementing some of these LID and stormwater management practices we can improve the quality of our surface waters. Streams, ponds and lakes can become more productive; we can reduce the flooding potential, minimize pollutant levels and add value to a sometimes neglected resource.

A healthy stream system is more resilient to negative impacts from both human and natural events. Protecting our water resources is everyone's responsibility and Low Impact Development methods allow for continued growth while minimizing the environmental disturbance. The challenge is dealing with the water quantity issue onsite without sacrificing water quality. If successfully met, the end result will be a more enjoyable setting for both man and nature.

Disclaimer

Any reference to companies, individuals, trade names, commercial products or manufactures in this report does not constitute an endorsement.

Safety Reminder

Before digging or doing any excavation work, always have underground utilities located by the proper company, agency or individuals and be aware of overhead power lines.

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Summary of the Earth's Total Water Supply

The water we have on Earth today is all we have ever had and all there will be. New water isn't being created and old water isn't being lost. It is the same water going around and around and being used over and over. If it becomes contaminated it will have to be cleaned up by some process or its usefulness will be diminished.

Of the total amount of water here on earth, 96.5% is contained in oceans and is salty. Saline groundwater accounts for an additional 0.93% and saline lakes make up another 0.07%. Therefore, 97.5% of the earth's total water supply is salt water.

This leaves only 2.5% of the total water supply as freshwater. 68.6% of this 2.5% is locked up in glaciers and ice caps. Another 30.1% is groundwater. Only 1.3% of the freshwater is above ground and not in a glacier or ice cap. This 1.3% breaks down as follows: ice and snow (73.1%), lakes (20.1%), soil moisture (3.52%), swamps and marshes (2.53%), rivers (0.46%), biological water (0.22%) and atmospheric water (0.22%). (USGS Water Science for Schools)

Principle Components of Low Impact Development (LID)

Low Impact Development is a method of managing stormwater onsite through or by duplicating methods that mimic natural processes in an attempt to replicate the site's pre-development hydrologic conditions. Undeveloped areas allow rainwater to flow within natural drainage basins and infiltrate the soil to recharge groundwater supplies. Plants, soil and the organisms that reside in the soil provide the primary means for filtering and reducing pollutant concentrations in stormwater runoff.

Plants take up water and release it to the atmosphere through transpiration, utilize nutrients and take up some pollutants. They are also used to add visual appeal to projects. Additional amounts of water are lost to the atmosphere through simple evaporation. LID practices are frequently "low-tech" and cost effective.

As urban areas become developed or "improved", streets, sidewalks, driveways, parking lots, curbs, roofs, pipes and gutters channel stormwater from these impervious surfaces directly into our waterways. The transport of pollutants from non-point sources is primarily the result of meteorological events like rain or snow. Typically this runoff is funneled through "grey infrastructure" which relies heavily on concrete and pipes. Using heavy equipment to grade and prepare a site for development often results in compacted soils and a change in surface water flow patterns. The end result can be more runoff and a more direct channel to receiving waters such as lakes, rivers and streams.

Low impact development practices are intended to minimize the negative effects of development and allow a more natural dissipation of rainwater onsite. LID consists of various strategies intended to mimic natural processes to manage stormwater runoff and help protect surface and groundwater supplies. "Green infrastructure" can be used to slow, treat or absorb runoff and includes the existing waterways, wetlands, infiltration areas, parks, natural features and vegetation within the watershed. It also includes permeable surfaces, rain barrels, cisterns, green roofs, rain gardens, vegetated swales, etc. which are intended to assist in the natural dissipation of runoff. The goal is to capture raindrops where they land. In the end, each community will need to find the proper mix of grey and green infrastructure needed to manage their stormwater runoff.

A methodical approach to implementing LID practices will maximize returns on investment and time. Generating detailed maps of the area can make the process easier and geographic information systems (GIS) allow the user to present information in usable map formats. Aerial photos and maps will reveal high concentrations of pervious and impervious surfaces, open areas, creeks, rivers ponds and lakes. Soil survey maps will reveal soil types such as sand, loam and areas of clay or rock. Elevation maps will show slope and drainage patterns. Land use and zoning maps will show business and residential areas. Floodplain maps will show the low areas prone to flooding.

After reviewing these maps it will be much easier to identify high density areas and areas with a lot of runoff (steep areas with hard, impervious ground cover). Best infiltration areas (relatively level with pervious soils). The natural drainage corridors, flood prone areas and naturally wet areas will be easy to locate. You will also know how much space you have to work within and county assessor's records will reveal who owns which parcels. Now you can determine where infiltration projects like rain gardens would be most appropriate; whether a large parking area can be disconnected and allowed to drain to a grassy field; who owns the field; where rain barrels and cisterns are more appropriate or grey infrastructure and detention ponds may be needed because of poor infiltration rates and steep hillsides. Maps should also identify where natural areas still exist and which ones should be protected; land that might be appropriate for parks and recreation areas and what types of activities are appropriate and compatible with your goals. This type of analysis will help ensure the correct best management practice (BMP) is employed in the proper location.

Though other parts of the country have been very active in the implementation of LID principles, Oklahoma has been a little slow, but is gaining momentum. The following sections will discuss some of the benefits of LID, potential problems emphasizing the need for LID and some of the BMPs that will help solve some of these problems. State agencies and two universities in particular are leading the way for LID in Oklahoma. Oklahoma State University (Division of Agricultural Sciences and Natural Resources, Stillwater, OK http://lid.okstate.edu) and University of Oklahoma (Division of Landscape Architecture, Norman, OK) have a wealth of information on their websites and ongoing research projects for those individuals desiring to learn more. In addition, the resources section at the end of this paper lists additional websites and publications for further research. This is a rapidly developing field and new information is becoming available every day.

LID Benefits

Many of the LID practices benefit multiple users. The same practice can benefit the environment, a community, a homeowner and the original developer of the property. Some LID benefits are listed below in categories, but remember, the benefits extend beyond the categories in most cases.

To the *Environment*

- Increases and improves wildlife habitat
- Improves water quality by reducing sediment and nutrient runoff
- Increases infiltration and helps recharge and protect groundwater supplies
- Reduces thermal impacts to surface waters
- Stabilizes stream beds and shorelines
- Minimizes erosion
- Preserves and enhances streams, wetlands, ponds and lakes
- Preserves existing trees and vegetation

To *Communities*

- ➢ Reduces the rate and volume of stormwater runoff
- ➢ Helps communities grow in a more attractive way
- ➢ Manages and reduces flow from impervious surfaces
- ➢ Reduces urban heat island effects
- ➢ Reduces the demand for publicly treated water
- ➢ Reduces stormwater detention needs
- ➢ Helps meet regulatory stormwater requirements

To *Landowners/Homeowners/Businesses*

- ➢ Reduces flooding potential and flood related damages
- ➢ Can reduce heating and cooling energy needs
- ➢ Makes surface waters more aesthetically pleasing
- ➢ Enhances property values
- ➢ Preserves open spaces and natural features
- ➢ Creates additional green space

To *Developers*

- ➢ Reduced land clearing and grading costs
- ➢ Potential reduction of infrastructure costs (streets, storm sewer systems)
- ➢ Improved marketability of developments

Potential Problems

Sedimentation and Erosion

Soil exposed to the effects of wind and rain is subject to erosion. Falling raindrops hit with enough force to dislodge soil particles and the loosened particles are then washed away with runoff. Suspended sediment is one of the most common water quality impairments in the U.S. Wind can also dislodge dry soil particles and blow them away. It isn't just the movement of the soil particle that causes concern. Some pollutants, like hydrocarbons, oils, pesticides, etc. can bind to these particles and are transported with them. To minimize soil erosion, leave as much ground cover as practical, plant a cover crop or spread a ground cover (like mulch) to prevent long-term exposure of bare soil. Temporary cover crops like rye, oats or winter wheat can protect a site after initial grading and clearing activities if the next development phase will be delayed.

Streams naturally transport sediment. If erosion and sedimentation rates are basically the same in a stream reach there is little net change. If a stream is depositing sediment in amounts sufficient to replace its losses, it is in a steady state. The particulates entering a stream channel provide nutrients, organics and food in general to invertebrates. On the other hand, too many fine particulates can bury gravel spawning beds, disrupt normal gill functions and result in lower dissolved oxygen levels. To avoid stream sedimentation or the streambed from down-cutting, the sediment transport load should be balanced.

If more sediment is being deposited in the stream than it can transport, mid-channel sediment bars form and substrates get buried. If the stream is picking up and transporting more sediment than it receives the streambed is experiencing erosion and down-cuts or the channel grows wider. The faster the water is moving, the greater the erosion potential. This sediment load is transported downstream until the water velocity slows to a point the sediment will drop out or is ultimately deposited in a pond or lake.

The sediment load in the rainwater runoff might be very low in an urbanized area that is built out (meaning most suitable sites have been developed and not much construction is occurring) with a high percentage of impervious surface area. A higher amount of impervious surface means larger quantities of runoff. Since this water may lack sediment or total suspended solids (TSS), it is free to pick up transportable sediment and has nothing to deposit in return (Bernhardt and Palmer, 2007). These conditions can result in rapid streambed erosion. If the stream cuts a deeper channel (incision) the groundwater table may drop below the root zone of riparian (streamside) plants resulting in their stress and death during dry times.

Bank stabilization projects become necessary if streambed erosion threatens structures, roadways or utilities. In urbanized areas this can be difficult and expensive due to the high cost of land and limited space to work in. Ideally, an undeveloped riparian buffer should be left along waterways if possible. The benefits of a buffer zone are discussed in a later section.

Alteration of Stream Channels

More runoff reaches a stream or creek more quickly as the percentage of the impervious surface area increases within the watershed. Stormwater runoff moves more rapidly over smooth hard surfaces (like paved areas and roof tops) than over rough naturally vegetated surfaces. As a result, more rainwater is quickly funneled into streams than under predevelopment conditions increasing the volume of water the stream must carry thus increasing the potential for flooding and erosion. The stream originally may have had an adequately sized streambed and floodplain to handle the predevelopment flows, but not the flows after development.

These higher volumes and faster flows have the energy to cut deeper channels and wider streambeds, carrying away the excess sediments. A single large storm can blow out a creek moving the channel laterally many feet or cutting off a meander. When this happens, developments previously considered safe can be left hanging over or sliding into a creek channel. Bank erosion is a continuous process and occurs at different rates according to local circumstances.

If filling and developing in the floodplain was allowed, floodwaters will be forced into new areas so the problem is shifted to somebody else. The infrastructure needed in populated areas such as water lines, sewer lines, electric lines, communication cables, roads and buildings must be protected. To protect the financial investment in these developments, the stream may have been contained by hardening or armoring (hard surfaces placed in the streambed or bank to prevent erosion and the natural movement of the stream channel) so highly valued property isn't eroded. If this armoring isn't properly engineered or water starts flowing around or under it, it too will fail.

Because of this development, the streambed isn't allowed to enlarge to accommodate the increased flows and flooding becomes more frequent with higher peak discharges. Minimizing surface water runoff can decrease flooding potential. Since more water flows directly into the stream channel the flows become flashier meaning the water level rises and drops faster.

Moving water has energy and the ability to do work. Straightening a channel and removing roughness and vegetation increases the flow's velocity. The greater the velocity of the water the more energy it has. The greater the volume, the more particulates it can move. This energy can erode the channel resulting in greater width and depth as the flowing water carries sediment away. Unstable streambeds are relatively common in urbanized areas where uncontrolled runoff is an issue. The normal curves in a stream (sinuosity) and roughness (rocks, roots, woody debris, vegetation, etc.) in a stream channel slow the flow and dissipate energy reducing the erosive force of the water. Straightening a channel, removing roughness and vegetation or piping water does just the opposite and creates a more erosive situation just downstream. When stream flows increase, but lateral constraints prevent the stream from scouring a wider channel the only direction it can go is down. Down-cutting or channel incision may become a problem if the stream bed isn't hard enough to resist this force.

Stream bank erosion can occur when loose soil particles along the bank's surface are not protected by vegetation, rocks or boulders and are swept away by moving water. High flows, rainfall or over-land flows can all contribute to bank erosion. The dislodged particles will be deposited downstream when the current slows.

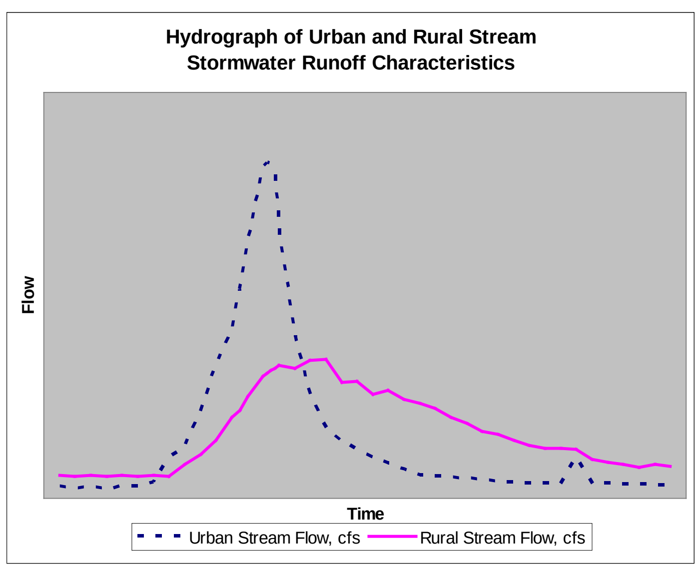
Bank failure is when a large portion of the bank slides or falls into the stream within a short period of time. This collapse can occur when the toe of the bank (the bottom of the bank exposed to the current) is eroded away leaving the upper part of the bank without support. Bank failure may also occur after a rapid change in channel shape or flow direction, high flows or the lowering of the stream bed as a result of channel incision. High, steep banks prone to failure can be stabilized by re-grading so the bank isn't as steep and then covering it with vegetation and/or armoring with hard surfaces like rocks, boulders and logs. These hard surfaces are more attractive and natural looking than poured or broken concrete chunks and demolition debris.

If bank failure is due to channel incision or the lowering of the stream bed, just armoring the banks won't prevent future bank failure. The stream bed is not in balance and will continue to lower, the bank toe will erode away and the bank *and* armoring will tumble into the stream. Before investing time and money in a stream bank restoration or protection project, determine the cause of the failure or anticipated failure and fix the root of the problem.

LID practices help maintain and restore natural stream conditions by reducing the volume of runoff, the speed at which runoff reaches a stream, and the sediment and pollutant loading. Effective LID measures can minimize streambed enlargement and erosion problems frequently encountered in urban streams.

Flooding

Flooding occurs when volumes of water enter a stream faster than they can be conveyed under bank-full conditions. When flows top the stream's banks, the water moves out to cover the floodplain. Factors affecting a flood include the intensity, duration and location of the storm, local topography and geology, size of the watershed, the amount and type of vegetation in the watershed and flow levels prior to the rain event. Urban creeks receive additional flows from surface grading (loss of depressions) and loss of roughness, loss of vegetation, soil compaction and impermeable surfaces. The result is less infiltration and surface storage, larger flow volumes and quicker runoff.



As a watershed becomes more urbanized, streams tend to rise faster, have higher peak flow discharges and recede more quickly and do so with less precipitation. A stream reacting to runoff in this manner is called "flashy." Urban and suburban areas generally have a vast and dense drainage network comprised of pipes, ditches, French drains, etc. so runoff and shallow groundwater quickly reach a body of surface water. This reduces infiltration and evaporative losses and quickly adds excess amounts of water to already overloaded stream channels. Unless LID practices and adequate and functional detention/retention basins are incorporated into the urbanized watershed, most urban streams will be flashy.

Under less developed conditions, some of the precipitation is initially stored on vegetation, the land (depressions) and in the soil. These natural forms of detention reduce the quantity and improve the quality of stormwater runoff. Significant amounts of runoff don't reach the stream until this storage capacity has been exceeded so peak flows build more gradually, don't get as high and dissipate more slowly. Less runoff reaches a stream channel and that which does takes longer to do so. An exception would be a rain event during a wet period when the depressions are full and the ground is saturated. Under these conditions runoff will occur more quickly and rural stream flows will more closely resemble urban conditions.

Alteration of Floodplains

Structures built in a floodplain, filling a portion of a floodplain or restricting a floodplain will displace floodwaters to new locations. If these practices are allowed, areas that were not previously within a floodplain may become part of the new floodplain. Structures that restrict a floodplain, like some bridges or undersized culverts, narrow the floodplain thus restricting flows and backing up water above the obstruction. This causes the backed up water above the restriction to extend further upstream and get deeper.

Alteration of Groundwater

In the predevelopment state, with less impervious surface area, much of the rainwater soaked into the soil and resided as soil moisture (vadose water) or groundwater. Once it enters the soil, it slowly migrates deeper until it reaches an aquifer. Along the way some of it is drawn up by plant roots and lost to the atmosphere through transpiration processes or slowly makes its way to a streambed or lake.

Increasing percolation rates can decrease the flooding magnitude by reducing stream peak flows and extends stream flow duration. Increasing the impervious surface area does just the opposite and can decrease the amount of rainwater that can soak into the soil to recharge groundwater stores. It is groundwater that maintains baseflows in streams between rain events and supplies water to wells.

Decreased groundwater stores can result in dry creek beds and wells. Groundwater inputs to a stream's baseflow will also help keep stream flows cooler in the hot summer months. In general, groundwater inputs are significantly cooler than surface water runoff inputs. As groundwater inputs decrease, stream flow temperatures can increase and elevated temperatures can lead to other problems. By taking measures to increase the percolation of water into the soil we can reduce peak stream flows and sustain baseflows in streams through increased groundwater recharge.

Construction Sites

Construction site runoff can carry heavy loads of chemicals, large material like rocks for shorter distances and very fine sediment, like clay, for long distances. If this sediment laden runoff is allowed to flow over and through filter strips, infiltration basins, rain gardens, biofiltration units or over pervious surfaces, the sediment can clog the pore spaces. If the pore spaces become plugged and the topsoil and/or subsoils become sealed, infiltration rates will drop rendering these formerly beneficial practices ineffective. If this sediment-laden runoff flows into a creek, it can smother benthic organisms and substrates, create mid-channel silt bars and plug the gills of fish and aquatic organisms resulting in stress and/or death. These suspended solids also increase the water's turbidity and reduce light penetration which reduces oxygen production by aquatic plants. Also, sediment deposits on roadways and trails can pose safety hazards for drivers and pedestrians. This is why the proper installation and maintenance of sedimentation reduction BMPs like silt fence is so important.

Pollutants

U.S. Geological Survey studies have found that total phosphorus concentrations exceed EPA goals for nuisance growth in 70% of urban streams. Also, urban streams usually have higher concentrations of insecticides than streams in agricultural areas, and fecal coliform bacteria commonly exceed the recommended standards for recreational water. (Chris Kloss)

The first portion of a rain event will infiltrate the soil or permeable surfaces. If it falls too fast to soak in or lands on an impermeable surface it flows across the surface as runoff. As it moves, it mobilizes particulates and carries sediment, but initially there isn't enough volume to significantly dilute pollutants. When a city or densely developed urban area receives a significant rainfall after a period of dry weather, the runoff for the first 20 to 30 minutes can be heavily contaminated. This is referred to as the "first flush". Since the first flush is the most contaminated, capturing it is critical to keeping pollutants out of creeks, rivers, ponds and lakes.

