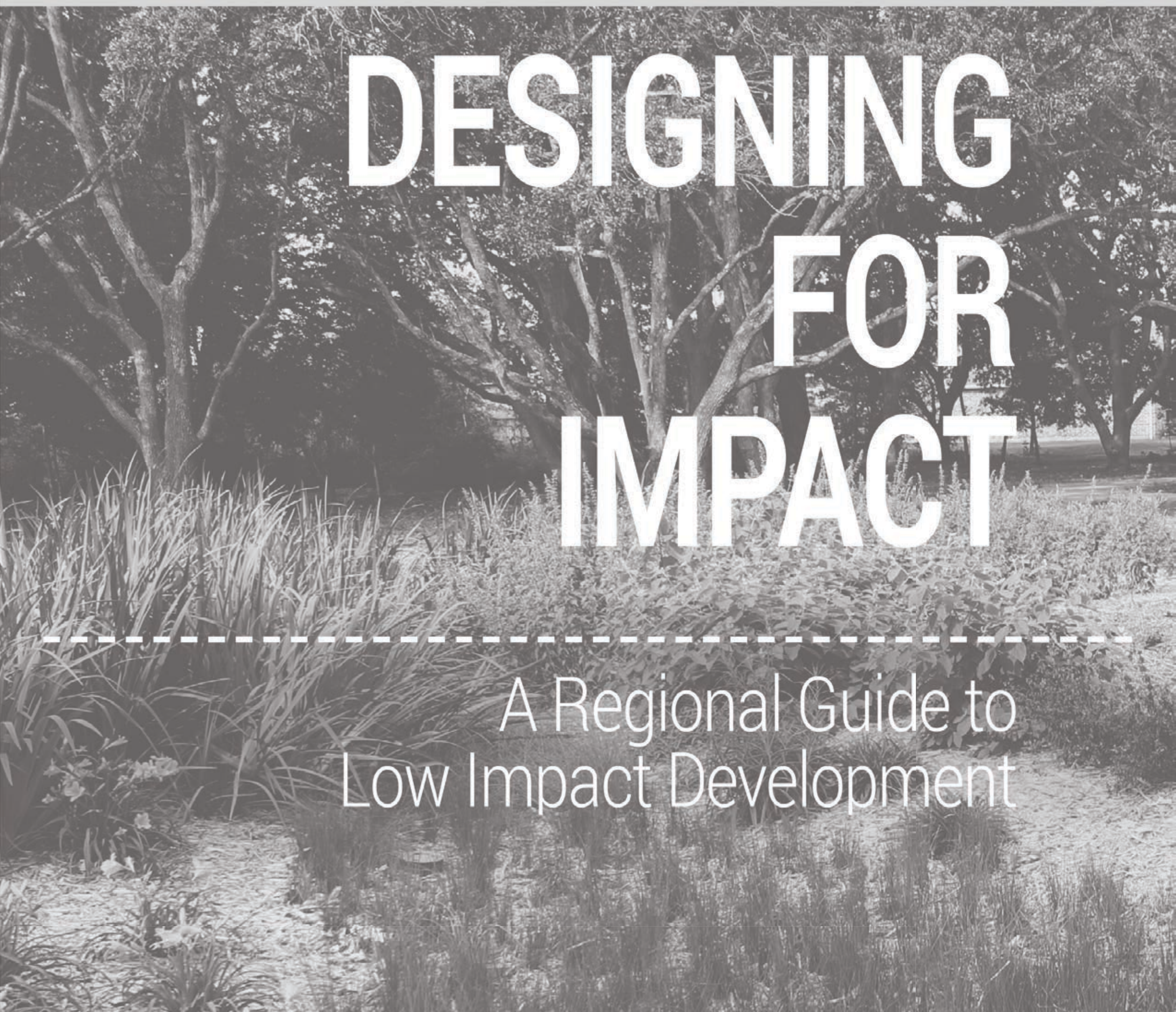
DESIGNING FOR IMPACT

A Regional Guide to Low Impact Development



DESIGNING FOR IMPACT

A Regional Guide to Low Impact Development

H-GAC

HOUSTON-GALVESTON AREA COUNCIL

The Houston-Galveston Area Council (H-GAC) is the voluntary association of local governments in the 13-county Gulf Coast Planning region of Texas. Since its formation in 1966, H-GAC has provided a venue for local governments to respond cooperatively to regional challenges.

For more information about the Designing for Impact project, please visit **www.h-gac.com/go/LID**

The preparation of this document has been financed in part through a grant from the Environmental Protection Agency (EPA) Gulf of Mexico Program. The contents of this document do not necessarily reflect the official views or policy of the (EPA) Gulf of Mexico Program.

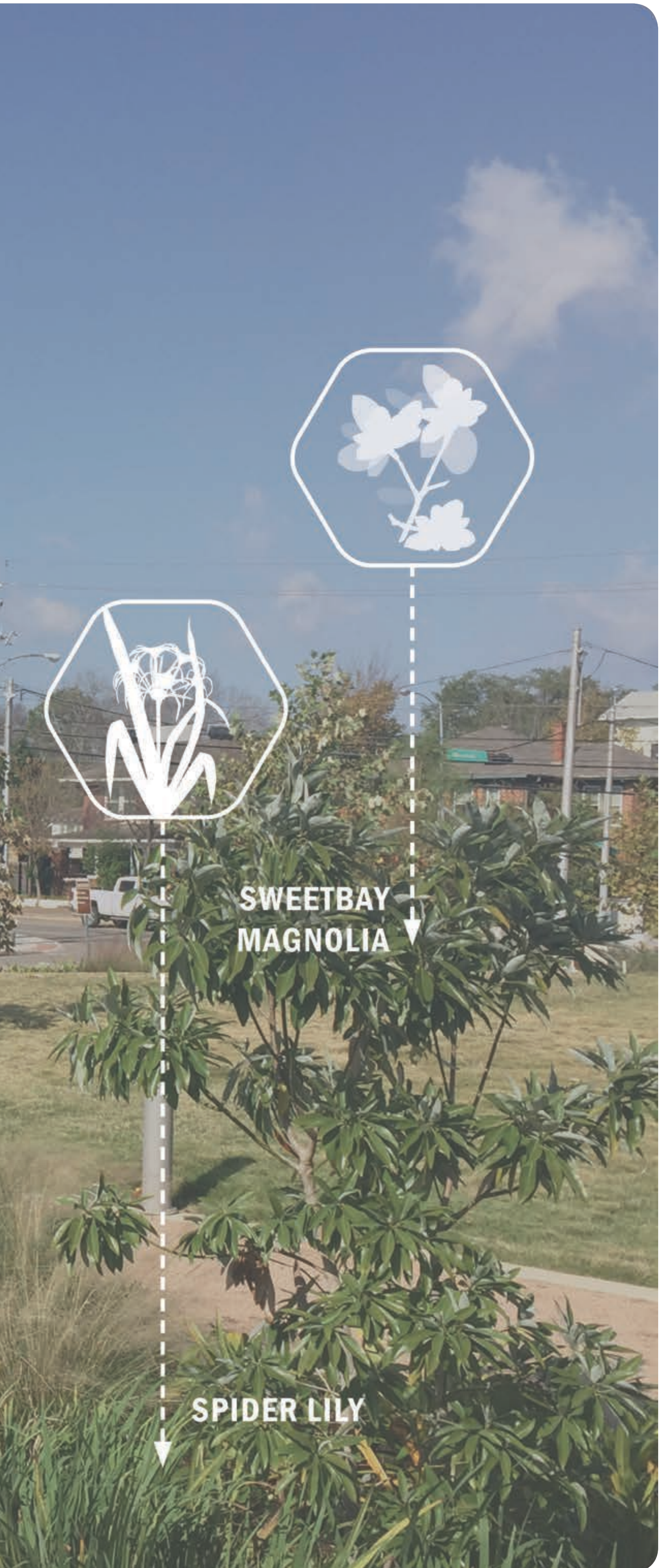
asakura robinson

DESIGNWORKSHOP

GULF OF MEXICO PROGRAM

EPA United States Environmental Protection Agency


CITRUS TREE
LOUISIANA
IRIS



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GREEN ROOFS

FOREWORD

The Houston-Galveston region is poised to grow by more than 3.5 million people by the year 2040. With that growth will come new homes, businesses, and roads. This development brings additional impervious surface area and stormwater drainage infrastructure that will alter natural drainage patterns and impact stormwater quality. The conventional way of dealing with the impacts of this growth will result in thousands of acres of detention ponds and other expensive drainage infrastructure and still will not address water quality. However, there is opportunity for an alternative.

