to infiltrate the soil and bedrock provides more water to private and public wells.

Habitat Protection – conservation easements, riparian buffers, urban, forested, wetlands and water quality improvements, achieved by decreased runoff, protects wildlife habitat.

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

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

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

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

Reduction in Streambank Erosion – By using practices that infiltrate stormwater into the soil near streams and creeks, the runoff is reduced and therefore less stream erosion occurs. This is achieved by reducing the total water volume entering waterways.

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

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

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

Table 3. Pollutant removal rates among low impact development practices [TSS: total suspended solids; TN: total nitrogen; TP: total phosphorous]. (From Glen, 2008)

<table>
<thead>
<tr>
<th>Quantity Control</th>
<th>TSS Removal Efficiency</th>
<th>TN Removal Efficiency</th>
<th>TP Removal Efficiency</th>
<th>Fecal Bacteria Removal Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioretention</td>
<td>Possible</td>
<td>85%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Sand filter</td>
<td>Yes</td>
<td>85%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Filler strip</td>
<td>No</td>
<td>25-40%</td>
<td>20%</td>
<td>35%</td>
</tr>
<tr>
<td>Restored riparian buffer</td>
<td>No</td>
<td>35%</td>
<td>20%</td>
<td>45%</td>
</tr>
<tr>
<td>infiltration devices</td>
<td>Possible</td>
<td>45%</td>
<td>30%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Stormwater wetlands  
Sawdust filter  
Grassed swale  
Restored riparian buffer  
Infiltration devices

The following are short descriptions of common LID practices:

Rainwater Harvesting through the use of trees and vegetation, and the incorporation of rain gardens and bioretention cells allows for a variety of landscape practices and designed systems which allow infiltration of stormwater runoff into the subsoil. Rainwater Harvesting is the practice of capturing stormwater runoff, often from rooftops, and storing the water for later use for such activities as irrigation, livestock watering, flushing toilets, or washing clothes.

Pervious Pavement utilizes pavers, porous concrete, or pervious asphalt to allow water to infiltrate through the pavement and drain off site or into underground pipes that carry the water into subsurface drain systems.

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

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

What is LID? 

Low Impact Development (LID) is a stormwater management approach which seeks to mimic a site’s predevelopment hydrology by using site-specific techniques that infiltrate, store and evaporate stormwater runoff at or close to its source.

Unlike traditional stormwater infrastructure that solely conveys runoff through a large system of underground pipes and above-ground concrete channels, LID addresses stormwater runoff through a variety of landscape practices and designed systems which preserve natural drainage features and infiltrate or capture stormwater runoff. LID can be applied to new development, redevelopment, or as retrofits to existing developments.

LID has been adapted to a range of land uses from high density urban settings to low density development (U.S. EPA 2007).

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

Understanding Stormwater Runoff and Low Impact Development (LID)

Jason Vogel
Assistant Professor and Stormwater Specialist
Department of Biosystems and Agricultural Engineering

Ashley Stringer
Graduate Student, Department of Environmental Science

Marley Beem
Assistant Extension Specialist
Department of Natural Resource Ecology and Management

Oklahoma Cooperative Extension Fact Sheets are also available on our website at: http://osufacts.okstate.edu

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Urbanization & Water Quality

As cities become more urbanized, the amount of area where water cannot soak in (also known as impervious area) increases and this prompts water from rain and snowmelt flows over land or impervious surfaces and does not infiltrate into the ground. As the runoff flows over the land or impervious surfaces such as paved streets, parking lots, and rooftops, it accumulates debris, chemicals, sediment and other pollutants that can adversely affect water quality. Traditionally in Oklahoma communities, the storm sewer system collects stormwater runoff from rain and snowmelt events. The storm sewer system then discharges all the stormwater, and its accumulated pollutants, directly into our ponds, creeks, streams and lakes.

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Division of Agricultural Sciences and Natural Resources • Oklahoma State University

Figure 1. Runoff diagram comparing natural ground cover to 75-100% impervious cover. (U.S. EPA, undated)
ing, cities must provide a collection system for the increased stormwater runoff. Figure 1 is a general illustration of how land development, on average, can increase stormwater runoff over five times. It should be noted that the percentages shown in Figure 1 are generalizations. In Oklahoma the climate and soils vary from West to East. As a result, the percentage of water that goes to each portion of the water budget varies as well. This is demonstrated in Table 1 using data adapted from the Water Atlas of Oklahoma for data from 1970-1979 (the most recent summary of its kind).

Table 1. Typical Oklahoma annual water balance. (GW: groundwater) (adapted from Pettyjohn et al., 1983)

<table>
<thead>
<tr>
<th>State</th>
<th>Precipitation (inches)</th>
<th>Runoff (inches)</th>
<th>Evapotranspiration (inches)</th>
<th>GW Recharge (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas County, OK</td>
<td>17</td>
<td>0.3</td>
<td>16.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Oklahoma County, OK</td>
<td>33</td>
<td>4.5</td>
<td>27.7</td>
<td>0.8</td>
</tr>
<tr>
<td>McCurtain County, OK</td>
<td>54</td>
<td>18</td>
<td>28</td>
<td>8</td>
</tr>
</tbody>
</table>

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

To deal with the harmful effects of stormwater runoff, the EPA began regulating specific pollutants. Polluted stormwater runoff is transported through Municipal Separate Storm Sewer Systems (MS4s), from which it is discharged untreated into local water bodies. The regulatory definition of an MS4 is “a conveyance or system (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains owned or operated by a state, city, town, borough, county, parish, district, association, or other public body) (U.S. EPA, 2007).