Water flowing over an impervious surface isn't filtered by natural processes. In the predevelopment state, rainwater is filtered as it percolates down through the soil or flows in and around surface plants and through organic debris. Microbes consume organic matter, plants utilize nutrients and particulates are physically removed. Impervious surfaces and residential areas tend to collect pollutants like deicing salt, heavy metals, oil and grease, automotive fluids, litter, nutrients and bacteria. These pollutants are then swiftly swept away by the next significant rain event directly into a receiving water. Minimizing surface water runoff, especially the first inch, can decrease pollutant loading to receiving streams.

Temperature Effects

Groundwater recharge to streams is relatively cool and helps keep stream temperatures in a cooler, safer range during hot weather. In the summertime, paved surfaces and rooftops heat up in the sun. Rainwater flowing over these surfaces, especially the first flush, also heats up and is then discharged to creeks. Water temperature affects plant and animal growth rates, reproductive cycles and can alter a stream's aquatic diversity. Elevated temperatures can also influence dissolved oxygen levels in a negative way.

The heat island effect many cities experience is due to the dense concentration of hard surfaces like buildings, roads, parking lots and sidewalks. This asphalt, concrete, brick and rock heats up during the day and continues to radiate heat long after the sun goes down. City temperatures in the summer can average 10° F higher than nearby suburban temperatures (Mark Norman). Plants reduce this effect by shading the surfaces below them and softening the environment.

Lining a natural channel with concrete eliminates the pools, roughness, structure and habitat necessary to maintain a healthy balance of aquatic organisms. Broad and shallow flows over heated concrete can raise stream flow temperatures and higher in-stream temperatures can result in undesirable plant growth and stressed aquatic organisms.

Lawns and Golf Courses

Runoff contains grass clippings, fertilizer (nutrients), pesticides and herbicides and bacteria from urban wildlife and pets. Fertilizers and lawn care products are often over-applied because many property owners fail to test the soil or thoroughly investigate a problem before they apply chemicals.

Impervious Surfaces

For LID purposes, an impervious surface is any surface which significantly restricts or prevents the movement of water into the soil or underlying aquifer. Some dense soils like clay may naturally act as a barrier to root development and water infiltration. Loose soils can also become compacted by heavy equipment, vehicle traffic and even heavy foot traffic.

LID practices are intended to counter the negative effects of man-made surfaces and compacted soils. As forests, prairies and fields are covered by rooftops, parking lots, roadways, sidewalks and driveways the natural hydrologic cycle changes. The percentage of impervious surface area increases and rainwater that previously would have percolated into the soils is forced to flow in a more direct and quicker route overland to a receiving stream. As the volume of flow increases, the ability to infiltrate the runoff onsite becomes more difficult and detention capacity and pipe size must be increased to minimize flooding.

If allowed to flow across the surface as sheet water under more natural conditions, the water would move slower and more would percolate into the soil and be lost to evaporative processes thus reducing the quantity quickly reaching the stream. An increase in impervious surface area can have numerous negative effects if not properly managed.

Changes to a stream channel as a result of urban development and increased runoff can limit a stream's ability to convey runoff and floodwaters. This increases the inundation threat to roadways and buildings in flood-prone areas. Understanding this principle can help community leaders reduce their current and future flood hazards.

Table 1: The Urban Water Cycle in Relation to Impervious Cover

% Impervious Cover	Evapotranspiration	Runoff	Shallow Infiltration	Deep Infiltration
Natural State	40%	10%	25%	25%
10 to 20 %	38%	20%	21%	21%
30 to 50%	35%	30%	20%	15%
75 to 100%	30%	55%	10%	5%

(National Management Measures to Control Nonpoint Source Pollution from Urban Areas, EPA, 2005)

Roadways, Parking Lots, Driveways and Sidewalks

These paved surfaces account for a huge percentage of the urban impervious surface area. These surfaces allow the accumulation of heavy metals (from brakes, tires and combustion products from engines), oils, grease, gas and diesel fuels, leaking automotive fluids and deicing salts between rain events. Pollutants often bind to road dust and particulates and are then washed into stormwater collection systems each time it rains. The first flush is usually the most heavily polluted. Reducing the impervious surface area and using greener surfaces where possible will help reduce the harmful affects of stormwater runoff.

Parking lot and driveway sealants can be a major source of polycyclic aromatic hydrocarbon (PAH) pollution commonly found in urban lakes and streams. Coal-tar sealcoats come from the coking of coal and have PAH concentrations about 1,000 times higher than asphalt based sealcoats, which come from oil.

Coal-tar sealcoat, the shiny black material applied to parking lots and driveways, is toxic to mammals, birds, fish, amphibians, invertebrates, and plants and some of these compounds are suspected carcinogens. The possible effects of PAHs on aquatic insects and other invertebrates include inhibited reproduction, delayed emergence, sediment avoidance, and mortality. Possible adverse effects on fish include fin erosion, liver abnormalities, cataracts, and immune system impairments.

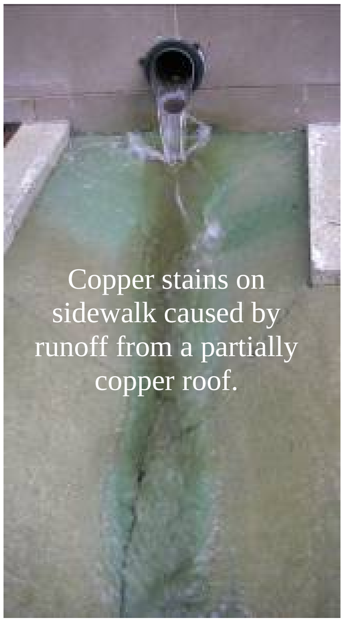
Coal-tar sealcoats can contain up to 30% coal-tar and particulates from treated surfaces are carried away in stormwater runoff. The USGS found that dust from coal-tar treated parking lots contained about 80 times more PAHs than dust from unsealed asphalt and concrete lots in the same city. PAHs from pavement dust is an important contributor to PAH contamination in urban lakes. (U.S. Water News, Dec. 2008)

The list of potential pollutants associated with vehicle use is long and vehicles are considered to be a primary source of the heavy metals found in urban stormwater runoff. Motor oils accumulate wear metals as they come in contact with moving engine parts and are released to the environment as crank-case oil drips to road surfaces or is burned and emitted with exhaust gases. Copper (Cu), lead (Pb) and zinc (Zn) are commonly found in road runoff. Lead concentrations have been decreasing since leaded gasoline use was curtailed, but lead is still lost to the environment as a result of tire wear, bearing wear, oil leaks and lead wheel weights frequently lost along roadways.

Other heavy metals like copper, nickel (Ni) and cadmium (Cd) are found in lesser amounts. Some of these metals are found in gasoline and diesel and emitted with engine exhaust. Brake dust contains copper which is released to the environment as brake linings wear out. Copper is also a bearing wear metal and accumulates in motor oil. Tire wear releases zinc which is also found in motor oil, grease, brake dust and from the corrosion of galvanize parts. Cadmium concentrations can come from tire wear and the combustion of fuels and batteries. Chromium (Cr) is found in air conditioning coolants, as an engine oil wear metal and in brake dust. Nickel is found in gasoline, diesel fuel, lubricating oils and brake dust. In addition to these heavy metals, vehicles use lots of fluids (transmission fluid, brake fluid, power steering fluid, windshield washer fluid) which contain numerous compounds, many of which are pollutants when they escape from their intended use or place.

Roofs

Roof-top runoff often contains measureable amounts of heavy metals, organics and bacteria. Runoff from the roofs of industrial buildings at the Norfolk Naval Base showed copper concentrations of 156 ppb and zinc was measured at over 1,000 ppb. To prevent these high metal concentrations from reaching local waterways, the Navy designed and built a filter-adsorption media bed containing bone char and ferrous-coated activated alumina which reduced the copper and zinc levels to less than 5 ppb before being discharged from the site. (Margaret Buranen, Jan./Feb., 2010) Copper and zinc are often used in downspouts and roofing materials and have attracted a considerable amount of attention since some stormwater permits have screening values for these parameters.



Copper stains on sidewalk caused by runoff from a partially copper roof.

Heavy metals like zinc, copper, chromium, lead, arsenic and organic pollutants are used in various roofing materials and are some of the same pollutants found on roadways, but originate from different products. Asphalt shingles contain and/or are treated with various materials that show up as pollutants in roof runoff. The asphalt in shingles can contain polycyclic aromatic hydrocarbons (PAH) like the asphalt in parking lots and roadways.

Wood or shake shingles are frequently treated with preservatives to protect the wood from the elements and from algae, moss and lichen growths. One common preservative is CCA which contains chromium, copper and arsenic. Both wood and asphalt shingles are sometimes protected from algae, moss and lichen growths with a galvanized metal (zinc) cap along the ridge line. The galvanized metal cap slowly releases zinc in levels toxic to these growths thus "protecting" the roof. Some shingles are made with zinc or copper particles embedded in them or an algaecide or fungicide formulated in. To accomplish the same thing, some homeowners have their roof sprayed with an algaecide to control unwanted growths. Regardless of the method, small amounts of these metals or compounds can wash off with each rain.

Roofs, especially large, flat, commercial roofs typically used for industries, office complexes and schools collect dust and airborne pollutants from the atmosphere and roof-top air conditioners. Rain then flushes these materials, untreated, to the closest receiving water. New roofs will often leach pollutants at a faster rate than older roofs and the first flush often contains the highest concentration of pollutants.

Ordinances, Codes and Regulations

Some local ordinances may need to be updated before a shift from grey to green infrastructure can occur and some of the following beneficial practices can be implemented. For instance, ordinances may have to be changed to allow narrower streets under certain conditions. "Weed" ordinances may have to be altered to allow the use of native vegetation and taller plants. Each community will have its own ordinances, codes and regulations. Reviewing these to ensure they are "LID friendly" will make it easier for developers and builders to incorporate LID practices in their plans which benefit the whole community.

Beneficial Practices

Best Management Practices (BMP)

NOTE: Check local ordinances, codes and regulations before constructing or altering existing structures, paved areas or grading natural or landscaped areas. Federal agencies, state agencies, counties, cities and neighborhood associations frequently have regulations stipulating acceptable construction materials and methods. Structures, paved areas or grading projects not meeting existing regulations might not be approved by the regulatory agency and result in project delays and additional costs. Professional engineering services may be required to implement some of the following practices.

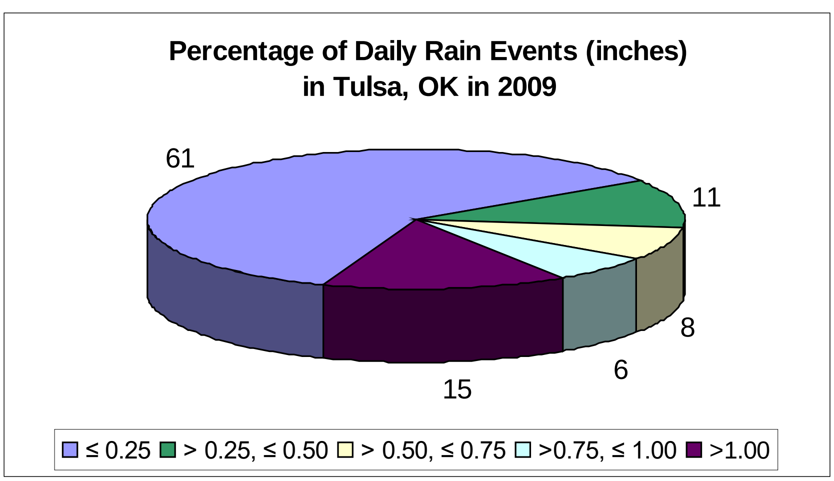
Some cities in Oklahoma have taken the initiative and developed voluntary programs encouraging the use of LID practices. For instance, the City of Broken Arrow is encouraging developers, builders, engineers, planners and landscape architects to incorporate these practices in developments through their "Living Green Certification Program." The city will award developments meeting certain criteria a platinum, gold, silver or bronze plaque they can proudly display at entrances to inform the community that environmentally friendly practices were utilized during the development.

Best management practices (BMP) are frequently used to achieve stormwater management goals. Which practices are implemented depends upon individual needs and site characteristics. Generally pollutant reduction is achieved through natural processes involving settling, adsorption, biological uptake, decomposition and infiltration. Runoff volume reduction is achieved through collection, evapotranspiration and infiltration. Collectively these methods can reduce stormwater runoff volumes and pollutant loading. If it is not possible to implement these BMPs on site, compensatory mitigation projects within the same watershed could include enhancing existing wetlands, creeks and shorelines, creating constructed wetlands and using native vegetation to improve site characteristics.

If a stormwater permit has been issued, a responsible party should be identified. Once BMPs are in place, they should be monitored on a regular basis and have maintenance performed as necessary. Finally, good notes and good records of all activities supporting the program should be kept. When city officials, the general public or regulatory agencies have questions or want to track the program's progress, these records will be useful.

To estimate the effectiveness of an LID design it is best to start with a precipitation analysis for your local conditions. Studying the precipitation recorded over a number of years will give averages that will help predict future precipitation patterns. As an example, consider the measurable rainfall at the Tulsa International Airport during 2009 (NOAA National Weather Service Data from the Gauge at Tulsa International Airport). 14.56 percent of the rain events during 2009, in Tulsa, were greater than 1.00 inch and 20.39 percent were greater than 0.75 inches. 61.17 percent were less than 0.25 inches, 71.85 percent were less than 0.50 inches and 79.62 percent were less than 0.75 inches. Therefore, a green roof that could absorb a 0.50 inch rainfall would have had no runoff from about 72 percent of the measurable rainfalls in 2009.

If BMPs could capture up to 0.75 inches of rainfall, that would result in zero runoff from about 80 percent of the measurable rainfall events and rainfall events of less than 0.75 inches accounted for 13.91 inches of rain in 2009. If the first 0.75 inches of rain from events delivering more than 0.75 inches of rain could be captured that would amount to another 15.75 inches of rain. Combined, this would account for 29.66 inches of the 46.12 inches of rain that



fell in 2009, or about 64 percent of the total rainfall. 2009 was wetter than average. Normal rainfall for this location is 42.42 inches.

A BMP stated to capture 0.50 or 0.75 inches of rainfall is based on the assumption a prior rain event hasn't partially filled its capacity. Multiple rain events in close succession can result in additional runoff. The Tulsa area does receive heavy rain events and some of these BMPs do not have the ability to economically contain a full rain event. In 2009, seven rain events greater than 1.50 inches delivered a total of 17.20 inches at the airport station. BMPs that could capture the first 0.75 inches would only contain 5.25 inches of this amount so there would still be considerable runoff. For a more detailed analysis of the measurable rain events for 2009 at the Tulsa International Airport in Tulsa, Oklahoma, refer to the Appendix.

Because of these heavier rain events, green infrastructure will not be able to replace all of the grey infrastructure, but can reduce the need for some of it. A good time to consider the addition of green infrastructure is when the existing grey infrastructure ages and becomes in need of repair or replacement. When an existing pipe can no longer handle the load, instead of digging up and replacing the undersized pipe with a larger pipe, consider leaving the pipe in place and adding a grassy swale, directing the excess flow to a vegetated area or treating the excess water at its source. In some cases it may be better to "daylight" the flow which involves removing the buried pipe and restoring the natural drainage system or creek that was there before the pipe was put in place years before. Utilizing LID BMPs is a good way to minimize or eliminate some of the negative aspects of development and the addition of trees, shrubs, grass, flowers and open spaces can enhance property values and a neighborhood's aesthetics.

The Los Angeles Low Impact development Ordinance will require "all of the rainwater from a ¾ inch rainstorm to be captured, infiltrated and/or used on most developments and redevelopments where more than 500 square feet of hardscape is added. Single family residences only need to comply in a more simple way, with a choice of options from a manual that is being developed by the Bureau of Sanitation." (Los Angeles Board of Public Works Closer to Implementing LID Ordinance) LID ordinances such as this are becoming more common across the country.

Beneficial Natural Features

Preserving natural features is the easiest and cheapest way to contend with some stormwater issues. If the natural features have already been removed or altered to a point they no longer function as intended, it may be possible to enhance the feature to bring back its stormwater benefits. If the natural features have been removed or damaged beyond repair it may be possible to recreate them if the underlying conditions are still suitable. Aim to preserve as many of the natural features as possible, enhance the marginal ones and rebuild the ones that have been lost if space and conditions permit it.

Soil and Microbes

Oxygen is diffused within the shallow soil horizons which therefore contain an active and dense concentration of aerobic microbes and invertebrates. These are biologically active zones where pollutants are broken down and nutrients and water are taken up by plant roots and the organisms that live here. This process helps to reduce pollutant loads transported by stormwater before it reaches the deeper, oxygen poor (anerobic) soil horizons and eventually an aquifer. Water can be evaporated from the soil and taken up and then transpired by plants. Water loss by these two mechanisms is collectively called evapotranspiration (ET).

Trees, Shrubs and Vegetation

Mature tree preserved at Forest Ridge.

Vegetated surfaces lessen the negative impact of stormwater events in multiple ways and benefit society and wildlife in many more ways. The right landscaping and vegetation can increase property values, improve urban aesthetics, minimize maintenance requirements and help ensure plant survival. Native plants will flourish under the local growing conditions. Plants that have adapted to the local temperatures, intensity of sunlight or amount of shade, soil conditions and annual precipitation patterns will be the most successful. Work around and preserve as many of the mature trees as possible when developing a site.

A plant should fit in the space allotted when fully grown without damaging any structures as a result of root or limb growth. Also, consider safety and security. Don't plant anything in a location that could become a safety hazard such as a shrub or tree that could obscure a driver's vision or a plant that is likely to trip a pedestrian. For security reasons, don't use plantings in a location that will provide concealment to burglars, etc. Consider underground and overhead utilities, roadways, buildings, likely future developments and safety (will it block a motorist's view or endanger the public). Large trees that produce shallow roots can lift sidewalks and damage building foundations when planted too close. Once site requirements are met, consider the plants' aesthetic value (flowers, color, fragrance, shape, size) and benefit to wildlife (edible seeds and shelter).

Erosion Control

Above ground vegetation and surface mulch intercepts raindrops, slowing their decent and minimizing the impact force which dislodges soil particles and starts the erosion process. Raindrops falling by the millions as fast as 30 feet per second can splash soil particles as high as three feet in the air and five feet from where they originally were. (James H. Stiegler and Jack Eckroat, 2004)

Sheet flow is the thin film of water that flows down hill after the surface depressions have filled and can no longer contain the rainfall that isn't absorbed by the soil. When sheet flow concentrates in small rivulets it is referred to as rill flow which frequently results in the formation of a gully. The particle detachment and transport potential is much greater for rill flow than sheet flow. On mild slopes raindrop impact can be a significant source of particle displacement, but many of these displaced particles may not be carried off by gentle sheet flows. On steeper slopes, overland flows will more readily carry these dislodged soil particles to the nearest receiving water. The roughness created by vegetation slows the overland flow of runoff and helps trap particulates keeping the particulates on the land and out of rivers and lakes. Slowing the velocity of the runoff also allows more time for the water to infiltrate the soil which reduces the quantity of runoff. Root systems help hold soil particles in place, stabilize sloped surfaces and native plants such as cattails, reeds, willows and grasses can stabilize drainage areas and minimize erosion in flow channels.

Oxygen Production and Gas Exchanges

Plants produce oxygen through photosynthesis. A mature leafy tree can produce as much oxygen in one growing season as ten people inhale in a year (Steve Nix). Leafy surfaces also filter the air by removing airborne particulates (less than 10 microns in size, Kim D. Coder) and gases like carbon monoxide and sulfur compounds. Finally, plants convert carbon dioxide (which is believed to contribute to global warming) to woody and leafy tissues.