Low Impact Development (LID) is a highly-effective, economically advantageous approach to controlling stormwater. There is growing interest in LID in the Houston-Galveston region, though there are still barriers to its broad acceptance, such as codes, lack of awareness, and misperceptions. Fortunately, incentives, new development policies, and education tools exist to encourage the use of LID in this region.

The Houston Land Water Sustainability Forum (HLWSF) is a voluntary partnership of engineers, developers, landscape architects, and architects in the Houston-Galveston region, along with key city and county staff. Our aim is to build awareness of the full range of LID and other sustainable development practices, to encourage their adoption to suit a range of conditions, and foster creativity in the development of new solutions and the regulatory infrastructure that enables them. The HLWSF was pleased to collaborate with the Houston-Galveston Area Council in developing this guide to encourage the use of LID in the region.

We hope you find it to be a helpful tool in learning more about LID and evaluating how it can be implemented in your community.

Thanks,

Robert Adair
HLWSF Steering Committee Chair
President, Construction EcoServices

Jeff Taebel, FAICP
Director of Community &
Environmental Planning
Houston-Galveston Area Council

LOUISIANA IRIS

The Louisiana Iris is a common flowering plant used in various projects throughout the H-GAC region. This semi-deciduous flower grows best in moist soil conditions and is flood tolerant. Maintenance typically requires clearing dead foliage on a semi-annual basis. Common LID applications include bioswales, vegetated swales, and rain gardens.

INTRODUCTION

The robust growth projected for the Houston-Galveston region is forecasted to lead to the addition of approximately 500 square miles of developed area, including an estimated 6 million parking spaces, 780 million square feet of non-residential uses, and 3.5 billion square feet of residential use. This impervious surface area has the potential to increase stormwater runoff volumes and associated pollutant loadings into local waterways, Galveston Bay, and the Gulf of Mexico. Low Impact Development (LID) provides an opportunity to explore a sustainable way to accommodate future development and manage stormwater.

The purpose of H-GAC's *Designing for Impact: Regional Guide to Low Impact Development* is to promote the use of LID as an environmentally friendly and cost-effective approach to development. If designed, installed, and maintained properly, LID can:

- Help enhance regional water quality by reducing and filtering stormwater runoff before it enters waterways.
- Reduce the chance of downstream flooding;
- Add value to development projects by reducing infrastructure costs and increasing marketability of a project; and
- Preserve or create on-site natural systems that manage stormwater, add aesthetic value and double as a public amenity.

This guide explains how LID functions, benefits of LID, and ways to overcome obstacles to implementation. This information is demonstrated through a series of site plans for five different land use types that compare costs and environmental impacts of LID versus conventional development practices. It also contains case studies showcasing successful on-the-ground projects in the H-GAC region.

Bioswale, Bagby Street

(Image: Shau Lin Photography)

LOW IMPACT DEVELOPMENT

HOW LID WORKS

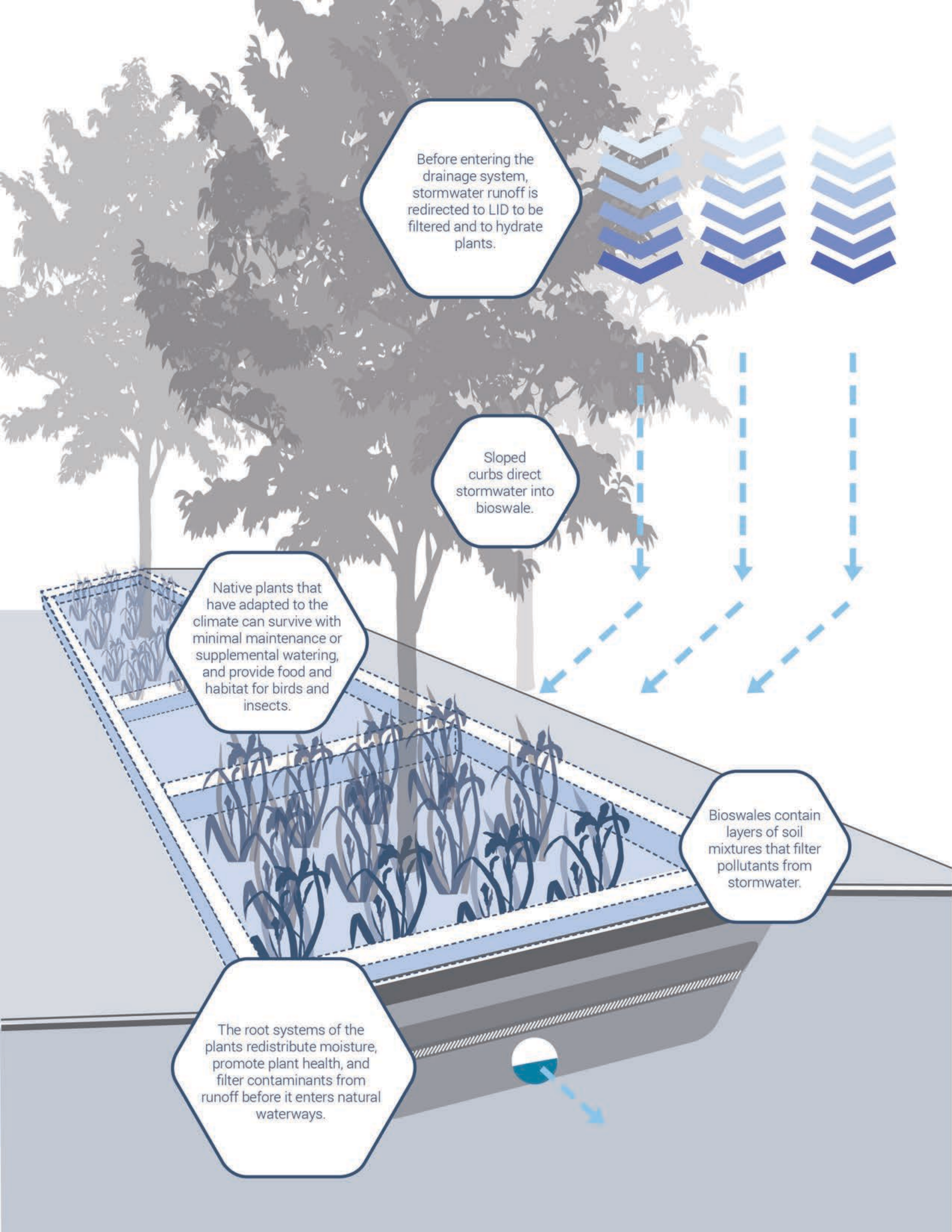
Stormwater runoff occurs during rainstorms when precipitation that would normally absorb into the ground collects and moves over impervious surfaces. Under natural conditions, most stormwater is infiltrated into the ground, evaporated into the air, or soaked up by vegetation; little stormwater becomes runoff. The natural water cycle depends on vegetation and infiltration to manage and cleanse stormwater.