Terms, MS4s can include municipalities and local sewer districts, state and federal departments of transportation, universities, hospitals, military bases, and correctional facilities (U.S. EPA 2007). Stormwater Phases I and II include MS4s, which can be used to regulate all discharges from nonpoint sources, such as military bases and correctional facilities by including them in the definition of small MS4s. MS4s can also be in agricultural areas or in small communities that are not designated as MS4s.

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

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

An urbanized area is a land comprising one or more places, central places (c), and the adjacent densely settled surrounding area (U.S. EPA, 2007). In common

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

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

Oklahoma Climate

“Oklahoma lies entirely within the drainage basin of the Mississippi River. The two main rivers in the state are the Arkansas, which drains the northern two-thirds of the state, and the Red, which drains the southern third and serves as the state’s southern border. Principal tributaries of the Arkansas are the Verdigris, Salt Fork, Grand (Neosho), Illinois, Cimar, Ron, Canadian and North Canadian. The Washita and Kiamichi serve as the Red’s principal tributaries in Oklahoma, with the Little River flowing into the Red after it crosses into Arkansas.” (Oklahoma Climatological Survey 2002).

The State of Oklahoma receives an average annual precipitation of 36 inches. Although precipitation is quite variable on a year-to-year basis, average annual precipitation ranges from about 17 inches for the Panhandle and 32 inches for the Panhandle to about 56 inches in the far southeast (Oklahoma Climatological Survey 2002).”

As indicated by the data shown in Figures 3 and 4, the rainfall in Oklahoma varies greatly from one year to the next. Figure 3 shows the distribution of annual rainfall, which decreases from east to west. LID techniques are well suited to this type of rainfall distribution. However, depending on the

Cost savings can be achieved by using fewer

More specifically, some of the benefits to adopting LID practices include (from US EPA, 2007):

- Enhanced Groundwater Recharge – The natural infiltration capability of LID technologies can improve the rate at which groundwater is replenished. Allowing stormwater

How Does LID Help Oklahoma?

In recent years, many community stormwater programs across the nation have become more sophisticated and environ-

Table 2. List of entities regulated as Municipal Separate Storm Sewer Systems (MS4s) in Oklahoma in 2011. (from GCBA)

<table>
<thead>
<tr>
<th>Altus</th>
<th>Noble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bartlesville</td>
<td>Bethany</td>
</tr>
<tr>
<td>Broken Arrow</td>
<td>Broken Arrow</td>
</tr>
<tr>
<td>Checotah</td>
<td>Claremore, City of</td>
</tr>
<tr>
<td>Clayton</td>
<td>Comanche County</td>
</tr>
<tr>
<td>Covell</td>
<td>Coweta</td>
</tr>
<tr>
<td>Oklahoma City</td>
<td>Oklahoma City</td>
</tr>
<tr>
<td>Oklahoma County</td>
<td>Oklahoma County</td>
</tr>
<tr>
<td>Ponca City</td>
<td>Ottawa County</td>
</tr>
<tr>
<td>Romans County</td>
<td>Oklahoma Turnpike Authority</td>
</tr>
<tr>
<td>Sand Springs</td>
<td>Osage</td>
</tr>
<tr>
<td>Spencer</td>
<td>Owasso</td>
</tr>
<tr>
<td>Jenks</td>
<td>Creek County</td>
</tr>
<tr>
<td>Lawton</td>
<td>Del City</td>
</tr>
<tr>
<td>McComb</td>
<td>Edmond</td>
</tr>
<tr>
<td>Jenks</td>
<td>Fort Sill Air Force Base</td>
</tr>
<tr>
<td>Tuskegee</td>
<td>Fort Sill Air Force Base</td>
</tr>
<tr>
<td>Wagoner County</td>
<td>Muskogee</td>
</tr>
<tr>
<td>Midwest City</td>
<td>Mustang</td>
</tr>
<tr>
<td>Oklahoma County</td>
<td>Muskogee</td>
</tr>
<tr>
<td>Tuls</td>
<td>Muskogee</td>
</tr>
<tr>
<td>Carter County</td>
<td>Muskogee</td>
</tr>
<tr>
<td>Muskogee</td>
<td>Washington County</td>
</tr>
<tr>
<td>Mustang</td>
<td>Washington County</td>
</tr>
<tr>
<td>Bartlesville</td>
<td>Washington County</td>
</tr>
<tr>
<td>Altus</td>
<td>Washington County</td>
</tr>
</tbody>
</table>

Figure 3. Average precipitation in Oklahoma by month. (from Oklahoma Climatological Survey, 2002)

Figure 4. Average precipitation in Oklahoma average rainfall by season. (from Oklahoma Climatological Survey, 2002)

Figure 5. Average annual precipitation across Oklahoma. (from Oklahoma Climatological Survey, 2002)