Pollutant Reduction

Plant roots absorb, and thus remove, chemicals, pollutants and nutrients from the soil before they have the opportunity to reach a surface or groundwater source. Some of these pollutants are stored within the plant, others are broken down into less harmful materials. Nutrients are taken up and stored and then slowly released when the plant dies and is decomposed. Woody tissues decay at a much slower rate than soft tissues like leaves. As a filtering mechanism, plants can reduce the pollutant loading to receiving waters.

Noise Reduction

Trees and shrubs can help muffle urban noise and when planted in the proper locations can make effective sound barriers.

Water Uptake

Plants can consume and release significant quantities of water to the atmosphere through evaporation and transpiration processes thereby reducing the amount of runoff from rain events. Plant surfaces are wetted during a rain event and much of this moisture is lost to the atmosphere through evaporation. An acre of grass or one large tree has a lot of surface area. One acre of vegetation can transpire as much as 1600 gallons of water on a sunny day. Increasing the tree canopy by 5% in a community can reduce stormwater runoff by approximately 2%. (Kim D. Coder)

Water infiltration Rate

Root systems can increase the permeability of compacted soils thereby increasing infiltration rates. Plants also add organic material to the soil which increases its permeability and water holding capacity.

Temperature and Weather Alterations

Vegetation helps shade and cool the ground and shades and insulates buildings thereby reducing cooling and heating costs. Trees and shrubs strategically planted as a windbreak help lower heating costs in the winter.

Trees and shrubs also help shade streams during the hot summer months and keep instream water temperatures cooler. Less sunlight and cooler temperatures help to reduce the amount of algae in a stream and reduce diurnal dissolved oxygen fluctuations. Cooler water can hold more dissolved oxygen than warm water and less algae means less oxygen consumption after sundown from respiratory processes. A good tree canopy minimizes the diurnal dissolved oxygen swings which a stream exposed to full sunlight experiences.

Wildlife

Vegetation provides the habitat (food and shelter) wildlife needs to survive. Wooded areas, ravines and buffer strips can provide safe travel corridors for wildlife and minimize genetic isolation. The type of vegetation, size of the parcel and the proximity to people and their activities will influence the species that inhabit the area. Each species has unique requirements and will seek out areas that provide for these special needs. Native trees, shrubs and grasses will generally provide the best food and shelter for wildlife, although agricultural crops can be favored certain times of the year. There is plenty of room for managed wildlife populations even in urban settings.

Riparian Buffers and Filter Strips

The riparian zone is the area along a stream channel which is frequently vegetated with water loving plants. A riparian buffer is a naturally vegetated and undisturbed (or area constructed to replicate a naturally vegetated area) area around a waterway. A filter strip is a vegetated area left to slow the flow of surface runoff and collect particulates being transported by the runoff. Leave buffers and filter strips as wide as practical. If a buffer zone is wide enough it will allow a stream to meander in a natural manner without threatening manmade structures. It may even include the floodplain (which changes in response to development) allowing the stream to rise out of its banks without causing damage to structures and utilities. At a minimum, buffers should allow enough room to regrade eroding slopes if necessary for bank stabilization projects.

Vegetation along the banks is beneficial in many ways. The roots help hold the soil in place and stabilize the stream banks. Shallow rooted grasses and other ground covers help keep topsoil in place. Trees, shrubs and grasses with deep and spreading root systems help hold large chunks of soil in place. Dense or woody vegetation can also be used to restrict foot, bicycle and vehicle traffic which further protects sensitive soils from erosion and compaction.

Low growing grassy plants help trap sediment transported in runoff before it reaches the stream. Above ground vegetation helps slow the decent of raindrops minimizing the impact forces which can dislodge soil particles resulting in erosion. Vegetation also uptakes nutrients in runoff thereby reducing the nutrient loading to the stream. Vegetation along the stream bank can also help shade the water and aid in keeping the water temperature cooler, dissolved oxygen levels up and improve the biodiversity in an urban stream. Finally, riparian buffer strips provide shelter and food for wildlife and pleasant settings for walking trails.

Many variables come into play when determining how wide a buffer zone needs to be to protect a stream and as a result different organizations recommend different widths. Consider the magnitude of the runoff, the frequency of runoff, the density and type of vegetation along the stream bank, the degree of slope within the buffer, soil type and the nature and density of the development up gradient from the buffer strip. For forested areas the Oklahoma Forestry Service recommends a 50 foot buffer along both sides of perennial and intermittent streams. (Implementation of Forestry Best Management Practices in Eastern Oklahoma) More heavily developed urbanized areas may need more and lightly developed areas with a small watershed and good vegetative cover may do well with less. The bottom line is to implement as wide a buffer strip as possible, within reason. It is better to err on the conservative side.

Maintain buffer zones by cutting undesirable trees that compete with more desirable species for sunlight, nutrients and moisture and thinning growth to provide space for more desirable plants without compromising the purpose of the buffer. Restricting livestock access to the buffer zone will help protect the vegetation and stream banks. During the summer, cattle will frequently congregate around water and shade. If the only shade trees are along the creek banks, congregating heavy animals with hard, sharp hooves can have a devastating impact on low-growing, sensitive plants and erodible soils.

Stream Meanders and Natural Channels

Allowing streams to meander (curve back and forth which is referred to as sinuosity) in a natural pattern lengthens the distance the water must flow between two points and decreases the slope of the river bed (often measured in feet per mile). This reduces the water's velocity and its erosive force. Straightening a channel does just the opposite. It decreases the distance the water must flow and increases its slope thereby increasing its velocity and erosive force.

Clear or free span bridges can be used instead of culverts and tubes to help preserve the natural stream channel. By completely spanning the stream channel, the stream bed and banks remain unaltered. This allows stream and wetland crossings with minimal stream bed disturbance.

Streams are dynamic, constantly changing. Over time, the streambed moves from side to side as it erodes away the outside bank and deposits sediment along the inside bank. If a stream could be viewed from above in time lapse photography over a few hundred years it would appear to slither like a snake.

Houses and other structures built too close to a stream may be threatened in the future when the course of the stream changes. This practice should be discouraged since threatened structures would have to be moved, reinforced or the stream would have to be redirected or the banks and bed would need to be armored to avoid structural damage. These options can be expensive and sometimes only marginally effective at protecting the structure. Altering the streambed can have a long term negative impact if not carefully thought out. It is better to avoid the need if possible.

To determine a workable stream setback ordinance, evaluate the stream's needs under the current conditions. Next determine the stream's needs when the drainage basin above that location is 60% developed, 80% developed and 100% developed, or whatever percentages are appropriate. Consider how large the channel will need to be to transport the anticipated base and flood flows. Next, allow room for natural meanders. The setback should also be large enough to allow room for any future slope mitigation or regrading that might be needed. Allow working room for heavy equipment if it might be necessary. This long range planning could save the community and its citizens a considerable amount of money in the future. Buffer strips utilized as natural areas, maybe with trails and little pocket parks, can add value to a development or community while enhancing a stormwater program.

Stream Roughness

Trees, shrubs, aquatic plants, rocks, boulders, woody debris, etc. create roughness in stream channels which helps decrease the velocity of the water. These objects also create habitat, shelter and provide food sources for the aquatic communities. Excess debris in stream channels can have a negative impact if the debris creates obstructions that back up water increasing flooding potential or rapidly changes the course of flow.

Floodplains

Floodplains serve a vital function in watershed management planning. During high water events, excess water (more than the stream channel can handle) has to go somewhere. If the floodplain has been left undeveloped the water can spread out, slow down and drop its silt load without causing flood related damage. When floodplains are filled in or built up, flood water is displaced increasing the depth or extent of flooding in another location. Flooding is a natural occurrence and as urbanized areas develop and the percentage of impervious surface area increases, floodplains become even more important.

Parks, playgrounds, soccer fields, recreational areas and agricultural activities are compatible uses within floodplains. Grounds developed for these activities are still able to function as floodplains during high water periods. During drier times, the community can use these locations for recreation and relaxation and enjoy the habitat that is provided for wildlife.

Preserving Wetlands

Wetlands provide water quality, aesthetic and ecological benefits that help achieve LID and stormwater management goals. The natural processes within a wetland remove sediment, nutrients, pesticides, metals and other pollutants through biological uptake by plants and organisms, microbial degradation and through physical and chemical processes. However, some of these pollutants, like metals, can be released when the plants die and decompose. Elemental materials, such as heavy metals, can also be bound to sediments and remain locked in place for years or until disturbed and resuspended. Other pollutants can be removed through adsorption, microbial decomposition and volatilization. In addition, wetlands store runoff water which helps reduce the flooding potential and many wetlands slowly release water to help replenish groundwater supplies.

Natural wetlands intercept and treat stormwater runoff and should be preserved, protected and enhanced whenever possible. They already have the proper hydrology, vegetation and biological systems necessary to function as nature intended and are difficult to simulate. Constructed wetlands can function properly if situated in the right location and properly designed. These can provide many of the benefits of a natural wetland and have been successfully used as low cost wastewater treatment facilities, but may require some maintenance.

Wetlands can also be used to treat stormwater runoff. For instance, the compounds benzene, ethylbenzene, toluene and xylene (BTEX) and other organics are commonly found in fuels, oils and other automotive fluids and therefore present in runoff from streets and parking areas. Aerobic biodegradation by wetland microbes and volatilization can remove these compounds before they enter a stream or groundwater supply.

Natural Wetland

In the proper setting, wetlands are very beneficial, but may pose a couple of problems in densely settled areas. Children are naturally attracted to lakes, ponds, creeks and surface waters in general. However, with proper adult supervision, exploring wetlands can be a positive educational experience. Without supervision there could be risk.

Another concern is mosquito production. The presence of certain minnows, predatory insects, birds and bats can help control mosquito populations.


Constructed Wetland at Forest Ridge

Preserving wetlands in less developed areas and maintaining a healthy and balanced wetland in urban settings can dramatically enhance a stormwater program. Protecting these areas in their undeveloped and natural state is an inexpensive way to help maintain water quality into the future. Replacing the natural hydrologic function of the land that is lost during development is costly, but at some point becomes necessary. Low-lying areas prone to flooding and outside of the urban area can often be purchased for considerably less per acre than urban land within the same watershed. When urban development requires off-site mitigation, consider purchasing, enhancing and protecting some of this acreage. If the land can’t be purchased, a conservation easement that prohibits future development might be purchased. This can cost considerably less than the purchase price of the land and may accomplish the same water quality goals.

One often overlooked benefit is the habitat wetlands provide for wildlife. Ducks and geese depend on wetlands for breeding, nesting and feeding habitat. In addition, more than 5,000 plant species, 190 species of amphibians and one-third of all native bird species are supported by wetlands (Small Scale, Small Field Conservation). A walking trail with interpretive signage through or around a wetland allows the public easy access and helps educate them about the benefits of water quality projects and how our society benefits from projects such as these while helping to provide habitat for wildlife.

Beneficial Constructed Features

Silt Fencing

Silt fencing is used to prevent sediment from being washed off construction sites and areas with disturbed soils. When properly installed and in the right location a silt fence will allow water to flow through, but retain soil particles and suspended solids. These tiny soil particles contain bits of clay and humus which can carry a negative (anion) electrical charge. This allows them to bind with positively charged material (cation) such as calcium and magnesium which are nutrients. As the soil particles get swept away by the water, the nutrients bound to them are also swept away.

The sediment trapped by a silt fence and any bound nutrients or pollutants can then be redistributed onsite and are kept out of local streams and waterways. For a silt fence to be effective, it must be properly installed and maintained.

Detention, Retention and Infiltration Basins

Detention basin east of Bishop Bldg., Saint Francis south campus.

Detention basins are used to temporarily store stormwater runoff and gradually release it at a controlled rate. They can have either permeable or impermeable bottoms. Their primary purpose is detention and not infiltration and they do little to remove excess nutrients in urban runoff. In addition to collecting suspended solids and associated pollutants adhering to the particulates, ponds can help remove some stormwater pollutants through microbial decomposition and biological uptake. For the most part, these basins are limited in their ability to improve water quality, but can be used as recreation areas when not inundated with water.

Stormwater detention basin with recreational equipment at Forest Ridge

Other than the water that percolates through the bottom of the basin or evaporates, they do little to reduce the total volume of runoff. They are designed to pass volumes of water over a prolonged period of time. The big benefit is the controlled release of the water which reduces peak flows in nearby streams. These slower releases over a prolonged period of time reduce flooding potential and the erosive force of the otherwise high flows.

Retention basins are designed to store runoff indefinitely and do not have a direct outlet to a surface water. Therefore, retention basins can retain most watershed pollutants. The disadvantage is the land area required. Since retention basins don't have a direct outlet they must be much larger than detention basins and frequently are designed to contain two 100 year rain events.

Infiltration basins are similar to retention basins with an emphasis on loss through infiltration and evapotranspiration. They collect stormwater runoff and hold it to allow maximum time for the water to percolate into the soil. Infiltration basins are dependent upon open or porous soils and therefore not always a suitable choice. Vegetation can be used to help improve water quality in a number of ways and provides wildlife habitat. Limiting water depth to 3-4 feet will maximize plant diversity. These basins lose water through evapotranspiration and infiltration into the soil and trap suspended solids and associated pollutants. The vegetation uptakes nutrients like excess fertilizer and microbes in the soil and sediment help break down organic materials. The water that percolates into the ground recharges groundwater stores, helps maintain base flow conditions in nearby streams and reduces runoff which helps minimize flooding events.

Reducing the amount of impervious surface helps reduce the amount of runoff and this in turn reduces (but likely will not eliminate) the need for detention. As with any pond, lagoon or basin, gradually sloping shorelines provides multiple benefits. It is safer, minimizes erosion and provides better shoreline habitat.

Relaxing detention basin at Natalie Medical Building.

Filtration

Filtering runoff at stormwater outfalls is a good water quality improvement BMP for removing sediment, litter and oil and grease. The Bishop Building at Saint Francis south campus (91st street in Tulsa, OK) installed two large Contech Vortechs Model 5000 filters. Stormwater runoff from streets and water from a large landscaped area is filtered to remove sediment and litter. Oil and grease can also be collected in these filters before entering the local creek if a spill occurs. Sediment and litter that accumulate in the filter is pumped out and sent to a landfill.


Roadway storm drain

Contech inlet filter box

Landscape storm drain

Rain Gardens

A rain garden is a landscaped garden intended to collect runoff water and then allow the collected water to dissipate to the atmosphere through evaporation, transpiration through plants or to percolate into the soil. This reduces the quantity of rainwater running off of the site and improves the quality of the water through natural processes. There are many different types of rain gardens. The available space, type of soil, local climate, location, surrounding developments, budget, maintenance requirements and the desired runoff volume reduction will dictate the type and size of rain garden.

Vegetation and infiltration from a rain garden can remove pollutants like sediment, nitrogen, phosphorus and organics. These can be inexpensive to install and provide aesthetic appeal to a site while providing habitat for numerous creatures, but not mosquitoes. Mosquitoes generally need at least seven days of standing water to go from egg to adult. Unlike wetlands and retention facilities, rain gardens do not impound surface water for days so mosquito breeding risks are eliminated. The water in a rain garden is stored below the surface in the soil and within the plants.

Due to various circumstances some rain gardens are lined or constructed in impervious soils and do not allow infiltration into the ground, only evaporation and transpiration to the atmosphere. Amending the soil is frequently required to get the desired infiltration or water retention rate. Adding organic matter can increase the water retention in sandy soils or increase infiltration and depth in clay soils.


Rain garden at the Tulsa Zoo

All gardens require some maintenance. Using native vegetation and grouping plants that have similar watering needs minimizes the amount of time necessary to keep a garden looking good and help ensure success. Plants requiring a lot of moisture are frequently not good choices for rain gardens. Though these gardens collect runoff after a rain event they are relatively dry for longer periods of time, especially in the hot summer months. Water-loving plants will be stressed, go dormant or die during these dry times unless supplemental watering is provided which runs counter to the LID philosophy. Remember, rain gardens are not wetlands or marshes. It they are planted with drought tolerant wildflowers and ornamental grasses they can look like ornamental gardens and still provide stormwater benefits. A list of suitable plants for Oklahoma (compiled by Kevin Gustavson with the Oklahoma Conservation Commission) can be found in the appendix.

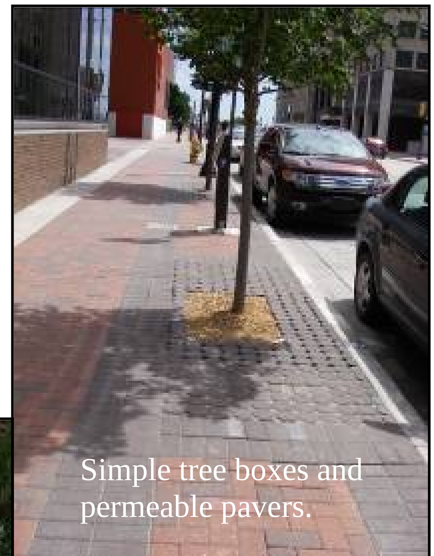
The soil in a rain garden should be rich in organic material to encourage vigorous plant growth, improve infiltration rates and help retain moisture. A small, shallow rain garden may only be four to ten inches deep. A large one could be a few feet deep. The depth of soil in a rain garden will depend upon the rooting requirements of the vegetation in the garden and could depend upon the infiltration rate. A deep hole in tight, compacted soil that doesn't percolate well could hold quite a bit of water for a prolonged period of time and drown the root system of certain plants. A large rain garden in tight, compacted soil will need a good drainage system. In situations like this, a few shallow rain gardens might be more effective and easier to construct than one deep one.

Trees and shrubs that have deep and spreading root systems will need a large and deep area for healthy growth. Also, the moisture holding capacity of the soil must be considered as well as how much water the garden needs to retain. Smaller plants like flowers, grasses and small shrubs will do fine in a much smaller rain garden.

If the percolation rate of the subsoil is slow, it may be necessary to place a porous aggregate underdrain in the bottom. If the rain garden is intended to store larger volumes of water an open-graded gravel storage trench with 20 to 40 percent void spaces can be placed below the root zone. This can be something as simple as a gravel and/or sand trench with perforated pipe that discharges excess water. Ideally, standing water within a rain garden would drain within 12 to 24 hours. Plants that can withstand a saturated root zone for longer periods could go up to 48 hours. Maintaining aerobic conditions in the root zone most of the time is necessary or non-wetland plants will be stressed. A rain garden is not a wetland so plants need to be able to withstand these wet/dry cycles.

Rain gardens can collect runoff from yards, fields, streets, patios, sidewalks, driveways, parking lots, rooftops, etc., wherever excess runoff is generated. Natural depressions are frequently good locations for rain gardens. Rain gardens can be used to reduce stormwater runoff from residential and commercial lots and provide wildlife habitat. For suggestions and construction help, see the rain garden section under Resources at the end of the report. A rain garden brochure is included in the appendix and can be used for educational purposes.

INCOG, the Oklahoma Conservation Commission, various cities and other organizations worked together to install a few rain gardens in prominent locations as a part of this project. The goal was to place these rain gardens in high traffic areas where they would be highly visible, help solve a runoff problem and could be used to help educate local residents and individuals that frequent these areas. A summary report of the rain gardens, their locations and the individuals and organizations that helped install them is attached at the end of this report.



Simple tree boxes and permeable pavers.

Tree Boxes

A tree box is an unpaved area frequently between a curb and sidewalk or in a parking area that will accommodate a shrub or tree. It allows room for the tree to grow, provides a bed of soil that will support a healthy root system and collects runoff from the surrounding impervious surfaces. Tree boxes can be used to preserve trees in developing areas or add trees to urban landscapes. An urban forest provides many benefits to urban residents and local stormwater programs.

Elaborate and decorative tree box.