Impervious surfaces interrupt this cycle by preventing the absorption of runoff. Fast-moving runoff flows over impervious surfaces, carrying loads of pollutants into waterways. Downstream waters are impacted by contaminated stormwater runoff.

Conventional methods of stormwater management methods, like detention ponds and pipe-and-pavement systems, do not address, prevent or remove pollutants from stormwater runoff.[ii] Alternatively, LID uses a system of decentralized stormwater techniques distributed throughout a site to capture and filter stormwater runoff at the source, reducing the total volume and the amount of pollutants entering waterways. LID meets its goal of reducing development impacts on watersheds by applying the following five tools[iii] :

- Preserve natural hydrology and environmentally-sensitive areas;
- Design a system of distributed LID practices;
- Control stormwater at the source;
- Apply non-structural approaches first; and
- Create a multifunctional landscape.

LID is suited for new development, redevelopment, and retrofit projects and can be adapted to a diversity of land uses and geographic settings throughout the Houston-Galveston region.


Before entering the drainage system, stormwater runoff is redirected to LID to be filtered and to hydrate plants.
Sloped curbs direct stormwater into bioswale.
Native plants that have adapted to the climate can survive with minimal maintenance or supplemental watering, and provide food and habitat for birds and insects.
Bioswales contain layers of soil mixtures that filter pollutants from stormwater.
The root systems of the plants redistribute moisture, promote plant health, and filter contaminants from runoff before it enters natural waterways.

CONTEXT

MAKING THE CASE FOR LID

LID strikes a balance between the conservation of natural resources and the economics of successful development. The list below highlights the six main benefits of LID.

1. IMPROVED WATER QUALITY

As LID captures and releases stormwater, it filters pollutants from runoff, thus cleaning it before it enters natural waterways. U.S. Environmental Protection Agency (EPA) studies demonstrate the effectiveness of LID for removing pollutants, such as metals, nutrients, sediments, and pathogens from stormwater. [iv] [v]

2. COST-EFFECTIVE

The National Resource Defense Council analyzed 17 LID case studies comparing the cost of LID and conventional stormwater management practices. In most cases, LID methods were both economically and environmentally beneficial, with capital cost savings ranging from 15 to 80 percent.[vi] The savings can be attributed to:

- Decreasing the amount of site grading and preparation;
- Decreasing the size of stormwater management ponds and storm sewers;
- Reducing pipes, inlet structures, curbs, and gutters; and
- Decreasing the volume of concrete for roadway paving.

3. MORE SPACE FOR MORE STUFF

LID can reduce the need for large detention facilities and heavy stormwater infrastructure, like pipes. By reducing the size and costs of stormwater management facilities, more land and more capital become available to develop additional units or public amenities, like parks, on the site.

4. REDUCED POTENTIAL FLOOD IMPACTS

Conventional stormwater conveyance systems carry stormwater runoff into pipes that drain the site as quickly as possible. This has the potential to overwhelm infrastructure and cause flash floods. However, LID systems are designed to capture and retain water on-site, allowing runoff to soak into the ground and/or slowly discharge from the site. [vii]

5. MULTI-FUNCTIONAL

LID features not only manage stormwater, but can serve as a public amenity. For example, a trail system can meander around a bioswale or wetlands, and other natural features can be preserved as open space.

6. INCREASED PROPERTY VALUE

If LID is designed to maximize its dual functionality as stormwater infrastructure and an attractive, natural amenity, then LID can increase property values and the marketability of developments. Studies reveal that lots in LID neighborhoods sell for $3,000 more than lots in competing areas not using LID. [viii]

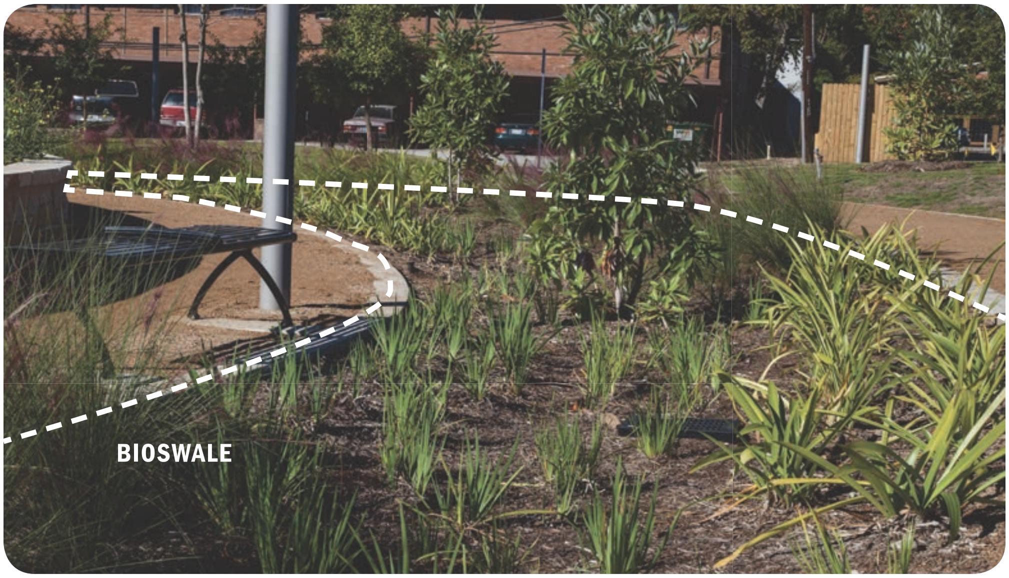
Native Plantings, Federal Reserve Bank of Dallas, Houston Branch

(Image: Asakura Robinson)

WHO BENEFITS AND HOW

Benefits Affecting Environment & Primary Stakeholders [ix]

STAKEHOLDER	BENEFITS
ENVIRONMENT	• Protect site and regional water quality • Preserve on-site hydrologic systems • Preserve trees and natural vegetation • Reduce potential for flooding impacts • Create and preserve open space
PUBLIC / MUNICIPALITIES	• Balance urban growth needs with environmental protections • Reduce impact on public stormwater infrastructure • Reduce potential for flooding impacts • Reduce system-wide municipal infrastructure and utility maintenance costs
DEVELOPER	• Reduce land clearing and grading • Increase quality of building lots and project marketability • Increase number of units due to less land needed for detention ponds • Reduce infrastructure costs (stormwater conveyance and treatment systems, roads, streets, and curbs and gutters) • Preserve or create natural amenities that can increase property values
PROPERTY OWNER	• Save money via water conservation • Reduce potential for flooding impacts



Bioswale, Mandell Park

(Image: Asakura Robinson)

BARRIERS & SOLUTIONS

COMMON BARRIERS & SOLUTIONS FOR IMPLEMENTATION

Many communities acknowledge the benefits of LID, yet barriers to LID implementation exist. Barriers can be categorized two ways: perceptual and regulatory.

REGULATORY BARRIERS

Regulatory barriers are requirements in development codes, zoning documents, stormwater management codes, or other policies that limit or restrict the application of LID techniques. The absence of guidelines and regulations for LID design, construction, and maintenance is also a major barrier to LID implementation. Some municipalities have regulations that include language that may apply to LID, but the language is often imprecise and still requires a variance, which costs developers additional time and money.

One of the best ways to encourage LID is to remove the regulatory barriers that increase developers' risk and costs. Standards and guidelines should specifically define the purpose, function, and specifications of LID while leaving room for flexibility to creatively apply these systems where possible. Design standards and development codes can be written and/or modified to ensure LID may be applicable on all land types and land uses.

Common examples of codes that impede LID use are:

BARRIER	SOLUTION
WIDE MINIMUM ROADWAY WIDTHS Many local governments require minimum roadway widths that are overly wide for certain uses, like low volume neighborhood streets.	**NARROWER ROADWAY DESIGNS** Narrow roadways reduce impervious cover and allow additional space for LID strategies within public right-of-ways, such as rain gardens or bioswales. Local governments could revise road design standards to allow for narrower roadway designs on low traffic volume streets.
CURB AND GUTTER REQUIREMENTS Many municipalities require new and reconstructed streets to include curb and gutter conveyance. These standards render many LID strategies useless because curbs and gutters often restrict stormwater runoff from draining into pervious areas such as lawns, swales, and forested areas.	**FLEXIBLE CURB AND GUTTER REQUIREMENTS** Local governments should review curb and gutter requirements to allow flexibility, such as allowing bioswales in rural or suburban environments where runoff volumes do not require the added infrastructure of curbs and gutters.
EXCESSIVE IMPERVIOUS COVER Conventional development patterns typically cover a majority of a site with impervious surfaces. Community standards that may seem unrelated to LID, such as parking minimums, may indirectly encourage the development of more impervious surfaces and flood and water quality problems.	**EFFICIENT SITE DESIGN** Communities can identify ways to promote reduced impervious cover in developments and ensure they are not requiring more paving of an area than is required. For example, parking requirements could be reduced, or shared parking ordinances enacted.
LACK OF INCENTIVES Many Texas communities do not offer incentives for the use of LID. Without a time- or cost-saving benefit, developers may be unlikely to include LID in new projects.	**OFFER INCENTIVES FOR LID** Incentives should help lower construction costs, reduce risks, and add value to projects.[x] Communities can reduce permitting fees, decrease detention volume requirements, offer stormwater fee discounts, cut stormwater utility rates, decrease detention requirements, or create award programs to encourage the adoption of LID.

PERCEPTUAL BARRIERS

People may not be aware of what LID is, its benefits, and how it functions, resulting in a lack of interest in requesting, installing, and maintaining LID practices. Misperceptions discourage developers, designers, municipalities, building owners, and the public from choosing LID practices.

Perceptual barriers can best be overcome by data-based research and educational efforts.

BARRIER	SOLUTION
“LID IS COST-PROHIBITIVE.” LID is often perceived as more expensive than conventional stormwater management infrastructure and is overlooked.	**LID CAN REDUCE DEVELOPMENT COSTS & ADD VALUE.** LID reduces development costs because it requires less land clearing and grading, less heavy stormwater infrastructure like pipes and treatment systems, and it does not need curb and gutter systems. LID can reduce the size of detention facilities, which adds value to the site by making more land available to develop additional units or public amenities.
“WE DON’T KNOW WHAT LID IS.” Many local governments, design review teams, maintenance teams and the public either are unfamiliar with LID or do not understand how it functions or its benefits. This lack of understanding deters the use of LID.	**INCREASE AWARENESS VIA EDUCATION PROGRAMS.** Local governments or developers can educate the general public by employing signage campaigns that identify and explain specific LID practices in their communities. Additionally, local governments and development review teams could invite LID consultants to educate them on how LID works.
“LID IS TOO DIFFICULT TO MAINTAIN.“ LID is often overlooked because it is perceived to be overly time-consuming and difficult to maintain.	**LID MAINTENANCE IS NOT OVERLY BURDENSOME.** LID maintenance can be similar in time and effort to that of conventional stormwater management systems. For example, plant pruning, mowing, litter removal, and mulching are practices required for some LID BMPs. Sometimes, LID requires less maintenance than other landscaped features and stormwater infrastructure. Native grasses can only require mowing 1-2 times per year. Maintenance programs should be drafted that specifically describe how LID will be cared for and how often.

BARRIER	SOLUTION
"WE DON'T KNOW WHO WILL TAKE CARE OF LID." Often there is ambiguity over which entity will maintain LID: a homeowner's association, the developer, or local governments.	**MAINTENANCE AGREEMENTS DEFINE THE RESPONSIBLE PARTY.** Maintenance agreements between developers, communities, and property owners can help take the guesswork out of who is responsible for ongoing maintenance. People who maintain LID systems should be trained on how these systems function to know how to take care of it properly.
"CLAY SOILS PREVENT THE USE OF LID." The Houston-Galveston region is largely comprised of clay soils. Clay soils are mostly impermeable, preventing runoff from infiltrating into the ground. Therefore, many people discount LID as a viable solution to stormwater management for sites composed of clay soils.	**NOT ALL LID PRACTICES REQUIRE INFILTRATION.** Many LID practices do not require infiltration to function properly. For example, constructed stormwater wetlands, stormwater planter boxes, green roofs, rainwater harvesting, and permeable pavement do not require infiltration processes and can be designed on sites with clay soils.
"LID BREEDS MOSQUITOES." Rain gardens and bioswales are designed to hold water and allow it to drain slowly; however, standing water in a planting bed can create a perception of swampy insect breeding grounds.	**LID DRAINS IN 24-48 HOURS.** When properly designed and installed, water-retaining LID BMPs, like rain gardens, self-drain within 24-48 hours, less time than mosquitoes need to reproduce.

SPIDER LILY

As a native plant, the Spider Lily is commonly found along roadsides and in moist soil conditions. Spider Lily is mostly evergreen in this region and flowers during the summer months.

Common LID applications of Spider Lily include bioswales, rain gardens, constructed stormwater wetlands, vegetated swales, and vegetated filter strips.

LID TOOLBOX

WHAT DOES LID LOOK LIKE ?

LID practices mimic the natural processing of stormwater runoff and can create more attractive communities. Most LID techniques and strategies are applicable throughout the Houston-Galveston region.

- **Vegetated Filter Strip**
- **Vegetated Swale**
- **Bioretention Systems**
  - Rain Garden
  - Bioswale
  - Stormwater Planter Box
- **Permeable Pavement**
- **Constructed Stormwater Wetlands**
- **Rainwater Harvesting**
  - Cistern
  - Rain Barrel
  - Underground Storage
- **Green Roof**

Vegetated Swale and Native Plantings, Federal Reserve Bank of Dallas, Houston Branch

(Image: Asakura Robinson)

VEGETATED FILTER STRIP

RELATIVE COST

$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	○
Weeding	●	●	●	○
Mowing	●	●	●	●
Water	●	●	●	●
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	○	○	○
Repair Erosion	●	○	○	○
Repair Sediment Build Up	●	●	○	○
Repair Ponding	●	○	○	○
General Inspection	●	○	○	○