Vegetated Swales (Biofiltration, Grassy Swales, Bioswales)

Golf Course Bioswale.

Vegetated swales (both dry and wet) are vegetated, open channels intended to collect sheet flow runoff. These swales conduct, retain and infiltrate surface water runoff or any combination of the three. In the process, sediment can be removed from the flow, nutrients can be taken up by the vegetation and organics can be broken down by soil microbes. These systems are also less costly to construct than channeling the flow in enclosed pipe. Establishing and maintaining the correct grade and using grade stabilization structures when necessary is essential to preventing standing water (where not intended) or gully erosion. Grassy swales are not appropriate for all locations, but work well under the right conditions. These swales are frequently vegetated with native plants and are designed to infiltrate a storm of a certain magnitude and conduct flows from higher volume storms.

Bioswale at Forest Ridge

A bioswale's size is dependent upon the type of soil and size of the drainage area and should drain in about 24 hours. At least 12 inches of top soil should be provided to help protect groundwater quality and maintain a healthy root zone. A 60% sand, 20% clay and 10% organic mix will provide good filtration and infiltration rates. In dense soils with poor percolation rates, an underground gravel storage area or underdrain may be necessary to prevent ponding of water. Water volumes are reduced by the amount of water that infiltrates the soil and is lost through evapotranspiration processes. This is one way to provide water conveyance with water quality improvement aspects while reducing the volume and flow rate of runoff.

Reducing the slope to slow the flow of runoff and planting native, deep-rooted grasses and forbs (to increase channel roughness) helps filter sediment and prevents erosion. Residential areas, parks and golf courses are just a few locations where vegetated swales can be used effectively.

Rainwater Harvesting

Captured rainwater and runoff is ideal for watering gardens, flower beds, yards and other landscaped areas during dry periods. It can also be used as a secondary drinking water source (in some areas) and for other domestic uses (including clothes washing and flushing toilets where permissible) if adequate protection and treatment is provided and the plumbing meets all code requirements. European countries have been using harvested rainwater for toilet flushing, clothes washing and showers for years (Lyn Corum).

Harvesting rainwater benefits both the property owner and the community in numerous ways. After the initial cost of the capture and storage system, the collected water is free. Using harvested water reduces the need for publicly treated water. This lowers treatment costs for the utility and the water bill for the business or homeowner. Producing potable water consumes energy, chemicals, man-hours, source water and requires expensive pumps, basins, piping and facilities. Collecting rainwater also reduces consumption of a limited municipal source which may become stressed especially during times of drought or rapid growth. Only a small portion of the potable water produced by a water plant is actually consumed. Water used for irrigation, washing a vehicle, etc. does not need the advanced treatment drinking water receives and therefore rainwater is perfect for these uses.

Capturing runoff from property also reduces the flooding and erosion potential for a storm event by reducing total runoff and peak flows in receiving waters. If this harvested water is used to water gardens, flower beds and yards, most of it will infiltrate the soil and be used by vegetation and to recharge groundwater stores.

To determine legal uses and requirements for harvested rainwater, contact the appropriate local and state authorities. The American Rainwater Catchment Systems Association (ARCSA) collaborated with the American Society of Plumbing Engineers to write the Rainwater Catchment Design and Installation Standards, published in late 2009. "The standards are intended to be consistent with and complimentary to the requirements of the Uniform Plumbing Code, International Plumbing Code, and National Institute of Health." (Lyn Corum) In general, collection systems that use outside storage systems (above or below ground) and don't pipe harvested water inside a building intended for occupancy are lightly regulated and not regulated at all in many cases.

The basic components of a rainwater harvesting system are as follows:

1. A catchment surface (roadway, roof, patio, etc.) that collects the rainwater.
2. Piping, gutters and downspouts to channel water to the containment vessel.
3. Filters to remove grass, leaves and sediment before the water reaches the storage unit. Disinfection or other treatment processes may be needed depending upon water sources and end uses.
4. Storage vessels or tanks. These could be small 50 gallon rain barrels or tanks holding thousands of gallons.
5. End use filtration or treatment processes if required.
6. Distribution system with pumps as necessary to deliver the water to its final location.

Harvested water should be tested for impurities as necessary depending upon its intended use. Raindrops can pick up airborne pollutants; however the majority of the pollutants present in runoff (microbes, organic material, metals, nutrients, suspended solids, etc.) are washed from collection surfaces. Roof-top runoff can contain measurable amounts of heavy metals, organics, bacteria, viruses and suspended solids. Roofing surfaces made of petroleum products (like asphalt shingles and petroleum based membranes) can contain toxic materials. Treated wooden shingles can also leach toxic and carcinogenic materials. If using wood, untreated cedar shingles may be best. Clay tile and metal roofs are often good options for roof top runoff collection. In addition, roadways and parking areas can contain vehicle fluids, oils, greases, fuels and deicing agents like salt.

The majority of these pollutants are washed from collection surfaces with the first flush (the first volume of water rushing over the surface). If this is a concern and will impair the reuse of this water, a first flush diverter can be installed to divert the initial flow to a discharge area and the remainder of the flow to the collection vessel. A diverter can be as simple as manually moving a pipe to a discharge area and then back to the storage cistern after the first flush or an automated system can be installed which performs this task unattended. Filtration and treatment needs will depend upon the source of the water and its intended use. Cost effective systems should be easy to maintain and inexpensive to operate.

A one inch rain falling on a 1,000 ft^2 roof will yield 623.4 gallons of water. Harvesting this free water would allow a homeowner to water flower beds for days after the rain event and greatly reduce the amount of runoff from their property. To determine the amount of rain that can be collected from your rooftop, multiply the length of the roof times the width in feet. This will give you the square feet of surface area. Next divide the inches of rain by twelve to convert the inches of rainfall to feet of rainfall. Now multiple square feet of roof surface by the rainfall in feet to get cubic feet of water. To determine gallons of water, multiply the cubic feet of water by 7.4805 which is the number of gallons per cubic foot.

Ex: 1 inch of rain falling on a 100' x 10' roof.

100' x 10' = 1,000 ft^2 of roof surface
1" of rain ÷ 12 = 0.08333 feet of rain fell on the roof
1,000 ft^2 x 0.08333' = 83.33 ft^3 of rain fell on the roof
83.33 ft^3 x 7.4805 gallons/ft^3 = 623.4 gallons of water fell on the 100' x 10' roof

This is enough water to fill 11.3 drums (55 gallons each). Even a half inch of rain on this rooftop would fill 5.7 drums.

Rain Barrels and Above Ground Cisterns

Rain that falls on roofs, collects in gutters and then is discharged from a downspout can easily be discharged into a rain barrel or cistern instead of onto the ground. This stored water is perfect for watering gardens, flower beds or the yard during dry periods and minimizes the amount of water that otherwise would have to be purchased for these purposes.

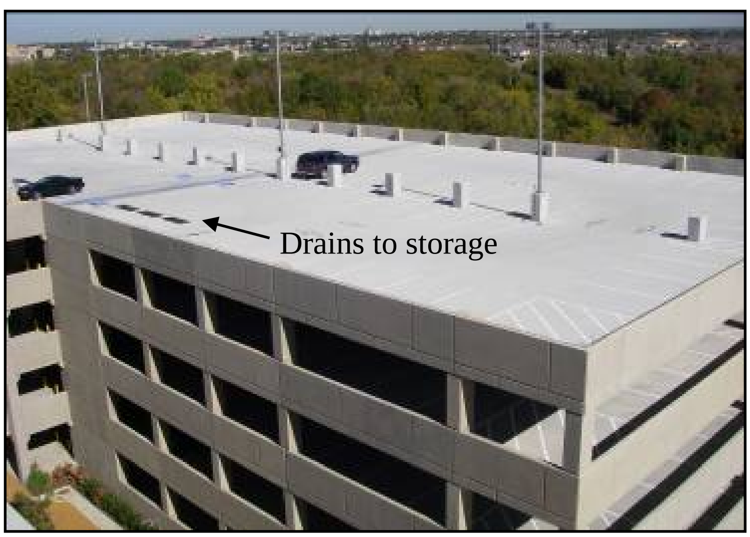
The City of Austin (TX) Water Utility first offered rebates to citizens to install rainwater barrels in 1998. In about 2003 they discontinued the rebates and bought rain barrels in bulk and distributed them. In 2008 they quit distributing barrels and went back to offering rebates. They still offer $30.00 rebates to customers for up to four barrels and larger rebates for larger systems. Since the program began they have given away over 12,000 rain barrels and estimate they have reduced peak day demand by over 300,000 gallons. (Lyn Corum) Various cities and organizations in eastern Oklahoma have promoted the use of rain barrels and given a few away, but nothing like Austin's program which has really been effective.

Building a rain barrel is not a difficult project and there are numerous plans and instructions on the internet. It is best to use a plastic barrel and make sure it is placed on a solid, level surface since a full barrel could weigh 400 pounds or more. If you prefer, there are a number of sources, including some internet sites and home improvement stores, which sell completed rain barrels. The homeowner just installs the barrel and attaches a garden hose. For safety reasons, every rain barrel or cistern should have a sturdy top that will keep children and pets out. Openings exposed to the atmosphere should be screened to prevent mosquitoes from laying eggs in the barreled water. Barrels can fill quickly, so there should be an overflow that directs excess water away from a home's foundation. Also, freezing winter temperatures might damage a full or partially full rain barrel (water expands as it freezes) that isn't constructed for cold climates, so consider draining it before cold snaps if necessary.

Underground Stormwater Storage

Numerous manufacturers sell flexible and hard-walled underground water storage chambers. These can be used under pervious pavements to store runoff allowing additional time for infiltration when the surrounding soil has poor percolation characteristics. They can also be used to harvest runoff (from catchment surfaces) which can be used at a later time to water landscaped areas during dry periods.

Installing storage chambers under parking areas, courtyards, tennis courts, etc. reduces runoff, maximizes land usage and does not detract from architectural or landscaping goals. Land in general and parking spaces in particular can be expensive or in short supply in developed areas. Detention ponds take up surface area. Underground storage accomplishes the same thing, but allows the surface to be used for other purposes. Rain harvesting is a good way to collect stormwater runoff onsite for later reuse or to allow it to infiltrate soils. A discharge pipe from the storage vessel can direct excess flows to a detention pond, wetland, grassy swale or other appropriate location.



The Bishop Building at the Saint Francis south campus at 10507 E. 91st St. in Tulsa, OK (managed and designed by the Warren Professional Building Corporation) utilizes underground storage for their rainwater harvesting system. They use 6,000 and 40,000 gallon tanks in series. The 6,000 gallon tank collects grey water form sinks and showers in the Bishop Building and the rooftop runoff. Before entering the 6,000 gallon tank the water is filtered through two sock filters in series and then chlorinated. The 6,000 gallon tank allows contact time for disinfection before entering and being diluted by the contents of the 40,000 gallon tank.

Runoff from all levels of the five story parking garage is filtered before being collected in the 40,000 gallon tank. The combined water from the 40,000 gallon tank is pumped out and used for landscape purposes as necessary. This kind of innovative thinking saves the company money by reducing the amount of treated water they would have otherwise had to purchase. It also reduces the amount of runoff after a storm event. Being good stewards of the land, a good neighbor to the adjoining property owners and the community as a whole is an admirable goal. Tom Cooper, Chairman and Chief Executive Officer with Warren Professional Building Corporation has been instrumental in the design and implementation of many innovative LID BMPs in the Tulsa area and can be reached at 918-481-7911. Tom's first hand experience may be beneficial to others new to these concepts.

Landscaping above tanks.

Over 90 percent of the stormwater entering the system from the parking garage is filtered through four WISY Vortex fine filters (WFF). Each filter removes particles larger than 0.38 mm and has a capacity of 16 liters per second. The collected particulates are sent to a municipal landfill thus minimizing sludge and large particulate buildup in the tank. The vortex flow over vertical filters makes these filters self-cleaning and there are no pumps, moving parts or electricity requirements. The natural forces of gravity, inertia and adhesion are all that is needed to make these filters work. They are also designed to be installed below ground so they will blend in with the landscaping and be unobtrusive. The underground tanks at the Bishop Building are below a pleasantly landscaped area which provides a nice transition from the parking garage to the building.

Disconnect Impervious Surfaces

Disconnecting impervious surfaces like driveways, patios, roofs, parking lots, curbs, gutters and tennis courts from conveyances that discharge water directly to a surface water can achieve multiple benefits. By removing the pipe or concrete lined channel and allowing the stormwater to flow through a grassy swale or across a vegetated field some of this water will infiltrate the soil, evaporate or be taken up by the vegetation. The surface roughness will slow the flow of the water and filter out some of the suspended solids. Ultimately, less water will reach the local creek, the travel time will be longer and the water will transport fewer pollutants.

In densely developed and urbanized areas this BMP must be applied cautiously. Some impervious surfaces collect large quantities of water which could overwhelm the limited green spaces available and flood surrounding properties and structures if discharged to a surface area.

Another option is to collect runoff from an impervious area in a linear drain, also called a trench or slotted drain. This flow can then be directed to a rain garden, dry well (a pit filled with gravel or an underground container that stores water and allows infiltration over time) or infiltration trench. These can be used to temporarily store runoff below the surface until it is able to soak into the soil. This works well for small impervious areas like roofs or patios. Larger parking lots may require a few linear drains in low lying areas or along the down-grade edge.

Seemingly small measures such as disconnecting downspouts from impervious surfaces can make a noticeable difference if enough people do it. Allow this water to drain to a rain barrel, cistern, dry well, rain garden or grassy portion of the yard instead of down the driveway, into the street and then down a storm drain.

Pervious Surfaces

Pervious, porous or permeable surfaces have spaces or pores that allow the transmission of water to a porous aggregate subbase, soil that has a good percolation rate or an underground storage vessel. Suitable soils are necessary to allow infiltration to groundwater. Allowing runoff to percolate into the soil reduces the quantity of surface water runoff, replenishes groundwater stores, contributes to the base flow in local streams, and helps reduce the local flooding potential and peak flows in local creeks.

Because porous surfaces allow water to quickly percolate into the soil and underlying groundwater reservoirs they should not be used near areas likely to be exposed to high concentrations of pollutants. Commercial nurseries, auto recycle facilities, fueling stations, vehicle service centers, chemical storage areas and industrial sites using organic solvents are a few locations that should not use porous surfacing. Groundwater contamination risks are too high.

In addition to LID and stormwater benefits there are some significant safety benefits. These surfaces drain and dry more quickly so ponding of water is minimized, there is less freezing of pooled water, less “black ice” and fewer icy spots in the winter. Since they dry quicker these surfaces are also safer in the summer for bicycle and vehicle traffic. Parking areas, driveways, sidewalks and patios can be well suited to porous surfacing and parks and recreation applications could include cycling, running and walking trails. These are not heavy load applications and the porous nature of this material will allow the surfaces to dry and become useful more quickly than regular concrete or asphalt after rain or snow.

Early attempts with porous pavements met with limited success. The failure rate was high because the technology was new. In the late 1990s and early 2000s a number of articles were written cautioning people about the high failure rates and rigorous maintenance schedules for pervious surfacing. Since then, much has been learned about the proper formulations of porous concrete and asphalt, how to pour and finish it, how to engineer a project and then maintain it. As a result, the success rate is much higher now when knowledgeable individuals plan the project and perform the work. Therefore, check the date on printed material and only use current information when deciding whether pervious surfacing is appropriate for your project.

If well drained soils are not present, a subbase of washed rock can store a significant amount of water within the voids which can then slowly percolate into the ground over the course of days. This is called an infiltration trench and is often designed to contain a 1 to 1½ inch rain event, but can be designed to hold greater amounts. The storage bed under a porous surface is frequently a bed of clean, washed stone of consistent size. The void space may be 40% or so and a geotextile cloth can be used to separate the stone bed from underlying soil and keep small particulates from filtering up into the stones and plugging the voids. A network of perforated pipe can be placed within the stone bed to quickly disperse and balance water stores within it. Perforated pipe can also be placed at the top of the storage bed to discharge excess water after the reservoir or infiltration trench has filled thus preventing water from backing up into the porous concrete or asphalt layer.

Another option is an underground cistern or large perforated pipe in a gravel trench which can store the water that percolates through the pervious surface and be reused for landscape irrigation. A drain below the pervious surface should be installed to allow excess water to flow away from the pervious surface and not back up within it when rainfall exceeds the storage capacity.

Extending the stone to the surface (no pavement over the top) along one side of the parking area or in a rectangular patch can also be used to collect surface flows or rooftop flows discharged to this area allowing water from other areas of the property to collect in the underground storage area beneath the parking lot.

Rainwater harvesting systems replace purchased treated water with free rainwater which makes sense for certain applications. This can lower the demand for publicly treated water, reduce stormwater runoff volumes and rates from the site and save the property owner money.

Without adequate drainage beneath the pervious surface, water will collect within the porous surface and immediately under it. Freezing and thawing cycles can then quickly destroy the surface by cracking and heaving it up. Adequate drainage in the subbase layer is necessary to prevent freeze damage which can occur if the porous concrete is saturated when exposed to freezing conditions. When the project is correctly engineered and the right mix is poured properly, these surfaces have been successfully used in cold climates and offer some advantages over impermeable asphalt and concrete. In all cases, an engineer should be part of the decision-making team and consulted early in the planning process to ensure a successful outcome.

Putting a pervious surface over an impervious subbase, like clay or heavily compacted soil, provides minimal infiltration benefits. If storage is provided under the pervious surface, even a slow infiltration rate might be workable. “We do not consider infiltration rates between 0.1 and 0.5 in/hr. too slow; rather, this means that infiltration will occur slowly over a two- to three-day period, which is ideal for water-quality improvement.” (Michele C. Adams) Some subbase compaction may be necessary to provide structural stability to the surface, but a good bed of rock might minimize the need for compaction. Storage tanks and various types of underground storage vessels can be used to harvest runoff for reuse as landscape irrigation water during dry periods if the soil is too dense.

For a porous surface to continue to function as it was originally intended, the pores must remain open. If fine silt, clay, oil, grease, etc. gets trapped in the voids and plugs the surface, it loses its porous nature. Consider the suspended solids loading in the runoff before selecting a pervious surface and design in a sediment reduction process if necessary. The first flush from a rain event frequently carries a high particulate load and runoff from a construction site or a gravel parking area can have a very high silt load. Porous surfaces must be protected from high sediment loading events. A parking lot could be curbed to protect the porous pavement from overland flows or be built at a higher elevation. Vacuum trucks can be used to suck particulates out of the voids and help reestablish the porosity of the surface as necessary.

During cold weather, the use of deicing salts and sand should be restricted on permeable asphalt and concrete. In a number of instances the need for these materials was found to be much lower with pervious surfaces than impervious surfaces. The sun tends to heat asphalt and concrete surfaces, especially darker surfaces more quickly than surrounding soils. As long as water can move through the surface, puddles don’t form and freeze on pervious surfaces.

A number of pervious surfacing methods are available and, under the right conditions, can be used in place of impervious surfaces. The advantages and disadvantages of each should be carefully weighed before determining which method is the most appropriate for any given situation. Reducing the amount of impervious area can be achieved by reducing street widths, reducing building setbacks, replacing impervious surfaces with pervious surfaces and altering codes and ordinances if necessary to make them more LID friendly. Directing flows from impervious surfaces like roofs, roadways and parking areas to pervious surfaces and rainwater collection systems is the next best thing to reducing the amount of impervious surface area and in some cases even better.