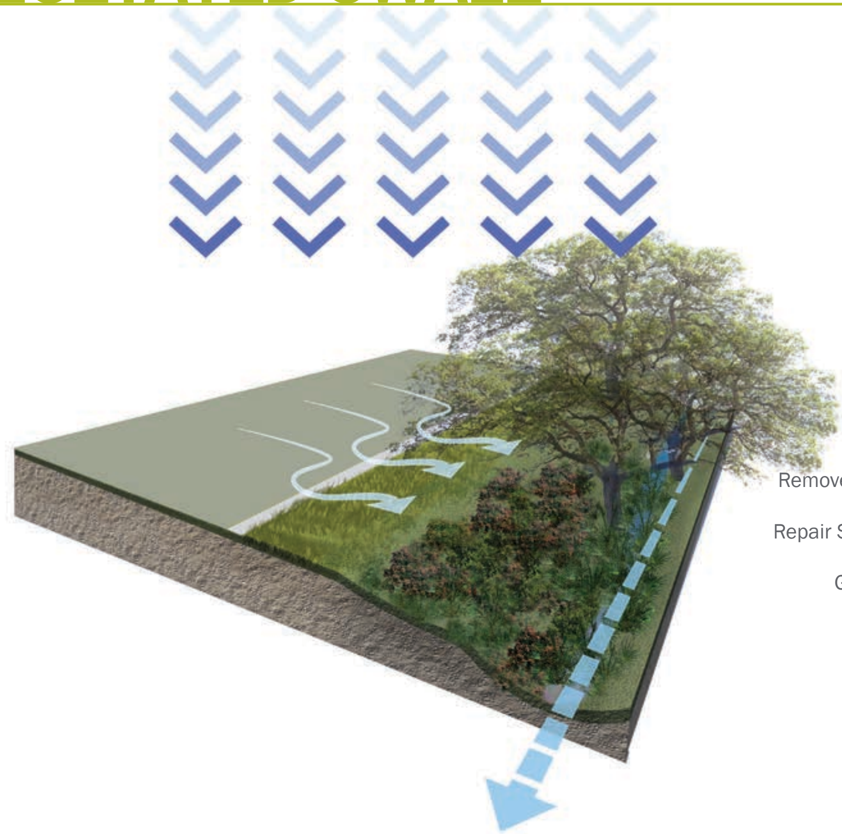
A vegetated filter strip is a band of vegetation, usually a mix of grasses and native plants that acts as a buffer between an impervious surface and a waterway. They are designed to slow runoff from adjacent impervious surfaces, filter pollutants, and provide infiltration (depending upon the permeability of underlying soils). They can also provide aesthetic benefits, stormwater storage, and wildlife habitat. In addition to stormwater management, vegetated filter strips can add recreational value with opportunities to incorporate trails into their design.

Filter strips are best suited on sites that naturally support dense vegetation. Filter strips are best used in treating runoff from roads, roofs, small parking lots, and other small surfaces.

Vegetated Filter Strip, Lone Star College Victory Center

(Image: Asakura Robinson)

VEGETATED SWALE



RELATIVE COST

$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	○
Weeding	●	●	●	○
Mowing	●	●	●	●
Water	●	●	●	●
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	○	○	○
Repair Erosion	●	○	○	○
Repair Sediment Build Up	●	●	○	○
Repair Ponding	●	○	○	○
General Inspection	●	○	○	○

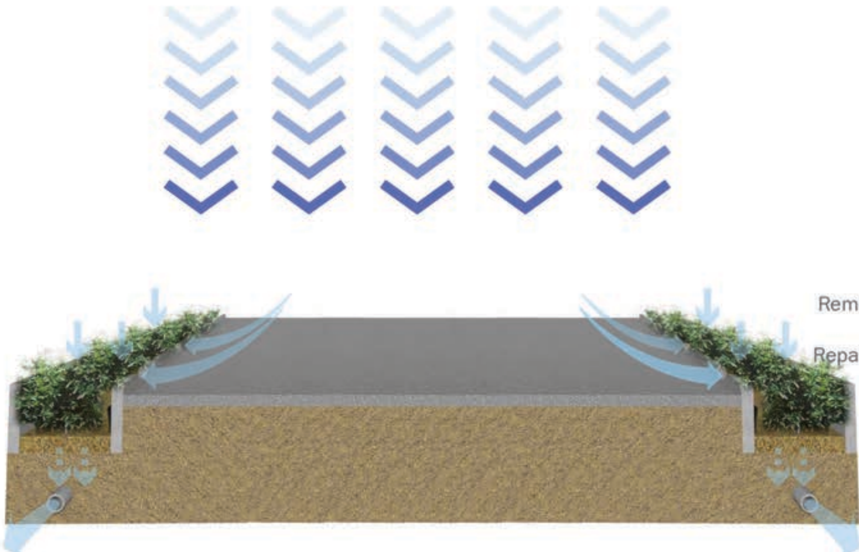
A vegetated swale is a wide, shallow channel with vegetation covering the sides and bottom. Swales are designed to convey and treat stormwater, promote infiltration, remove pollutants, and reduce runoff velocity. Vegetated swales mimic natural systems better than traditional drainage ditches.

Vegetated swales can be used on sites that naturally cultivate a dense vegetative cover and have an appropriate area, slope, and infiltration potential. Swales are most effective when used in a treatment train with other LID techniques. They are widely used to convey and treat stormwater runoff from parking lots, roadways, and residential and commercial developments and are compatible with most land uses.

Vegetated Swale, Federal Reserve Bank

(Image: Asakura Robinson)

BIORETENTION CELL / RAIN GARDEN



RELATIVE COST

$$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	○
Weeding	●	●	●	○
Mulch	●	○	○	●
Water	●	●	●	●
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	○	○	○
Repair Erosion	●	○	○	○
Repair Sediment Build Up	●	●	○	○
Repair Ponding	●	○	○	○
General Inspection	●	○	○	○

Bioretention cells, or rain gardens, are vegetated depressions layered with **engineered soil media** that filter pollutants, increase the time water stays on the site, and provides stormwater storage. These systems usually have an underdrain to ensure the cell drains in a reasonable time period. Although they are applicable in most settings, rain gardens are best used on small sites, urban areas, suburban areas, and parking lots.

Rain Garden, Kempwood Manor

(Image: EHRA)

Rain Garden, Dickinson Library

(Image: Asakura Robinson)