If a totally pervious surface is beyond the project scope, a mix of pervious and impervious materials can be used. A pervious border around a slightly crowned parking lot, along the down-gradient edge or pervious panels can be combined with traditional impervious surfacing if slightly sloped to direct runoff to the pervious portions. Major travel lanes constructed with traditional and more durable and maintenance-free impervious materials can carry the heavy traffic loads. The pervious sections then act as drains without the need for grates. Grates can pose safety hazards to pedestrians, bikers and strollers. A pervious border or panels can also be added to an existing impervious parking area to improve onsite water retention without the need to totally replace a surface in good condition.

Porous Asphalt

Under certain circumstances porous asphalt can be used in place of traditional asphalt. Porous asphalt is made with standard bituminous asphalt without the aggregate fines. Removing the fines and just using the coarser material creates voids in the asphalt which allows water to percolate through. To function properly, the subbase material under the porous asphalt must allow this water to continue on its way.

If porous asphalt is properly installed, has good subsurface drainage and is protected from particulates, it can last for many years and be a good addition to a stormwater management program. A porous asphalt lot (600 parking spaces) was built in 1983 at the Shared Medical Systems (now Seimens) world headquarters just outside of Philadelphia, Pennsylvania. As of 2003 it was still functioning as originally intended and had not been repaved. “Because porous asphalt has reduced fines, it has less shear-strength capability and therefore is not recommended for such situations as airport taxiways or slopes greater than 6%.” (Michele C. Adams)

Twelve asphalt paving and maintenance companies in the Tulsa, Oklahoma area were surveyed by telephone on June 15, 2010. Conversations with various personnel at these facilities did not reveal the presence of any LID porous asphalt projects in this area or plans for any in the immediate future. According to the personnel INCOG spoke to, there have been no LID requests for porous asphalt. Road Science, LLC (66th and Yale, Tulsa, OK, phone: 918-960-3800) does have some experience working with porous asphalt. Individuals seeking additional information can contact them concerning the applicability of this product.

Road Science, LLC makes a porous asphalt overlay material which is used over a moisture barrier placed over an existing asphalt roadway. This product is intended to allow water to drain through the overlay and flow out the sides of the roadway thus minimizing any standing water on the road surface. This reduces splash, spray and hydroplaning which makes driving on this surface in and after a rainfall safer. There is a 22 mile stretch of this surfacing on the Turner Turnpike between Tulsa and Stroud. However, since there is no rainwater harvesting and/or reuse mechanism and the rainwater does not percolate through the road bed this does not qualify as an LID project.

Water is simply allowed to flow through the overlay to an edge, instead of across the surface, and discharged to the roadside ditches.

Porous asphalt has been used successfully in other areas of the country, but has been slow to receive acceptance in eastern Oklahoma.

Porous Concrete

Porous concrete is made by mixing water, cement and aggregate particles without the fines (little or no sand) commonly used. This leaves a network of voids, typically between 15% to 25%, allowing the passage of water through the concrete at the rate of about 5 gallons per square foot per min (5 gal/ft^2/min) (Paul D Tennis *et.al*.).

The two photos above (taken on November 14, 2006) are of the porous concrete test pad that was jointly poured by Twin Cities Ready Mix and Cantera Concrete, Inc. at the Twin Cities Ready Mix facility in Tulsa, OK. The pad depth and porosity is readily apparent.

The two photos below (taken on June 21, 2010) are of the same porous concrete test pad three and a half years later. Numerous gallons of water were quickly discharged to various portions of this pad and rapidly filtered through with no lingering puddles and the pad surface dried in minutes in the 90 degree heat. This pad has been used for parking for about 3½ years, exposed to freeze and thaw cycles during three winters and summer heat during three summers. It is adjoined on one side by a gravel parking area and has had no routine maintenance. There were no visible signs of cracking or frost upheaval. Freeze/thaw damage can occur if the voids in the concrete are saturated when the concrete is exposed to freezing temperatures. A base or surrounding surface that allows the porous concrete to drain quickly minimizes saturation and the possibility of freeze damage. (Phillip W. Kresge)

One section of the pad had been accidentally exposed to a large quantity of fines (a load of sand was dumped on it) and the surface was visibly contaminated with sand and other fine particles. The first discharge of water to this section of the pad drained slower than the cleaner sections, but still drained with a little runoff. The water hose on the truck was used to blast the surface clean. This process removed a noticeable amount of sand and grit and appeared to open the surface and restore some of the original porosity. After three years of use and exposure to silt and sand with no maintenance, this test slab allowed the infiltration of large quantities of water with no lingering puddles and minimal runoff.

Pressure spraying the surface will dislodge loose surface particles, but the possibility of forcing particulates deeper into the slab could result in plugging that could be difficult to fix. Under normal conditions surface clogging is limited to the top 1 to 1.5 inches. (Phillip Kresge) Street sweeping the dry surface, or better yet, using a vacuum truck to maintain the open pores, would likely prolong the useful life of porous concrete for many years.

The two photos above show the porous concrete at Twin Cities Ready Mix under a layer of snow and ice. The porous nature of the concrete allows warmer air from below ground to melt the ice from the bottom (notice the key and business card slid under the ice) while the sun melts the ice from above without puddling. This coupled with sublimation (when ice changes from its solid phase directly to a gas without going through a liquid phase) allows the concrete to clear quickly, minimizing the need for deicing agents.

GCC Mid-Continent Concrete Company and Cantera Concrete, Inc. also jointly poured two porous test pads at the GCC Mid-Continent Concrete Company facility in Tulsa about two and half years ago. These pads are also being used for trailer parking. In addition they have poured porous concrete in Springdale, Arkansas and so have some experience with this product.

From June 18 to June 21, 2010, INCOG contacted twenty local concrete production companies and finishing companies. Twin Cities Ready Mix and GCC Mid-Continent Concrete Company were the only two that said they have the ability and experience to make porous concrete and Cantera Concrete, Inc. was the only contractor contacted that said they have used and have experience with porous concrete. Making and finishing pervious concrete is different than impervious concrete. It requires some novel equipment and additional knowledge to successfully pour and finish. As the use of porous concrete becomes more common, others will gain the skills to successfully pour and finish this product.

If the project is properly engineered and correctly poured, pervious concrete can assist builders in achieving Leadership in Energy and Environmental Design (LEED) certification and stormwater managers in meeting stormwater goals. LEED is an internationally recognized green building certification program.

Good engineering upfront, proper installation by a knowledgeable crew and routine maintenance would likely keep porous concrete functioning for many years. The use of porous concrete over a pervious subbase, an infiltration trench or a rainwater collection system is an excellent way to minimize stormwater runoff from a site and will help developers and city stormwater departments meet state and federal stormwater regulations.

In warm climates, a properly designed porous pavement can also store water within the pavement. To prevent freeze damage, saturated porous pavement should not be subjected to freezing conditions. Five inches of porous concrete with 20% voids will store a one inch rain event and allow it to slowly percolate into the subsoil. The capacity to store a one inch rainfall would handle the majority of rain events in eastern Oklahoma. In 2009, 85.4% of the measurable rain events at the Tulsa International Airport were one inch or less.

The National Ready Mixed Concrete Association operates a Pervious Concrete Contractor Certification Program to train individuals in the proper way to place, compact, finish, edge, joint, cure and protect pervious concrete pavements. Pervious concrete is not made or finished in the same manner as impervious concrete. To ensure that a pervious concrete project will perform as expected, check the credentials of the concrete supplier and finisher.

Pervious Concrete Resources:

- Twin Cities Ready Mix, 1818 N. 127th East Ave., Tulsa, OK 74116-1711 918-438-8888 or 918 438-9206
- GCC/Mid-Continent Concrete, 431 West 23rd Street Tulsa, OK 74107-3005, 918 582-8111
- Cantera Concrete Company, 5601 South 122nd East Ave, Tulsa, OK 74146, 918-878-3498
- American Concrete Pavement Association (ACPA)
  Chicago Office, 5420 Old Orchard Road, Suite A-100, Skokie, IL 60077-1059, 847-966-2272
  Washington Office, 500 New Jersey Ave., NW, 7th Floor, Washington, DC 20001, 202-638-2272

- Portland Cement Association (PCA) South Central Cement Promotion Association
  5215 E. 71 St., Suite 1500, Tulsa, OK 74136, 918-610-0552
- National Ready Mixed Concrete Association (NRMCA)
  900 Spring St., Silver Spring, MD 20910, 888-846-7622

Permeable Pavers

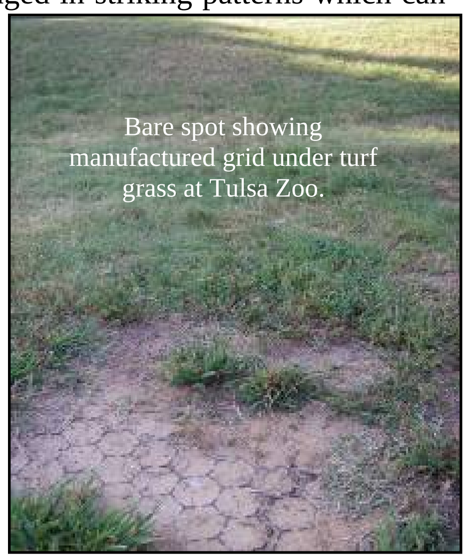
Permeable pavers are bricks, stones, blocks, or manufactured grids that have voids or are placed with spaces between them. If the voids are large enough, soil, sand and sometimes vegetation is arranged in the voids between the hard surfaces. This allows rainwater to soak into the soil around the load bearing hard surfaces. Pervious pavements like concrete and asphalt have pores that can plug, but permeable pavers rely on larger voids that are less prone to clogging. Bricks, stones and solid pavers often sit on a layer of sand with sand between the solid blocks. These surfaces can drain quickly and are generally low maintenance.



Permeable pavers at Tulsa Zoo.

Permeable pavers can be used for patios, trails, sidewalks, driveways, overflow parking areas, emergency fire lanes and areas where people congregate. The crack or porous material between the pavers allows infiltration while the hard surface provides the support necessary for heavy traffic and prevents soil compaction. Pavers may not be a good choice where snow plows will be used since the plow blade could catch on the edge of a paver and lift the blocks or bricks.

Pavers can be purchased in various colors and arranged in striking patterns which can add interest to developments. They can be installed by contractors or homeowners. Manufactured grids are flexible and can be used in hilly areas to support heavy foot traffic or moderate vehicle traffic while allowing grass to grow through and blend with other turf grass areas. For light foot traffic like walking paths in a residential yard only a sand base may be necessary beneath the pavers. For heavier vehicle traffic and parking areas a more substantial subbase of gravel and then sand may be needed.


Bare spot showing manufactured grid under turf grass at Tulsa Zoo.

Load Supporting Systems

Load supporting systems are used to stabilize soils and bear the weight of pedestrians and light traffic. An open grid which supports the weight is placed on the soil surface and then the openings in the grid are filled with soil, sand or rock. If filled with soil, it can be planted to turf grasses. Once established, it can look like the surrounding area, but the grid will allow it to bear additional weight without soil compaction or rutting. This could be a good option for overflow parking areas, emergency access for fire trucks and ambulances, trails and public gathering sites.

If the grids are filled with sand or rock it can be used for on-site stormwater retention, enhance infiltration rates and to stabilize drainage layers.

Roadways

Narrower roads result in less surface area, thus less runoff. This may be a viable option in some areas as long as public safety issues have been addressed. Fire trucks, police and emergency vehicles require a certain amount of space to operate. By limiting parking to one side or not allowing on street parking, narrower roadways can minimize runoff while meeting the community's safety needs. In addition, many homeowners prefer to *not* have vehicles parked in front of their houses and children are easier to see if they dart out into the street to chase a ball if vehicles are not creating blind spots.

Directing runoff to open areas (no curb and gutter if codes allow it) that will allow infiltration will reduce the quantity and improve the quality of the water that ultimately reaches a receiving stream, river or lake. Recessed center islands with rain gardens can be constructed to collect runoff from roadways and can be planted nicely to add aesthetic appeal to cul-de-sacs and neighborhoods. Some of the beneficial practices listed for parking lots will also apply to roadways.

Parking Areas

City codes, ordinances and regulations frequently dictate how many parking spaces or how large a parking area must be. The surfacing material is generally determined by city codes and ordinances, volume of traffic and weight of the vehicles that must be supported, cost and availability of materials. Impervious concrete and asphalt can be replaced with pervious concrete and asphalt. Paving stones can be used to carry vehicle weight and prevent the compaction of pervious soil or overflow parking areas might be gravel. There are many pervious options to impervious surfaces. Individual circumstances will dictate which options might work under different conditions. Carefully review available options before deciding to use an impervious surface material.

Allow parking lots to drain to grassy fields or land that will allow the runoff to infiltrate the soil instead of being channeled or piped to a storm sewer or nearby creek. This will help reduce the loading of water, sediment and pollutants to the receiving water and thereby reduce flooding potential and improve water quality in the receiving stream. If curbing is not required, removing the curb might allow water to flow off an impervious surface as sheet flow. As long as the runoff does not flood neighboring properties, this can be beneficial.

Curbed center islands with grass and a few shrubs or trees are somewhat beneficial. However, they only allow the infiltration of rain that falls directly on the island. Curbing prevents runoff from other portions of the parking lot from reaching the infiltration area. A recessed island at a lower elevation with curb cuts or no curbs will allow a larger area of the parking lot to drain into the infiltration zone providing maximum benefits. An overflow channel or pipe can allow excess water to flow off of the parking area for safety reasons.

On-street parking spaces are often about 7 to 8 feet wide and 20 feet long and add a considerable amount of surface area to the travel lanes. A full parking lane can increase the surface of a roadway by about 25 percent. If local stormwater ordinances require post-development flows to not exceed pre-development flows, evaluating parking area size and surfacing type can be critical.

Driveways

Making a driveway narrower or shorter reduces the amount of paving required. Leaving an unpaved strip in the center of a driveway will also reduce the amount of paving required. Always check building codes to make sure your plans will meet local requirements. Many of the beneficial uses for roadways and parking areas can be applied to driveways as well.

Green Roofs

Green roofs are not a new idea. They have been a part of the European landscape for years and today Europe has more than 100 million square feet of planted roofs (GreenGrid). The early green roofs were complicated and problems with media retention, plant health and leaking had to be overcome. Over the years these problems have been solved and today's green roofs are affordable and designs are suitable for many applications.

Green roofs are becoming more common in U.S. cities. A green roof is basically a roof with a growing medium, plants, and root and moisture barriers. The principle is simply to allow the growing medium to absorb precipitation and then the plants will store and release this moisture to the atmosphere through evapotranspiration processes. Water will also evaporate from the growing medium. Depending upon the quantity and moisture content of the growing medium and density of the plants, the roof will retain precipitation and runoff will be minimized. In general, the deeper the growing medium, the more water the roof is capable of absorbing before runoff occurs and the greater the variety of plants you have to choose from.

A green roof can also help reduce the amount of heavy metals (particularly zinc) that are commonly found in runoff from metal-roofed structures. The amount of nutrients in the runoff from a green roof will depend upon the type and amount of mulch and fertilizer that is used to maintain the vegetative growth and atmospheric deposition.

Additionally, the insulating value of the growing medium and shading effect of the vegetation cools the roof and reduces energy (gas and electric) bills. The Chicago Department of Environment stated that the green roof on the Chicago city hall building has saved a projected $3,600 each year in energy costs. On August 9, 2001 at 1:45 p.m., the temperature on the paved portion of the city hall roof ranged from 52°C to 54°C (126°F to 130°F) while temperatures on the garden portion of the roof ranged between 33°C and 48°C (91°F to 119°F). The temperature on the adjacent Cook County building's black tar rooftop was 76°C (169°F). (Green Infrastructure in the Windy City)

A green roof contributes oxygen to the atmosphere and can also help reduce the urban heat island effect. The heat island effect is caused by sunlight striking and heating up hard surfaces like concrete, brick and asphalt during the day. After the sun goes down and air temperatures start to drop, these surfaces continue to radiate heat resulting in higher nighttime temperatures in heavily urbanized areas. Many cities do not cool down in the evening like surrounding rural areas do. This is especially noticeable on windless nights. Frequently, urban residents don't get to enjoy the cool evening breezes after a hot summer day like their more rural counterparts.

Green roofs need to be designed with certain criteria in mind. First, the roof must be relatively flat or moderately sloped and the building structure must be able to withstand the weight of the growing medium, plants and required roofing materials. The weight of a cubic foot of growing medium can vary widely. Generally, multiple layers are used to create successful green roofs. Typically, green roofs are classified as either extensive or intensive. These categories refer to the amount and type of growing media which ultimately determines the weight of the roof and size of the plants.

Extensive roofs generally have one to five inches of growing medium which will weigh about 10 to 50 pounds per square foot when wet. These roofs are typically vegetated with drought-tolerant sedums, short grasses, vegetables and flowers. The thinner the growing medium depth, the quicker it dries out. Sedums may only need 2.5 inches of medium, require little or no watering or fertilization, minimal maintenance and come in a variety of colors. They can make an attractive covering for large or small expanses of roof. Shallow rooted grasses and wildflowers may only need 4 inches of medium.

These roofs are frequently installed by assembling a collection of modules or grids. The modules are generally small and light enough to carry to the roof on an elevator or larger ones (or bundles of them) can be lifted up with a crane. The modules can be purchased with medium and plants and ready to go or empty and medium and plants can be added onsite. Some of these modules can be placed directly on a roof membrane or adequately prepared surface. This makes the roof layout easy to arrange and rearrange and any roof repairs or maintenance projects are easy since the modules can be moved as necessary and then put back in place without disturbing the plants. Walking paths can be moved and garden grids can be relocated. Costs for a grid type extensive roof range from $12.00 to $15.00 per square foot (RainGarden Network).

Intensive roofs have as little as 8 inches of medium, but more commonly at least 1 foot of growing medium and can support some trees, shrubs and perennials. In hot, drier climates, these roofs may require some watering or irrigation to establish and maintain some of these plants. Intensive roofs can weigh 30 to 150 pounds per square foot when wet and require more maintenance. The cost can range from approximately $16.00 to $100.00 per square foot depending upon the type and amount of growing medium, plants, labor required and who installs the roof.

These two types of roofs can be combined to create a unique look depending upon the project goals. For instance, an intensive roof might be built along the south side of a building to create shade for benches in a sitting area and an extensive roof can spread out over the remaining areas to create an open look with grass, sedum, flowers, a herb garden and a vegetable garden. Since an intensive roof has more growing medium, it can absorb more runoff. If a roof has multiple levels, an intensive roof could be installed on the lower level and an extensive roof could be installed on the upper level. Excess runoff from the extensive upper level could be channeled to the intensive lower level to further reduce any runoff from the building.

The bottom layer of a green roof is a water proof barrier with a root barrier above it. This prevents water from seeping through and damaging the interior of the building. The root barrier prevents roots from penetrating the water proof barrier. Ford Stryker, associate vice president for Penn State's Physical Plant stated "Properly installed green roofs are less likely to leak than a conventional roof. The soil and plants shield the roofing membrane from ultraviolet rays that would break them down. For this reason, green roofs can last up to twice as long as conventional roofs." (Margaret Buranen, Oct. 2008))

A granular or sandy drainage layer possibly with a perforated pipe type collection system can be placed above the water and root barrier and acts as a means of conveying excess water off of the roof. This may be necessary to prevent the pooling of water. This layer will usually be at least four inches thick. This excess water could be diverted to a rain garden or cistern-type storage vessel instead of funneled off the property as stormwater.

A media separator is frequently placed above the drainage layer and then a minimum of four inches of growing media is added. This is the layer the plants will be rooted in.

Sometimes a thin, permeable, cloth-like layer will be placed above the growing medium to prevent the wind from blowing it away. Water can freely move through this layer and it does not hinder plant growth.