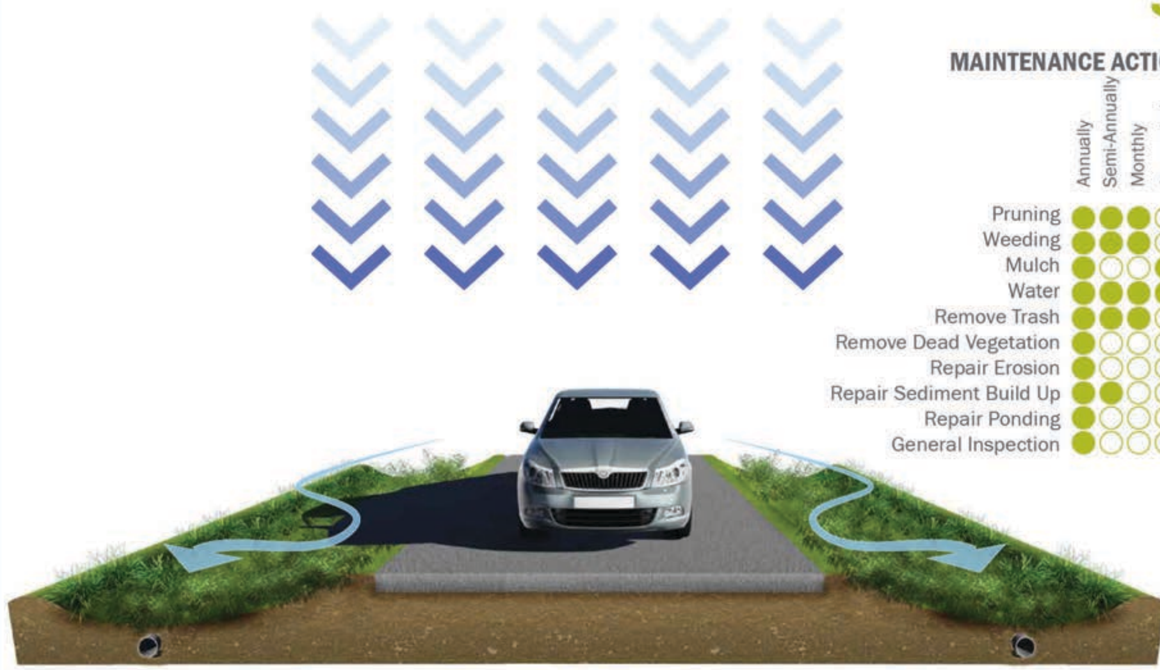
BIOSWALE

RELATIVE COST

$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	○
Weeding	●	●	●	○
Mulch	●	○	○	●
Water	●	●	●	●
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	○	○	○
Repair Erosion	●	○	○	○
Repair Sediment Build Up	●	●	○	○
Repair Ponding	●	○	○	○
General Inspection	●	○	○	○



Bioswales are similar to bioretention cells in design and function but are linear elements that can also be used for conveyance and storage in addition to their **biofiltration** function. They can be used anywhere and are best used on small sites, in urbanized and suburban commercial areas, residential areas, and parking lots.

Bioswale, Bagby Street

(Image: H-GAC)

Bioswale, Houston Permitting Center

(Image: H-GAC)

STORMWATER PLANTER BOX

RELATIVE COST

$$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	
Weeding	●	●	●	
Water				●
Remove Trash	●	●	●	
Remove Dead Vegetation	●			
Repair Erosion	●			
Repair Sediment Build Up	●			
Repair Ponding	●			
General Inspection	●			

A stormwater planter box is a bioretention system enclosed in a concrete container that contains porous soil media and vegetation to capture, detain, and filter stormwater runoff. Stormwater planter boxes are lined, contain an underdrain, have various small to medium plantings, and are installed below or at grade level to a street, parking lot, or sidewalk.

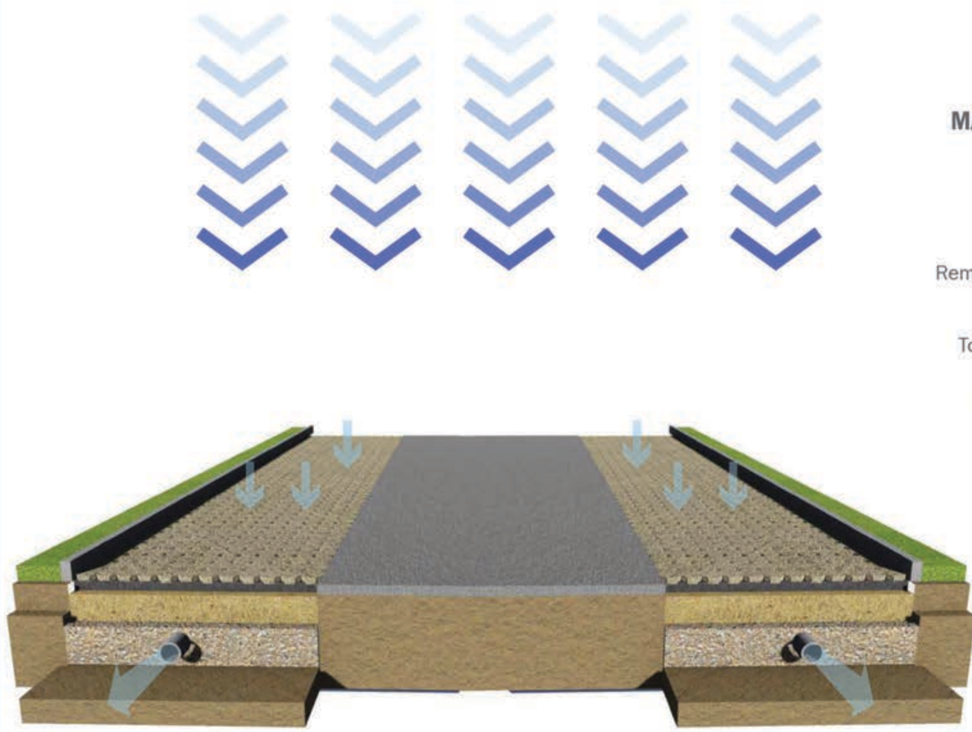
Runoff is directed to the stormwater planter, where water is filtered by vegetation before percolating into the ground or discharging through an underdrain. The stormwater is also used to irrigate the tree or other vegetation in the planter box.

In addition to stormwater control, stormwater planter boxes offer on-site stormwater runoff treatment and aesthetic value. Stormwater planter boxes are optimal for urban or streetscape environments.

Stormwater Planter Box, Darling Street

(Image: Jones + Carter)

PERMEABLE PAVEMENT



RELATIVE COST

$$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Remove Trash	●	●	●	○
Vacuum	○	○	○	●

To maintain the structural integrity of permeable pavement, refrain from pressure washing

Permeable pavement is a durable, load-bearing paved surface designed to allow water to pass through and into an underlying rock base. Due to the prevalence of clay soils in this region, runoff flows through the permeable pavement and is directed to an underdrain, subsurface detention, or rainwater harvesting system. Permeable pavement allows for streets, parking lots, and sidewalks to mimic pre-development runoff conditions while sustaining the functional attributes of the site area they replace. Permeable pavements reduce pollutant loads and control runoff volume and peak flow rates. Permeable pavement includes a wide range of materials, such as permeable stone pavers, porous asphalt, and porous concrete. These materials can be used as a substitute to conventional pavement on parking areas, roadways, playgrounds, and plazas.

Permeable Pavement, Kempwood Manor

(Image: H-GAC)

LID TOOLBOX

CONSTRUCTED STORMWATER WETLANDS

	Annually	Semi-Annually	Monthly	As needed
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	●	●	○
Remove Invasive Species	●	●	●	●
Repair Erosion	●	●	●	●
Repair Sediment Build Up	●	●	●	○
Control Pests	●	●	●	○

Constructed stormwater wetlands are manmade shallow-water ecosystems designed to treat and store stormwater runoff. These wetlands allow pollutants to settle out or to be treated by vegetation. Runoff is slowly discharged over one to three days. Wetlands provide plant and wildlife habitat and can be designed as a public amenity. While constructed stormwater wetlands have limited applicability in highly urbanized settings, they are a desired technique on larger sites with relatively flat or gently sloping terrain. They are also well-suited to low-lying areas, such as along river corridors.