Finally the vegetation is put in place. Plants must be carefully selected to withstand the sun's intensity, drying effects of the wind and the anticipated wet and dry cycles. Low-maintenance plants, shrubs and grasses are preferred. Some drought tolerant succulents are also good choices.

The Natalie Medical Building, (6475 S. Yale, Tulsa, OK) managed by Warren Professional Building Corporation, has a very nice green roof with conical skylights between the medical building and the parking garage. This green roof has approximately eight inches of media for the vines, native grasses and irises. The trees are grown in large pots to provide additional soil depth, added stability and to protect the water-proof barrier from their more aggressive roots. Since it is directly over a medical facility with patients coming and going it was critical that the structure not leak, and it hasn't. This garden area has existed for eight years and requires minimal care while providing a relaxing view for patients and staff.

Many green roofs are designed to provide building occupants with a green space, pleasant view, trails, a quiet space with benches and tables and even garden areas and fresh produce. The plants and habitat can also provide a nesting place for birds and provide a food source for butterflies and bees. The aesthetic benefits may not be the primary reason for adding a green roof, but are a very nice bonus.

Summary

LID practices are becoming more common in many areas. As more people begin to understand these principles and see the benefits they will request and require their use. Research and scientific studies are being conducted to determine which measures are most effective and under what conditions. Climate, soil type, terrain, population density, funding, local regulations and the public's state of mind must be considered when selecting the methods that will be most beneficial for your situation.

Stormwater regulations are becoming more stringent and the cost of managing stormwater programs is going up every year. At this point there is no reason to believe this trend will be reversed anytime soon. Eventually, numerical limits will likely replace visual checks. This has already occurred in some parts of the country. Stormwater regulations are part of the Clean Water Act (CWA) and in one way or another affect everybody. Penalties and fines for noncompliance vary according to federal, state and local statutes, but can amount to tens of thousands of dollars a day per violation.

An onsite "no net increase" policy in the quantity of stormwater runoff, sediment, pollutants and nutrients is a good goal. It may not always be achievable and offsite mitigation within the watershed may be necessary, but if we do the best we can we will see positive results. An ordinance took effect on January 1, 2008 in Chicago, Illinois that requires all new developments and redevelopments over a certain size to capture the first half inch of runoff from all impervious surfaces. This included roofs, driveways, sidewalks, etc.

The LID ordinance Los Angeles, California is moving through the approval process will require the first ¾ of an inch of rainfall to be captured and/or used onsite for many developments and redevelopments. Developers and builders are accomplishing this by installing rain barrels, cisterns, dry wells, infiltration trenches, green roofs, rain gardens, permeable pavements and other creative methods that will help them achieve this goal. The long term benefits to Los Angeles and Chicago's stormwater programs and their citizens could be enormous.

The problems we are facing today are the results of out-dated policies, lack of knowledge, lack of planning, lack of funding and, unfortunately, in some cases neglect. Planning and development projects should include green infrastructure in the form of tree-lined streets, parks, golf courses and the preservation of natural areas like fields, woodlots, wetlands, streams, waterways and even constructed vegetated areas.

By raising public awareness, incorporating LID strategies into stormwater programs and by working together we can improve the quality of the water around us, decrease flooding potential and increase water stores to help see us through periods of drought. Future water shortages due to shrinking usable supplies, rapid growth and increasing demand could limit economic growth and development for communities that don't plan ahead. These benefits will improve our quality of life and the world around us for many generations to come. Achieving these goals will require patience, cooperation and a desire to do the right thing.

It is hoped that new development and redevelopment projects will utilize as many of these practices as possible and work around the natural features that benefit stormwater programs like streams, wetlands and natural areas. If existing drainage features remain functional there will be less need for built infrastructure and the costs associated with it. Natural features rely on filtration, infiltration, surface and subsurface storage and evapotranspiration processes to manage stormwater. By incorporating these processes, with help from the technology available to us today, our communities can continue to grow and prosper without the damage we have seen from past activities.

Appendix

Table 2

24 Hour Measurable Rainfall in Inches for Tulsa, Oklahoma in 2009 (NOAA Station at Tulsa International Airport)												
Number of Measurable Rain Events	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.17	0.16	0.05	0.20	3.01	0.01	1.16	0.13	0.10	0.05	0.43	0.03
2	0.51	1.27	0.01	0.01	0.27	0.12	0.12	0.70	0.25	0.01	0.01	0.02
3		0.85	0.13	1.85	0.06	0.84	0.13	0.13	0.24	0.11	0.03	0.18
4			0.02	0.01	0.05	0.03	0.09	0.03	0.02	2.64	0.11	0.61
5			1.75	0.02	0.20	0.98	0.33	1.08	0.58	0.21		0.84
6			0.26	0.52	0.01	0.21	0.02	0.36	1.36	0.01		0.02
7			1.09	0.44	0.02	0.01	0.87	1.29	0.11	0.06		0.14
8			1.23	0.04	0.01	1.22	0.03	0.04	0.12	0.13		0.04
9			0.48	0.70	0.07	0.09	0.09		0.01	0.04		
10				0.55	1.90				0.14	0.40		
11					0.36				0.01	0.71		
12					0.44				0.93	0.01		
13					0.29				4.42	0.13		
14					0.11					1.63		
Total 2009 Monthly Accumulation	0.68	2.28	5.02	4.34	6.80	3.51	2.84	3.76	8.29	6.14	0.58	1.88
Normal Monthly Average Accumulation	1.60	1.95	3.57	3.95	6.11	4.72	2.96	2.85	4.76	4.05	3.47	2.43

Total 2009 Measurable Rainfall	46.12
Normal Annual Measurable Rainfall	42.42

NOAA National Weather Service Data from Gauge at Tulsa International Airport.

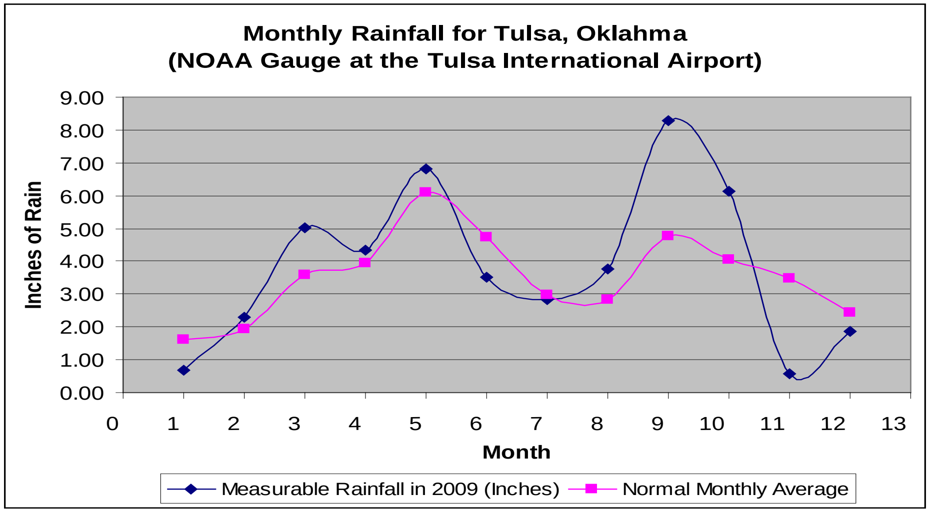
Table 3

Month	Number of Rain Events by Category (in Inches)				
	≤ 0.25	> 0.25, ≤ 0.50	> 0.50, ≤ 0.75	>0.75, ≤ 1.00	>1.00
January	1	0	1	0	0
February	1	0	0	1	1
March	4	2	0	0	3
April	5	1	3	0	1
May	8	4	0	0	2
June	6	0	0	2	1
July	6	1	0	1	1
August	4	1	1	0	2
September	9	0	1	1	2
October	10	1	1	0	2
November	3	1	0	0	0
December	6	0	1	1	0

MonthlyTotal	63	11	8	6	15
Percent of Yearly Total	61.17%	10.68%	7.77%	5.83%	14.56%

Yearly Total	103

Graph 1



Plants for Oklahoma Rain Gardens using Native Plants	**Spacing**	**Height**	**Where**	**Exposure**
SEDGES AND RUSHES				
Oak Sedge – *Carex albicans*	*6-8”*	*4-6”*	*shallow*	*Lt.shade-shade*
Tussock Sedge – *Carex stricta*	*18”*	*12-36”(16-24”)*	*deep*	*Sun-med.shade*
Soft Rush – *Juncus effesus*	*18”*	*12-24”*	*deep*	*Sun-lt.shade*
Prairie Dropseed – *Sporobolus heterolepis*	*24-36”*	*18-24”*	*BERMS*	*Sun*
SHRUBS				
Beautyberry – *Callicarpa Americana*	*3-5’*	*3-5’*	*shallow*	*Sun-med.shade*
Virginia Sweetspire – *Itea virginica*	*3-4’*	*3-4’*	*deep*	*Sun-shade*
Spice Bush – *Lindera benzoin*	*5-10’*	*6-14’*	*deep*	*Sun-shade*
Dwarf Yaupon Holly – *Ilex vomitoria ‘Nana’*	*6’*	*4-6’*	*shallow*	*Sun-lt.shade*
PERENNIALS				
Shining Blue Star – *Amsonia illustris*	*36-48”*	*30-48”*	*deep*	*Sun-lt.shade*
Columbine – *Aquilegia Canadensis*	*18”*	*24-36”*	*shallow/berm*	*Sun-shade*
Swamp/Marsh milkweed – *Asclepias incarnate*	*24”*	*36-60”*	*deep*	*Sun-lt.shade*
Butterfly milkweed – *Asclepias tuberosa*	*24” (18-30)*	*24-36”*	*shallow*	*Sun-lt.shade*
“Purple Dome” New England Aster – *Aster novae-angliae*	*18”*	*18-24”(40-60”)*	*middle*	*Sun*
Purple coneflower – *Echinacea purpurea*	*18”*	*30-40”*	*shallow*	*Sun-med.shade*
Little Joe Pye Weed – *Eupatorium purpureum*	*24”*	*48-80”*	*deep*	*Sun-lt.shade*
Wild Geranium – *Geranium maculatum*	*24”*	*36-48”*	*deep*	*Lt.shade-Shade*
Sneezeweed – *Helenium autumnale*	*18”*	*36-60”*	*deep*	*Sun-lt.shade*
Swamp Sunflower – *Helianthus angustifolius*	*60”*	*72-96”*	*deep*	*Sun-lt.shade*
Ox-Eye Sunflower – *Heliopsis helianthoides*	*24”*	*24-48”*	*deep*	*Sun-lt.shade*
Copper Iris – *Iris fulva*	*18”*	*30-40”*	*deep*	*Sun-med.shade*
Blue Flag Iris – *Iris virginica*	*18”*	*12-42”*	*deep*	*Sun-lt.shade*
Prairie Blazingstar – *Liatris pycnostachya*	*12”*	*30-48”*	*deep*	*Sun*
Dense Blazingstar – *Liatris spicata*	*12”*	*24-48”*	*deep*	*Sun*
Cardinal Flower – *Lobelia cardinalis*	*15”*	*24-54”*	*deep*	*Sun-lt shade*
Great Blue lobelia – *Lobelia siphilitica*	*15”*	*12-30”*	*deep*	*Sun-med.shade*
Black-eyed Susan “Goldsturm” / Orange Coneflower – *Rudbeckia fulgida*	*18”*	*18-30”*	*deep*	*Sun-lt.shade*
Missouri Black-eyed Susan – *Rudbeckia missouriensis*	*18”*	*18-30”*	*shallow*	*Sun*
Downy Skullcaps – *Scutellaria incana*	*16”*	*30-40”*	*deep*	*Sun-3/4shade*
Showy Goldenrod – *Solidago speciosa*	*18”*	*24-48”*	*shallow*	*Sun-lt.shade*
Ohio Spiderwort – *Tradescantia ohioensis*	*15”*	*24-48”*	*deep*	*Sun-med.shade*
Ironweed – *Vernonia faciculata*	*24”*	*36-48”*	*deep*	*Sun-lt.shade*
Culver's root – *Veronicastrum virginicum*	*18”*	*36-60”*	*deep*	*Sun-med.shade*

Compiled by Kevin Gustavson, Oklahoma Conservation Commission

Tulsa Area Rain Garden Demonstration Project

OKLAHOMA CONSERVATION COMMISSION

What is the problem?

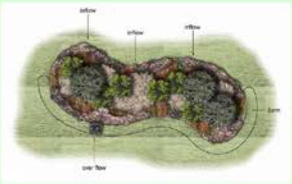
When it rains, water flowing over the landscape picks up pollutants and carries them to local streams. Fertilizers (nutrients), pesticides, and herbicides may wash off lawns. Oil, grease, and heavy metals may wash off of parking lots, driveways, roads, and roofs.

Excessive algae growth in a stream impacted by nutrients

What is a Rain Garden?

A rain garden is a planted depression in the landscape that catches water flowing over yards, business grounds, parking lots, and other urban areas before it reaches local streams.

How do rain gardens clean rain water?



- Water, and any pollutants it carries, enters the rain garden when it rains
- Water is ponded behind the berm (see photo) and allowed to infiltrate into the ground.
- Plant roots and soil microbes take up nutrients and help break down other pollutants.
- Cleaner water flows through the ground to streams or ground water aquifers.
- Rain gardens are designed to drain within a day, shown to actually reduce mosquito populations.

What are the best plants for rain gardens?

Many Oklahoma native plants are ideal for rain gardens because they:

- Tolerate periods of wet when it rains and dry periods between storms (supplemental watering not needed).
- Resistant to local pests (no pesticides needed).
- Low nutrient needs (no fertilizer needed).

Some of the Oklahoma native plants used in this project include:

Virginia Sweetspire

Dwarf Yaupon Holly

Swamp Milkweed

Copper Iris

Great Blue Lobelia

Cardinal Flower

Culver's Root

Swamp Sunflower

Columbine

Downy Skullcaps

Missouri Black-eyed Susan

Butterfly Milkweed

Prairie Dropseed

Beautyberry

Purple Coneflower

New England Aster

Spicebush

Added benefits: Native plants attract local wildlife. Butterflies need native plants to reproduce.

Spicebush swallowtail caterpillar on spicebush

Monarch butterflies on swamp and butterfly milkweed

Where are rain gardens used?

Rain gardens can pond and clean rainwater running off parking lots, roofs, and lawns in any urban/suburban setting.

Reduced flooding – an added benefit

By trapping rainwater, multiple rain gardens throughout a community can reduce peak flows in local streams and rivers. This hydrologic benefit also leads to reduced erosion of streambanks. Help out by building a rain garden at your home or business!!

Where are Tulsa Area Project Rain Gardens?

- Sapulpa Aquatics Center
  - captures lawn runoff from a city park
- Bixby Athletic Park (name???)
  - captures lawn and pavement runoff from athletic park
- Ray Harral Nature Center, Broken Arrow
  - captures runoff from a parking lot
- Eisenhower Elementary School, Tulsa
  - captures runoff from a roof downspout
- Remington Elementary School, Tulsa
  - captures runoff from a parking lot

Partners

Primary funding for this project was through a grant from the U.S. Environmental Protection Agency.

Essential additional support was provided by the following groups:

City of Bixby
City of Broken Arrow
City of Sapulpa
City of Tulsa

Tulsa Public Schools
Szfranski and Pugh
Planning Design Group

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Michele C. Adams. *Porous Asphalt Pavement With Recharge Beds 20 Years and Still working.* Stormwater, The Journal for Surface Water Quality Professionals. May/June 2003.

National Management Measures to Control Nonpoint Source Pollution from Urban Areas. United States Environmental Protection Agency, November 2005. Publication EPA-841-B-05-004.

Paul D. Tennis, Michael L. Leming and David J. Akers. *Pervious Concrete Pavements.* Portland Cement Association and National Ready Mixed Concrete Association. 2004

Phillip W. Kresge. *Maintenance Pervades in Pervious Concrete.* Storm Water Solutions. September/October 2010. Pages 20 – 22.

RainGarden Network. www.raingardennetwork.com Information retrieved from the internet on 2-16-10.

Dr. Kim D. Coder. *Identified Benefits of Community Trees and Forests.* University of Georgia. October 1996.

Small Scale, Small Field Conservation. United States Department of Agriculture. Natural Resources Conservation Service (NRCS) Southeast Region.

Steve Nix. *Top 10 Reasons Why Trees Are Valuable and Important.* http://forestry.about.com/od/treephysiology/tp/tree_value.htm web site. February 9, 2009.

UN Population Division. *Urban population growth table*, MSN Encarta website, 1-22-09.

USGS Water Science for Schools. http://ga.water.usgs.gov/edu/earthwherewater.html

U.S. Water News, December 2008, Volume 25, Number 12. *Pavement sealcoat linked to urban lake contamination.* USGS finding in Central and Eastern U.S.

Wadeable Streams Assessment, National Stream Report. Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. EPA 841-B-06-002, December 2006.

Resources

Mention of or reference to any product or company anywhere in this paper is not an endorsement. These are just a few of the companies and organizations that provide materials and information that could be used to achieve LID goals.

In 2005 INCOG created a website for its Oklahoma Stream Team (www.streamteamok.net). One of the web pages was devoted to LID (http://www.streamteamok.net/lid/lid.htm) and contained basic information about LID and links to LID resources. While the website was updated three years ago as part of the FY07-08 604(b) grant, it continues to require refreshing of content. During the past several years, Dr. Jason Vogel at Oklahoma State University has created an outstanding and comprehensive website for LID (http://lid.okstate.edu/) that he and other OSU faculty and staff now maintain expertly. Since OSU has far better resources for keeping abreast of LID in Oklahoma, including direct support and sponsorship of LID training and education outreach, INCOG's own LID web page will remain as a portal to the OSU LID website, and continue to include links to other LID information.

To better serve INCOG's Green Country Stormwater Alliance (GCSA) members, the website portion of the FY07-08 604(b) LID grant will include moving the Stream Team LID web page to the GCSA website (www.stormwaterok.net). The GCSA website will provide more opportunity for use of web-based LID information contained or linked to at the INCOG LID website. INCOG will have the web page transfer completed, along with updated information, by mid-June 2011.

Through the FY07-08 604(b) grant, as well as GCSA-sponsored activities, INCOG has played an important role in jump-starting LID in Oklahoma, especially among the critical stakeholders that are in greatest need of LID information (municipalities, developers and consultants). By focusing on this corps group, INCOG and others in Oklahoma have successfully transformed in just 5 years the knowledge and practice of LID in Oklahoma. INCOG's LID webpage will continue to provide basic information and links to outstanding resources for Oklahoma stakeholders.

Best Management Practices:

- *Stormwater Best Management Practices Design Guide: Volume 1 General Considerations.* EPA/600/R-04/121 September 2004
- *Stormwater Best Management Practices Design Guide: Volume 2 Vegetative Biofilters.* EPA/600/R-04/121A September 2004

Bioretention, Detention, Swales:

- *Bioretention Manual, Prince George's County*, Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division. November 2001, Revised December 2002
- Bioretention.com. An online reference for designers. http://www.bioretention.com

Databases and Reference Sites:

- Low Impact Development (LID) Urban Design Tools Website can be found at: www.lid-stormwater.net
- Natural Resources Defense Council can be found at: www.nrdc.org
- The Center for Watershed Protection can be found at: www.cwp.org
- The International Stormwater BMP Database can be found at: www.bmpdatabase.org.
- The Stormwater Manager's Resource Center can be found at: www.stormwatercenter.net
- U.S. Environmental Protection Agency can be found at: www.epa.gov

Funding and Finances:

- *Managing Wet Weather with Green Infrastructure, Municipal Handbook, Funding Options*. A joint effort by: American Rivers, Association of State and Interstate Water Pollution Control Administrators, National Association of Clean water Agencies, Natural Resources Defense Council and The Low Impact Development Center U.S. Environmental Protection Agency. EPA-833-F-08-007. September 2008.
- *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*. United States Environmental Protection Agency, Nonpoint Source Control Branch. EPA-841-F-07-006. December 2007.