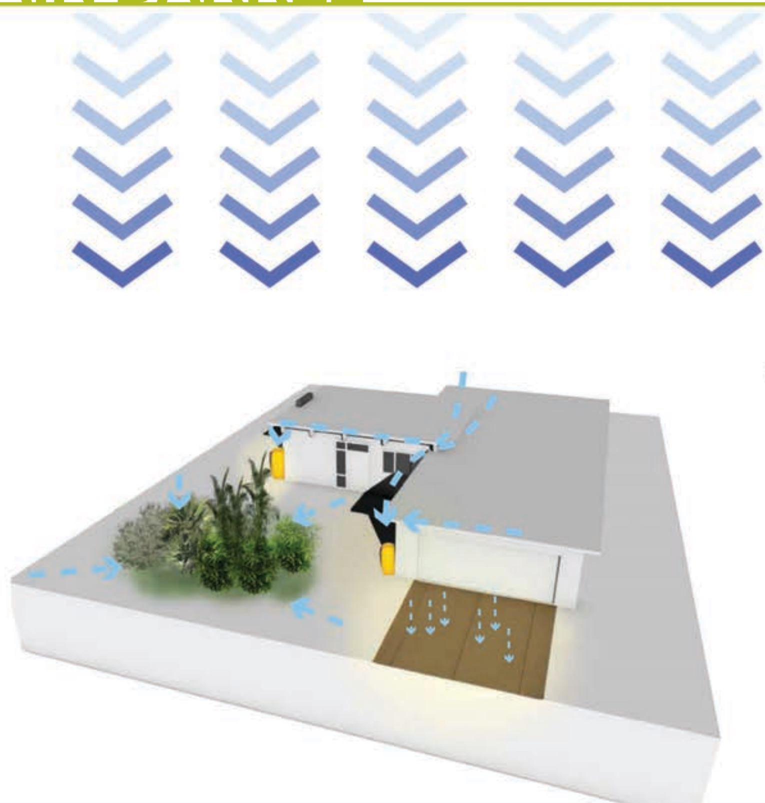
Stormwater Wetlands, Mason Park

(Image: H-GAC)

RAINWATER HARVESTING

Rainwater harvesting systems are above- or below-ground storage containers that capture and store runoff to be used for irrigation and other nonpotable uses. Rainwater harvesting systems are an appropriate LID technique for highly urbanized areas, where impervious surfaces are unavoidable and site constraints limit the use of other LID practices. These systems are also a sustainable building practice that reduce demand on municipal water resources. Systems range in size and complexity and include rain barrels, cisterns, and underground storage.

RAIN BARREL



RELATIVE COST

$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Remove Trash	○	○	○	●
Repair Sediment Build Up	○	○	○	●
Inspect for Leaks	●	●	○	○
General Inspection	●	○	○	○

ADDITIONAL MAINTENANCE

Clean annually to prevent bacteria growth

Maintain pumps (cisterns)

Empty before next storm event (some systems automate this process)

Rain barrels are small systems that guide runoff through a downspout into a barrel that usually holds less than 100 gallons. Rain barrels are typically installed and maintained by single-family homes.

Rain Barrel, Ghirardi WaterSmart Park

(Image: H-GAC)

Rain Barrel, Residence in Houston

(Image: Asakura Robinson)

CISTERN

RELATIVE COST

$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Remove Trash	○	○	○	●
Repair Sediment Build Up	○	○	○	●
Inspect for Leaks	●	●	○	○
General Inspection	●	○	○	○

ADDITIONAL MAINTENANCE

Clean annually to prevent bacteria growth

Maintain pumps (cisterns)

Empty before next storm event (some systems automate this process)

Cisterns are large rainwater systems installed above or below ground with a much larger capacity than rain barrels. They can store water from multiple downspouts and pavement areas.

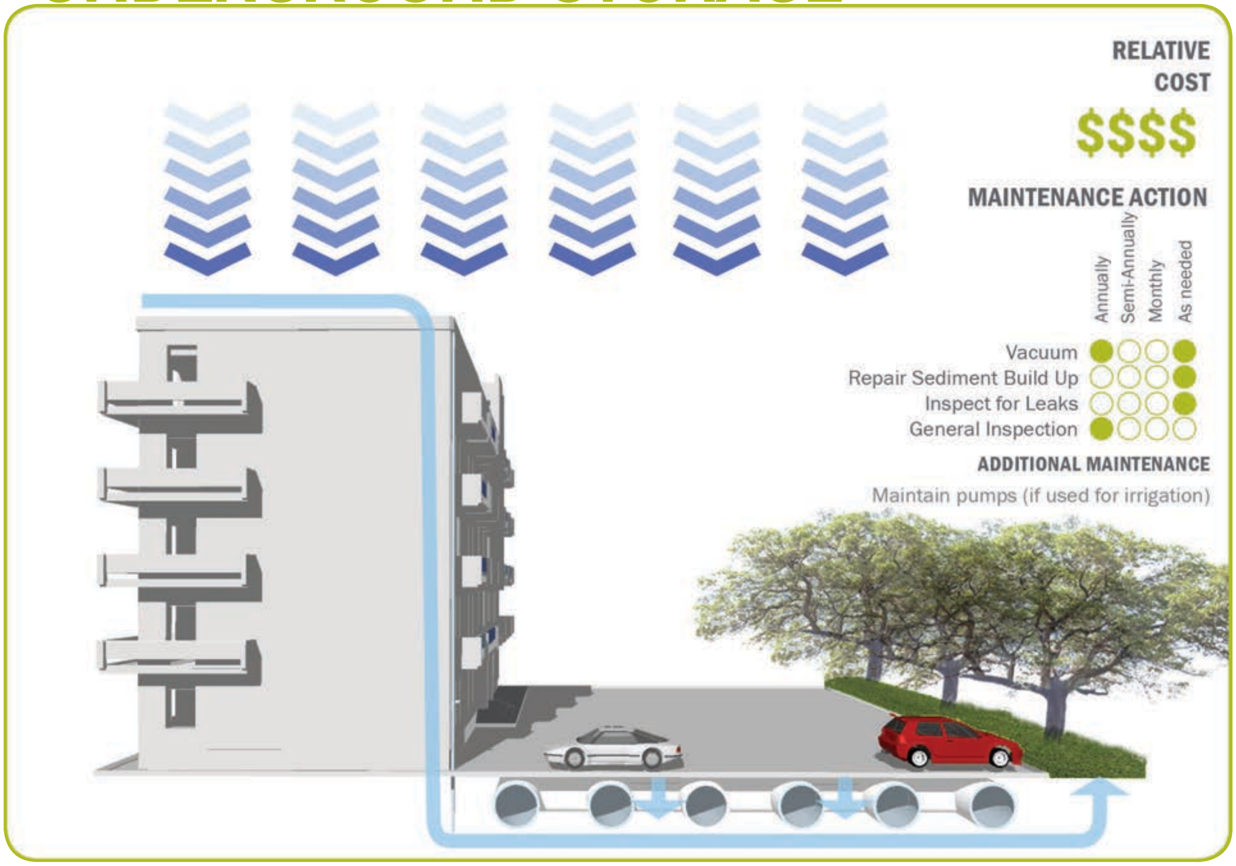
Cistern, Houston Arboretum

(Image: Asakura Robinson)

Cistern, Grocery Store in Houston

(Image: H-GAC)