Green Infrastructure and General Information:

- EPA's website Managing Wet Weather with Green Infrastructur) is at: http://cfpub.epa.gov/npdes/home.cfm?program_id=298
- EPA's website Low Impact Development (LID) and Other Green Design Strategies is at: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=124
- Low Impact Development. Division of Agricultural Sciences and Natural Resources. Oklahoma State University website: http://lid.okstate.edu
- Dr. Jason Vogel, Extension Stormwater Specialist. Biosystems and Agricultural Engineering, Oklahoma State University. 218 Ag Hall, Stillwater, OK 74074. Phone: (405) 744-7532. Email: jason.vogel@okstate.edu.
- *Low Impact Development (LID), A Sensible Approach to Land Development and Stormwater Management*. Office of Environmental Health Hazard Assessment & the California Water & Land Use Partnership. E. ruby & D. Gillespie.
- *City of Broken Arrow Living Green Program. Low Impact Development Recommended Practices for Certification Manual*. City of Broken Arrow Living Green Certification Program. Broken Arrow, Oklahoma. April 6, 2010.
- Using Rainwater to Grow Livable Communities. Sustainable Stormwater Best Management Practices (BMPs). Water Environment Research Foundation (WERF). http://www.werf.org/livablecommunities
- Green Values® Stormwater Toolbox. Website: http://greenvalues.cnt.org/. This is provided by the Center for Neighborhood Technology (CNT).

Green Roof:

- Green Roofs for Healthy Cities, www.greenroofs.org
- *A Stormwater Management Evaluation of the 2007 New American Home Stormwater Treatment System and the Stormwater Academy Green Roof.* Department of Environmental Protection, Florida and University of Central Florida Stormwater Management Academy. Matt Kelly, Mike Hardin and Marty Wanielista, FDEP Project number: WM864 Task 4, September 2007.
- *Stormwater Effectiveness of an Operation Green Roof Stormwater Treatment System and Comparison to Scaled Down Green Roof Stormwater Treatment System Chambers.* Department of Environmental Protection, Florida and University of

Central Florida Stormwater Management Academy. Mike Hardin and Marty Wanielista. FDEP Project number: WM 864, May 1, 2007.
- *The Effectiveness of Green Roof Stormwater Treatment Systems Irrigated with Recycled Green Roof Filtrate to Achieve Pollutant Removal with Peak and Volume Reduction in Florida.* Department of Environmental Protection, Florida and University of Central Florida Stormwater Management Academy. Marty Wanielista, PhD.P.E., Mike Hardin, M.S, E.I. and Matt Kelly, B.S. FDEP Project number: WM 864, April 1, 2007.

Parking Lots, Driveways, Roads and Sidewalks:

- *Driveways*. Nonpoint Education for Municipal Officials, Technical Paper Number 6. Jim Gibbons, UConn Extension Land Use Educator, 1999. Updated by Michael Dietz, CT NEMO Stormwater Specialist, 2006.
- *Impacts of Impervious Cover on Aquatic Systems*, Watershed Protection Research Monograph No. 1. Center for Watershed Protection, March 2003.
- *Infiltration Opportunities in Parking-Lot Designs Reduce Runoff and Pollution.* Stormwater, The Journal for Surface Water Quality Professionals. Buyers Guide, 2003.
- *Parking Lots.* Nonpoint Education for Municipal Officials, Technical Paper Number 5. Jim Gibbons, UConn Extension Land Use Educator, 1999.
- *Pavements and Surface Materials.* Nonpoint Education for Municipal Officials, Technical Paper Number 8. Jim Gibbons, UConn Extension Land Use Educator, 1999.
- Roads. Nonpoint Education for Municipal Officials, Technical Paper Number 9. Jim Gibbons, UConn Extension Land Use Educator, 1999.
- Sidewalks. Nonpoint Education for Municipal Officials, Technical Paper Number 7. Jim Gibbons, UConn Extension Land Use Educator, 1999.
- *Managing Wet Weather with Green Infrastructure, Municipal Handbook, Green Streets*. Robb Lukes, Christopher Kloss, Low Impact Development Center. EPA-833-F-08-009. December 2008.
- *Green Parking Lot Resource Guide*. United States Environmental Protection Agency Office of Solid Waste and Emergency Response (5101T). EPA-510-B-08. February 2008.

Permeable surfaces:

- Paul D. Tennis, Michael L. Leming and David J. Akers. *Pervious Concrete Pavements.* Portland Cement Association and National Ready Mixed Concrete Association. 2004
- *Field Evaluation of Permeable Pavements for Stormwater Management, Olympia, Washington.* Unites States Office of Water (4203) EPA-841-B-00-005B, EPA, Washington, DC 20460, October 2000.
- *Hydrologic and Water Quality Comparison of Four Types of Permeable Pavement and Standard Asphalt in Eastern North Carolina.* Biological and Agricultural Engineering Department, North Carolina State University. Kelly A. Collins, EI, William F. Hunt, Ph.D., PE, Jon M. Hathaway, EI. September 4, 2007.

- *Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems*. Center for Water and Watershed Studies, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA 98195. Benjamin O. Brattebo and Derek B. Booth
- *Permeable Pavement: What's It Doing On My Street?* An Introduction to Permeable Pavement Alternatives. The University of Rhode Island Cooperative Extension in partnership with the Rhode Island Department of Health Source Water Protection Program. November 2005.
- *Permeable Pavers, Part 1: Choosing Products and Installation Methods.* Stormwater, The Journal for Surface water Quality Professionals. September 2009.
- *Pervious Pavements, New Findings About Their Functionality and Performance In Cold Climates*. Stormwater, The Journal for Surface water Quality Professionals. Jeff Gunderson. September 2008.
- *Porous Asphalt Pavements for Stormwater Management*. Hot Mix Asphalt Technology MAY/JUNE 2008. Robert M. Roseen, P.E., Ph.D. and Thomas P. Ballestero, Ph.D., P.E.
- *Stormwater Performance of Permeable Pavement Systems*. The Water Center. University of Washington, Box 352100, Seattle, Washington 98195-2100. Derek Booth, Benjamin Brattebo, and Jennifer Friebel. January 2004.
- *Study on the Surface Infiltration Rate of Permeable Pavements.* Biological and Agricultural Engineering Department, North Carolina State University, D.S. Weaver Labs, Raleigh, NC 27695. Prepared for Interlocking Concrete Pavement Institute by Eban Z Bean, Engineering Intern, William F. Hunt, Ph.D., PE, David A. Bidelspach, Engineering Intern and Jonathan T. Smith, PE.
- *Permeable Pavement: Research Update and Design Implications*. Urban Waterways. North Carolina State University and North Carolina A&T State University. William F. Hunt and Kelly A. Collins. Published by North Carolina Cooperative Extension Service.

Rain Gardens:

- *Create You Own Rain Garden In 6 Easy Steps* URS Corporation, 8300 College Boulevard, Suite 200, Overland Park, Kansas 66210, Phone: 913-344-1022
- RainGarden Network, www.raingardennetwork.com
- *Rain Gardens: A How-to Manual for Home Owners*. Wisconsin Department of Natural Resources. PUB-WT-776. 2003
- *A Paradox of Nature, Designing Rain Gardens to be Dry*. Stormwater, The Journal for Surface Water Quality Professionals. Kevin Beuttell. October 2008.
- Rain Garden Design Templates. Low Impact Development Center, Inc. www.lowimpactdevelopmentcenter.org

Rainwater Harvesting:

- American Rainwater Catchment Systems Association (ARCSA). arcsa.org. ARCSA's goal it to educate and assist governments, engineers, plumbers, builders developers, etc. in the harvesting of rainwater.
- *Managing Wet Weather with Green Infrastructure, Municipal Handbook, Rainwater Harvesting Policies*. Christopher Kloss, Low Impact Development Center. EPA-833-F-08-010. December 2008.
- *Evaluation of Contaminant Mixing in Rainwater Harvesting First Flush Diverters*. Justin Keith Mechell. Texas A&M University. August 2009.
- HarvestH_2O.com, the online rainwater harvesting company. http://www.harvesth2o.com

Site Design, Codes and Ordinances:

- *Better Site Design: A Handbook for Changing Development Rules in Your Community* Prepared by the Center for Watershed Protection, 8390 Main Street Ellicott City, Maryland 21043 with assistance from The Morris and Gwendolyn Cafritz Foundation, US EPA Office of Wetlands, Oceans, and Watersheds, Chesapeake Bay Trust, Turner Foundation and Chesapeake Bay Program. August 1998
- Codes and Ordinance Worksheet (COW) Tool, in the *Post Construction Guidance Manual*. Center for Watershed Protection. 8390 Main Street, 2nd Floor, Ellicott City, MD 21046
- *Stormwater-Related Amendments to the Zoning Code*, Adopted Draft. City of Portland Bureau of Planning, Environmental Planning Team, March 2, 2001.
- *Water Quality Scorecard, Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales.* United States Environmental Protection Agency (EPA). EPA 231B09001, October 2009
- *Addressing Imperviousness in Plans, Site Design and Land Use Regulations.* Nonpoint Education for Municipal Officials, Technical Paper Number 1. Jim Gibbons, UConn Extension Land Use Educator, 1998.
- *Managing Wet Weather with Green Infrastructure, Municipal Handbook, Green Infrastructure Retrofit Policies*. Jennifer Bitting, Christopher Kloss, Low Impact Development Center. EPA-833-F-08-008. December, 2008.
- Low Impact Development Urban Design Tools Website, www.lid-stormwater.net

● *Stormwater Best Management Practice Design Manual*. North Carolina Division of Soil and Water Conservation Community Conservation Assistance Program. Prepared by the Biological and Agricultural and Engineering Department, North Carolina State University. William F. Hunt, Ph.D., PE, Jon M. Hathaway, EI, Ryan A. Smith, PE. E07-45836, 10/06 – JL.

Stormwater:
● *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. EPA-841-B-05-004 November 2005
● *Minnesota Stormwater Manual*. Created by the Minnesota Stormwater steering Committee. Published by the Minnesota Pollution Control Agency. Version 2, January 2008. Copyright 2005.

Vegetation:
● *Urban Watershed Forestry Manual, Part 2: Conserving and Planting Trees at Development Sites*. Prepared by: Karen Cappiella, Tom Schueler and Tiffany Wright, Center for Watershed Protection. Prepared for: United States Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry. NA-TP-01-06. May 2006.
● *Urban Watershed Forestry Manual, Part 3: Urban Tree Planting Guide.* Prepared by: Karen Cappiella, Tom Schueler, Jennifer Tomlinson and Tiffany Wright. Prepared for: United States Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry. NA-TP-01-06. September 2006.
● *Vegetated Best Management Practices*. PowerPoint Presented March 7, 2008 at: Low Impact Development for Stormwater Management, Michigan State University. Scott Dierks, PE and JF New.

Wetlands:
● *Ponds vs Wetlands – Performance Consideration in Stormwater Quality Management* By Tony H F Wong, Peter F Breen & Nicholas L G Somes.
● *Urban Waterways: Designing Stormwater Wetlands for Small Watersheds*. N.C. State University. Publication AG-588-02.
● *Wetlands Reference Guide*. Oklahoma Conservation Commission. James E. Henley, USDA Natural Resources Conservation Service and Mark S. Harrison, Oklahoma Conservation Commission. 2001
● *Riparian Area Management Handbook*. Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources, Oklahoma State University and Oklahoma Conservation Commission. E-952. 1998.
● *Valuing Urban Wetlands: A Review of Non-Market Valuation Studies*. Tracy Boyer and Stephen Polasky, Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, Department of Applied Economics, University of Minnesota St. Paul, Minnesota. Wetlands, Vol. 24, December 2004, pp. 744-755. The Society of Wetland Scientists.
● *Management of Ponds, Wetlands, and Other Water Reservoirs to Minimize Mosquitoes*. Water Quality, The Purdue Extension Water Quality Team. WQ-41-W.

Contractors, Consultants and Product Manufacturers:

Mention of contractors, consultants or product manufacturers is not an endorsement. The following companies expressed the ability to perform and assist with LID projects. Many other companies and individuals are capable of performing this type of work, but were not known to INCOG at the time this report was written. Before contracting with any company providing consulting, labor or products, research that company or individual to be certain they are capable of fulfilling your particular needs. Consultants and contractors are listed in alphabetical order.

●*AMEC Earth & Environmental, Inc.* 2905 South Harr Drive, Suite 201, Midwest City, OK 73110. Contact: Ivan Quate. Phone: 405-869-9195. Services, among others, include floodplain mitigation work and floodplain planning.

●*Contech Construction Products, Inc.* 3406 E. 75th St., Tulsa, OK 74136. Phone: 918-504-4236. Email: markess@contech-cpi.com. Contact: Sarah Kellert, P.E., Project Consultant. Contech Construction Products offers a complete line of LID products and can assist you from concept and project design through installation.

●*Geosyntec Consultants* 4000 N. Classen Boulevard, Suite 110-S, Oklahoma City, OK 73118. Phone: 405-996-5300. Contact: Jeff Shepherd. This company provides LID consulting services.

●*Green Earth, LLC* P.O. Box 54506, Oklahoma City, OK 73118. Phone: 405-887-1442. mike.greenearth@cox.net, penepalin@gmail.com, www.greenearthllc.org. Contact Michael Kennedy. This company provides LID consulting services.

●*Soil Restoration Technologies*, P.O. Box 639, Bixby, OK 74008. Contact: Bob Richardson at turf2max.com. Phone: 918-449-1175. Specialties include vegetative restoration, wetlands and remediation of brine spills.

●*URS Corporation*, 1437 S. Boulder, Suite 1020, Tulsa, OK 74119. (918) 582-2552. Contact: Stephanie Rainwater at stephanie_rainwater@urscorp.com. Specialties, among others, include vegetation restoration, biological surveys and low impact site planning.

Tulsa Area Rain Garden Project Final Report

Report Prepared by Kevin, Gustavson,
Environmental Educator and Technical Writer
Blue Thumb Program
Water Quality Division
Oklahoma Conservation Commission

Using funds provided by the EPA, Blue Thumb staff member, Kevin Gustavson, worked with INCOG (Indian Nations Council of Governments) and several cities in the Tulsa area to build demonstration rain gardens and conduct related educational outreach.

First, project staff worked through INCOG's Green Country Stormwater Alliance to find cities interested in cooperating on the project. A meeting was held at INCOG in March 2010 to introduce the project and criteria for selection of rain garden sites. Cities were expected to provide the labor, mulch and rock, and ideally, some volunteers to help plant and maintain the gardens. After initial requests were submitted via email, Kevin Gustavson met with stormwater managers and/or city engineers in Sand Springs, Sapulpa, Broken Arrow, Bixby, Tulsa, Bartlesville, Catoosa, Miami, and Coweta to visit potential sites. Many sites were investigated, but the top sites were determined mainly by the suitability of the soils, topography/surface hydrology, and visibility. The top sites were Ray Harral Nature Center in Broken Arrow, the Sapulpa Aquatics Center, Remington Elementary in Tulsa (a school with an environmental theme), and part of a larger project in Bentley Park (a sports complex) in Bixby.

The rain gardens were planted with native Oklahoma plants, the main product purchased with EPA money. A list of preferred plants was researched and compiled that would work well in a rain garden environment and provide year-round interest with different flowering times. The list was sent to several local native plant growers as well as more conventional nurseries to see who could provide the needed materials. One conventional nursery, Colebrook Nursery in Tulsa, showed great interest in searching for uncommonly grown plants and providing them at a significantly reduced price. Another local grower, Wild Things Nursery, was able to handle the diversity of plants sought after, so both of these nurseries were used to buy plants. Landscaping fabric and metal edging were also purchased with EPA grant money.

Ray Harral Nature Center, Broken Arrow

The great visibility of the site, the sandy soils suitable for drainage, the natural setting, the history of the City of Broken Arrow's involvement in LID promotion, and ability to address a runoff problem with the rain garden made the Ray Harral Nature Center the top site for implementation. A new Nature Center was completed in 2009 at the edge of a 40 acre mature woods with paved and unpaved walking trails. The property, adjacent to an elementary school and a middle school, is a highly visible location and attracts the attention of nature lovers and a large number of school kids and teachers. A rather small parking lot drains via a stormdrain to a nearby creek within the nature area. To alleviate some of the load on the stream and help clean the parking lot runoff, a rain garden was designed to take runoff from the parking lot via curb cut to a grassy area adjacent to the parking lot. The overflow was designed to return to the parking lot to use the existing stormdrain (Figure 1).

The main support for this rain garden came from the City of Broken Arrow staff: the city provided a three person crew, earth moving equipment, sand, rocks, and mulch. Construction took place in mid-October. City crews worked with Kevin Gustavson on excavation of the site using motorized equipment for heavy work and hand tools for more detailed work on the berms and initial installation of the metal edging. Later in the week, the Broken Arrow Beautification Committee, Blue Thumb volunteers, and city crews worked together to complete the rain garden (Figures 2 & 3). First, they built the inlet, outlet and internal “check dam” structures by sculpting the soil, laying down landscaping in the inlet, outlet, and drainage notch in the “check dam” and covering with decorative rocks. Volunteers and staff then planted the garden, finished adding in the edging, and added mulch.

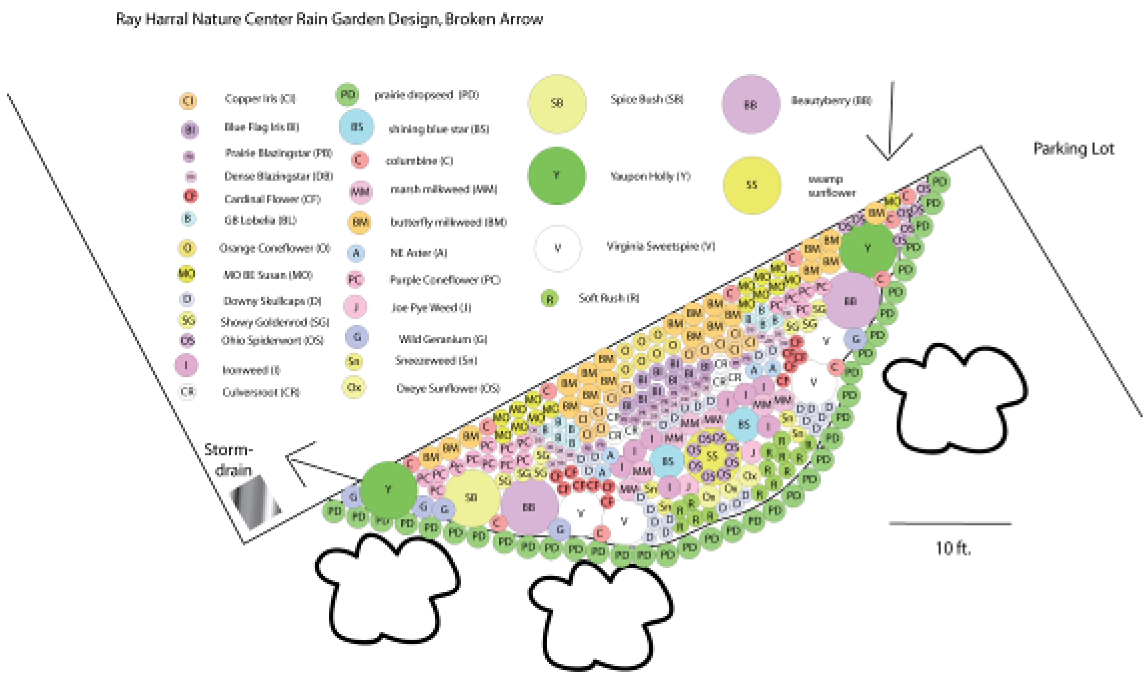

Figure 1: Design of rain garden at Ray Harral Nature Center indicating approximate location and spacing of plants. The arrows indicate inflow (with a curb cut) and outflow (with curb notches) allow water to run off the parking lot into the rain garden. The outflow notches allow excess water to drain to the pre-existing storm drain.

Figure 2: Rain Garden built in Broken Arrow at the Ray Harral Nature Center. Curb cuts will be Made in 2011 once the vegetation is better established. Outflow notches already exist.

Figure 3: Broken Arrow City Staff, Blue Thumb volunteers and Broken Arrow Beautification Committee volunteers helping to plant the Nature Center rain garden.

Aquatics Center, Sapulpa

The great visibility of the site, the sandy soils suitable for drainage, the park setting, the great enthusiasm of the Stormwater Manager and obvious support from the City, and ability to address a runoff problem with the rain garden made the Sapulpa Aquatics Center a top site for implementation. A new Aquatics Center was completed in Spring 2010 within Liberty park, a beautiful park with mature trees, play areas for kids, a picnic area, tennis courts, etc. This popular park, made more popular with the Aquatics Center, is a highly visible area in Sapulpa in a place people have time to stop and look at a garden. The garden was planned for a swale between the aquatic center and new sand volleyball courts that were planned for construction later that Fall (Figures 4 & 5). The swale took park runoff quickly toward the parking lot, then on to city stormdrains. Trapping some of that runoff helps infiltrate some of the water for a lighter load on the stream and improved water quality.

The rain garden in Sapulpa took the cooperation of the Stormwater Program and the Parks Department. We also worked with Planning Design Group (designer of the Aquatics Center and the landscaping of the property) to design the rain garden in Sapulpa. As a result, we used a different array of native plants more in line with those used around the Aquatic Center (Figure 4). The City provided rocks, soil, equipment, and labor. Construction took place in late September and early October. Early excavation took place with heavy equipment and detail work took place with hand tools. Construction was delayed when the excavator unexpectedly broke an unidentified water pipe. We put in metal edging and built a large, wide spillway at the downswale side of the garden in similar fashion to the ones built in Broken Arrow. Creek County Master Gardeners helped out in all aspects of the construction, but a larger group was present on the final day for planting and laying mulch (Figure 5).

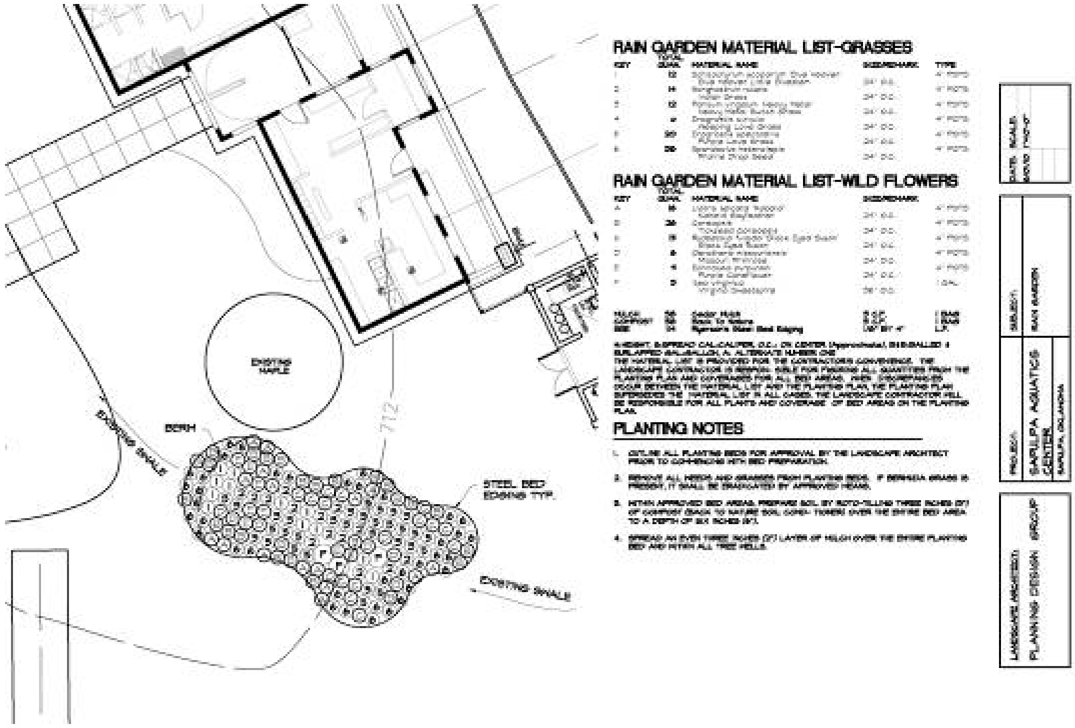

Figure 4: Design of rain garden at Sapulpa Aquatics Center indicating approximate location and spacing of plants.

Figure 5: The rain garden near the Sapulpa Aquatics Center; Creek County Master Gardeners and Sapulpa city staff planting the garden.

Remington Elementary School

The visibility of the site, the sandy soils suitable for drainage, the school setting (an elementary school with an environmental theme), the ability to address a runoff problem, and the great enthusiasm of the principal, Tulsa Stormwater Staff, and support from the Tulsa School District made the Remington Elementary School a top site for implementation. A new overflow parking lot was recently constructed at Remington Elementary that gets come and go traffic all day from visitors to the school (Figure 6). Fill was brought in to keep the parking lot surface relatively level (although it slopes away from the school). Constructing a rain garden around the perimeter of the parking lot prevents erosion of the steep slopes created by the parking lot and cleans runoff from the parking lot before it enters the woods and a beautiful stream in the wooded area (Figure 7).

Construction took place with the help of Tulsa Public Schools District, the City of Tulsa, IBM employees on the United Way Day of Caring, and Blue Thumb volunteers led by Scott Grant from Tulsa County Conservation District. Construction began in early September. Tulsa Public Schools provided a backhoe to remove the grass and some large rocks from the subsurface prior to the United Way Day of Caring. The District had a backhoe and three staff members back on site for the Day of Caring to help build the large exterior berms, to lay out the additional soil in parts of the garden, and to bring large loads of mulch to the garden. About a dozen IBM employees helped prepare the garden by removing additional grass using hand tools, sculpting the exterior berms, building several check dams along the narrow sloped part the the garden, building the large outlet on the lower end of the garden, and spreading out the mulch over the entire garden area. Two IBM employees stayed for an extra hour on a 95 degree day just to help get the job done. The City of Tulsa trucked in loads of additional soil, mulch, and rocks. The garden was planted in early November (Figure 8). Kevin Gustavson, two Blue Thumb volunteers led by Scott Grant of the Tulsa County Conservation District, and school staff members helped over 300 school kids plant one plant in the garden (one plant for each kid in the school Grades 1-5). Most of the kids have never planted before. The next day, Kevin, Scott, and one Blue Thumb volunteer put in the rest of the plants. Some of the kids came over just to watch us plant the next day. One tough kid said as we planted a yaupon holly that that was the kind of plant he put in the garden.

Figure 6: Air photograph of Remington Elementary School in Tulsa showing the location of the overflow parking lot (bright white concrete parking area) where the rain garden was built.

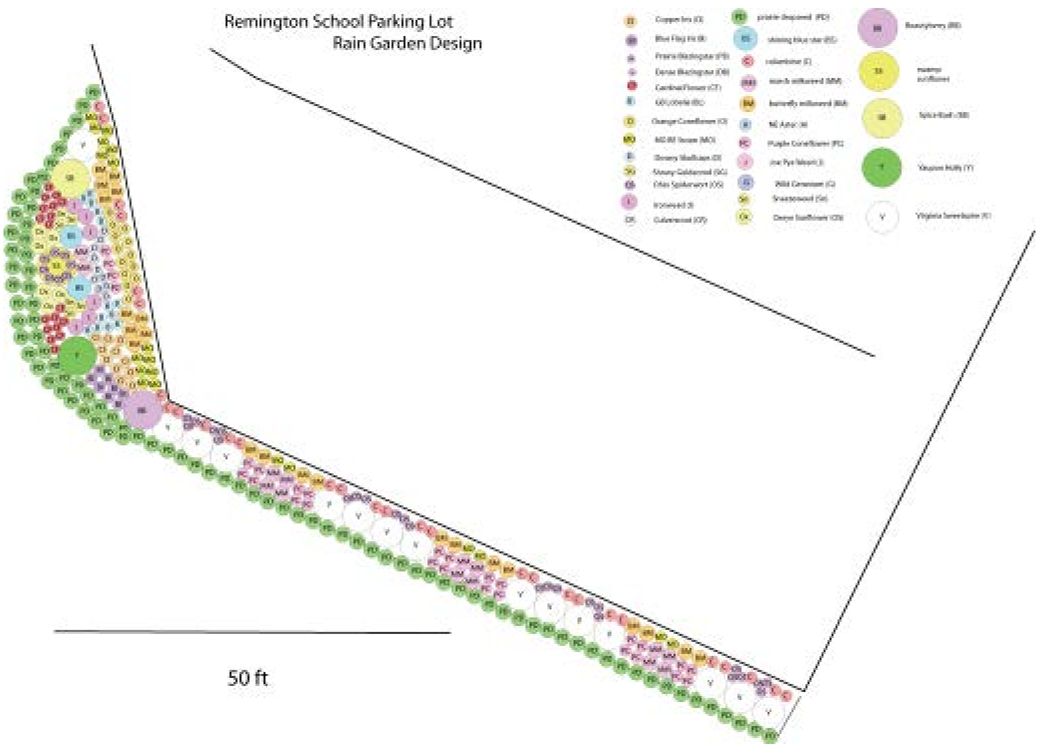

Figure 7: Design of rain garden at Remington Elementary School in Tulsa, indicating approximate location and spacing of plants.

Figure 8: Remington Elementary rain garden and Blue Thumb volunteers helping school kids plant the garden.

Bentley Park, Bixby

The final rain garden location was selected for its visibility, the ability to improve a runoff situation, and the enthusiastic support of the Public Works Director in Bixby. The rain garden was planned as part of a bigger construction project to build a roundabout at a busy intersection in Bentley Park (Figures 9 and 10, NW of the soccer fields). The rain garden was designed within the roundabout "island" and takes runoff from the surrounding fields through pipes. A raised overflow drain within the garden will send overflow to the stormwater drainage system. City of Bixby staff designed their rain garden with assistance from Kevin Gustavson on plant selection and availability.

Figure 9: A rain garden will be built in a roundabout island NW of the soccer fields in Bentley Park in Bixby.

Figure 10: Engineers design of the rain garden in the center of the roundabout that will draw runoff from the surrounding athletic fields.

Construction on this final rain garden has been delayed because the funding process for the larger project has been put on hold while the City applied for a loan from another State Agency. Construction is now on target for planting the rain garden in October 2011. A portion of the plant materials were purchased with the EPA grant to INCOG, the City of Bixby is responsible for the rest of the plant materials and the entire cost of construction. The plants were purchased in the summer of 2010 and the nursery is kindly taking care of those plants until the October planting.

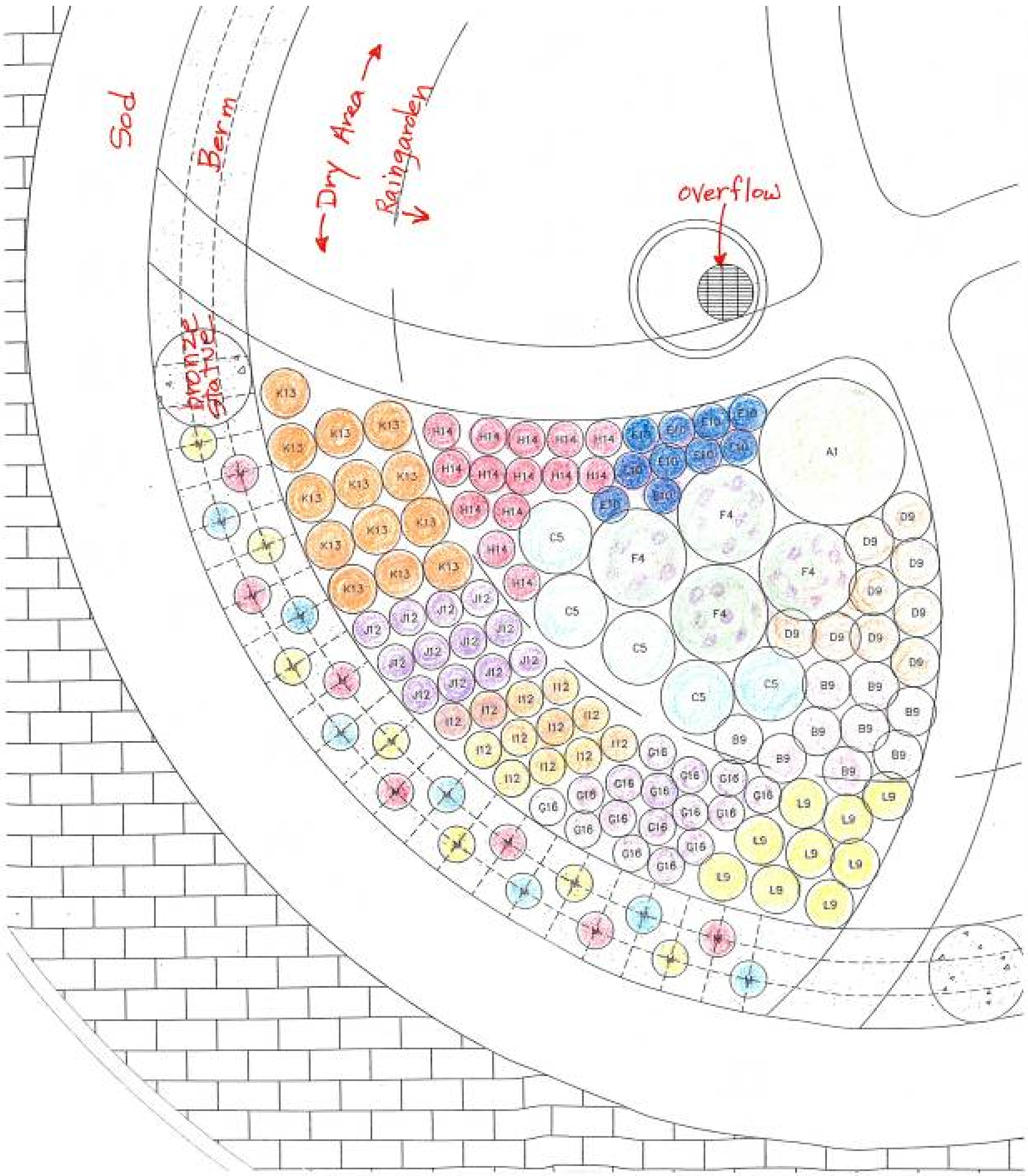

Figure 11: Design of rain garden at Bentley Park in Bixby, indicating approximate location and spacing of plants.

PUBLIC EDUCATION

Presentations on Rain Gardens and Oklahoma Native Plants:
Staff participated in a number of events where groups across the state learned about rain gardens:

- Tulsa Resource Management Conference, May 25-26, Tulsa – Oral presentation on urban pollution and incorporating native plants and rain gardens in residential properties.
- Oklahoma Gardening Television Program, June 5&6: 13 minute segment on urban lawn pollution and building your own rain garden. Now on youtube.com:
  Part 1: http://www.youtube.com/watch?v=PJSuHxcxyDg
  Part 2: http://www.youtube.com/watch?v=Iv_ioo60Vnk
- Oklahoma Gardening, GardenFest Keynote Speaker, June 12, Stillwater – Oral presentation on water-wise gardening and incorporating native plants and rain gardens in residential properties.
- Creek County Master Gardener Meeting, August 21, Kelleyville – Oral presentation to local master gardeners on urban pollution, rain gardens, and incorporating native plants in residential properties.
- Caney Valley Master Gardeners Meeting, August 30, Bartlesville – Oral presentation to city staff and local master gardeners on urban pollution, rain gardens, and incorporating native plants in residential properties.
- Blue Thumb Volunteer Conference, November 6, Oklahoma City – Oral presentation to Blue Thumb volunteers on urban pollution, rain gardens, and incorporating native plants in residential properties.

Media Coverage of Project
We were fortunate to get great television coverage of this project. We have one news story for the construction of each rain garden.

Sep 10 2010 - KJRH-NBC Tulsa, OK – "Rain Garden At Remington Elementary School"
http://67.214.99.203/Player.aspx?ShareId=02cee1b4-2195-4434-8c7e-6e338b881592&PortalId=3CDDB705-54F4-45F7-97D3-AE049AE4E988&EmailAddress=videoclips@metromonitor.com&FileId=2CFF1298-99B5-48C0-A0D6-A94687369731

Sep 29 2010 - OETA-PBS Oklahoma – "Going Green"
http://67.214.99.203/Player.aspx?ShareId=34a8d38d-0400-42ee-b5d5-7b03f679d8fb&PortalId=3CDDB705-54F4-45F7-97D3-AE049AE4E988&EmailAddress=videoclips@metromonitor.com&FileId=BFAFB82D-1659-4EF0-8F6A-C403960F36F5

Oct 20 2010 - KOTV-CBS Tulsa, OK – "Rain Garden"
http://67.214.99.203/Player.aspx?ShareId=34a8d38d-0400-42ee-b5d5-7b03f679d8fb&PortalId=3CDDB705-54F4-45F7-97D3-AE049AE4E988&EmailAddress=videoclips@metromonitor.com&FileId=94B70EF7-7E1C-4A12-AB20-00661FF35E95

Signage

Signs were developed for display at each rain garden site. Signage outlines the water pollution and runoff reduction issues to be addressed by rain gardens, what they are and how they work, what plants work best in rain gardens, where rain gardens are effective, and where to find other example rain gardens that are part of the Tulsa Area Rain Garden Project.

Handout

A handout was developed of recommended Oklahoma native plants for use in rain gardens. The handout lists the common and scientific names of the plants, the recommended spacing for planting, the potential eventual height of the plants, what sunlight conditions the plant tolerates, and how deep in a rain garden the plant is best placed. Many of the plants on the list were shown in the presentations to the local Master Gardener, Blue Thumb, and other groups.

Urban Streams Workshop

Blue Thumb teamed up with Jason Vogel of OSU Extension to hold the first Urban Streams Workshop in El Reno, a very distant suburb of Oklahoma City, on December 14, 2010. This day long workshop covered the following topics:

- The North Canadian Watershed Project
- The Blue Thumb Program
- Common Problems with Urban Streams and Urban Riparian Area Management
- Urban Pollution Problems Beyond the Streambanks (Stormwater Pollution)
- Rain Gardens, including the Tulsa Area Rain Garden Project
- Low Impact Development and Local Ordinances
- Outreach Education and Social Marketing
- Engineering Solutions: Green Roofs, and Permeable Pavers
- Urban Stream Restoration

The workshop was well attended (over 40 attendants) including city officials and staff from Bethany, Oklahoma City, Midwest City, Yukon, El Reno, Stillwater, and the Cheyenne and Arapaho Tribe. Blue Thumb plans to take this workshop to at least 2 other communities in the coming year.