UNDERGROUND STORAGE

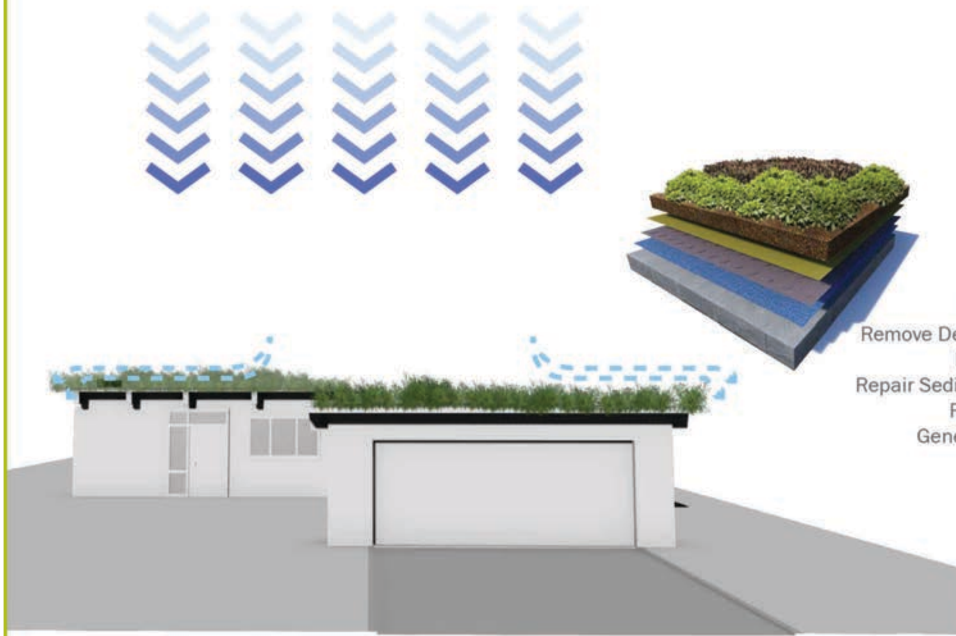


Underground storage systems capture and store runoff below grade in large chambers. The stored runoff is usually used for irrigation. If the soils are suitable, a portion may also infiltrate into underlying soils. Underground storage may be used for stormwater detention instead of surface ponds. If used under parking, this method of detention can increase the land available for development.

Underground storage tank, Birnamwood Drive

(Image: Harris County Public Infrastructure Department)

GREEN ROOF



RELATIVE COST

$-$$$$$

MAINTENANCE ACTION

	Annually	Semi-Annually	Monthly	As needed
Pruning	●	●	●	○
Weeding	●	●	●	○
Mulch	○	○	○	●
Water	●	●	●	●
Remove Trash	●	●	●	○
Remove Dead Vegetation	●	○	○	○
Repair Erosion	●	○	○	○
Repair Sediment Build Up	●	●	○	○
Repair Ponding	●	○	○	○
General Inspection	●	○	○	○

A green roof is a vegetative layer grown on a rooftop that filters, absorbs, and/or detains rainfall. The green roof system typically contains a soil layer, a drainage layer, and an impermeable membrane. Water is captured and detained in the soil and dispersed through **evaporation or transpiration** by the plants. Green roofs reduce volume and peak rates of stormwater and enhance water quality. Other benefits include reduction in **heat island effect,** extension of roof life, recreational and gardening opportunities, air and noise quality improvement, and reduced building heating and cooling costs. [xii] They can be integrated into new construction or added to existing buildings, including buildings with flat and sloped roofs. This practice is effective in urbanized areas where there is little room to accommodate other LID systems.

Green Roof, Houston Permitting Center

(Image: H-GAC)

PUTTING IT ALL TOGETHER

HOW LID BMPS CAN FUNCTION TOGETHER

SUSTAINABLE SITE DESIGN

Sustainable site design incorporates approaches which reduce impacts of new and redevelopment projects by conserving natural areas and better integrating LID stormwater treatment into the site plan. The aim of sustainable site design is to increase the environmental values of the site while retaining and enhancing the purpose and vision of the developer. Many sustainable site design concepts employ non-structural on-site treatment that can reduce the cost of infrastructure while maintaining or increasing the value of the property relative to conventionally designed developments.

There are three techniques that accomplish the goals of sustainable site design as they pertain to the mission of LID:

CLUSTER DEVELOPMENT

Cluster development is a LID practice that places buildings in a concentrated manner to minimize land development impacts, reduce impervious surfaces, and preserve open space. The residual space can be used as a stormwater management tool, used as a public amenity, and/or used for additional units.

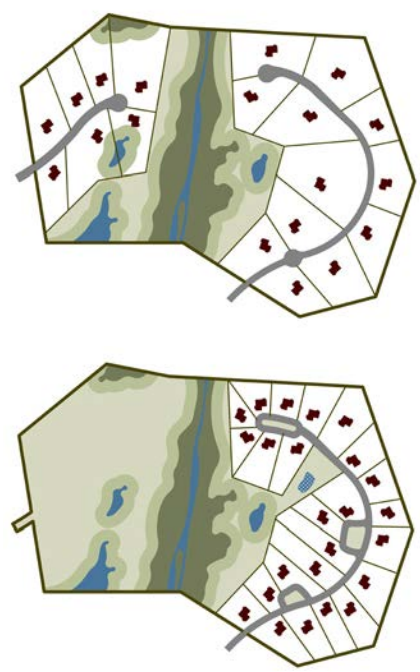
MINIMIZE PAVEMENT WIDTHS

Minimizing pavement widths is a LID practice that decreases the total amount of impervious area associated with land development projects, including streets and parking lots. Traditionally, roadways have been designed to be wider than necessary for vehicle usage.

By reducing roadway widths, more pervious area is available to capture and distribute stormwater. Also, construction and infrastructure costs will decrease.

OPEN SPACE PRESERVATION

Open space preservation is a LID practice that encourages the conservation of natural areas to assist in maintaining a site's natural hydrology. Preserved open spaces allow for infiltration, reduce runoff, and filter pollutant loads from stormwater runoff. Open spaces can also reduce the need to construct structural stormwater infrastructure.



Sustainable Site Design

(Image: Design Workshop)

TREATMENT TRAIN

A treatment train consists of multiple LID stormwater practices installed in a series. Implementing a number of practices together provides the opportunity to include a variety of processes (sedimentation, filtration, etc.) to treat runoff, which optimizes pollutant removal. The use of multiple systems provides a level of redundancy, so at least partial treatment is being achieved even if one system is not functioning properly.

The configuration for a treatment train can take many different forms. Common applications include the use of a vegetated swale to convey stormwater to or from other LID BMPs, such as bioretention cells. Swales can provide some level of pretreatment when installed upstream of other facilities and allow for infiltration. If there is excess runoff at the end of a treatment train, the treated stormwater could then be connected to the storm sewer. Treatment trains should be designed with maintenance considerations in mind. This includes reducing velocity and erosion.

Treatment Train, Ghirardi WaterSmart Park

(Image: H-GAC)


Rainwater and stormwater runoff can be redirected before entering the drainage system, allowing excess water to be utilized rather than discharged.
Sloped edges direct stormwater into the green roof system.
Stormwater runoff is collected and channeled into the cisterns.
Native Plants that have adapted to the climate can survive with minimal maintenance or supplemental watering, and provide food and habitat for birds and insects.

VIRGINIA SWEEETSPIRE

Virginia Sweetspire is a common grass native to South Central and Southeastern US. It is a semi-evergreen plant that flowers annually. In LID projects, Virginia Sweetspire is both drought and flood tolerant, and its root structure provides erosion control.

APPLICABILITY

CAN LID WORK FOR ALL LAND USES AND LAND COVERS?

To demonstrate the applicability of LID on a range of land cover and land uses and showcase the economic and environmental benefits of LID, H-GAC assembled a team of designers to draft a conventional site plan and a LID site plan for each of five different properties. Each site represents a different land use category: commercial, multi-family, institutional, single-family, and roadway. The site plans created are realistic, market-driven plans but have two assumptions: 1) there are no barriers to LID implementation and 2) LID BMPs count as a stormwater control.

The overarching LID design goals were to

- Reduce development and infrastructure costs;
- Reduce amount of land dedicated to detention facilities;
- Reduce runoff by managing stormwater as close to its source as possible;
- Improve stormwater quality; and
- Add value to development projects through LID amenities.

To estimate the performance, costs, and benefits of LID compared with stormwater infrastructure of conventional site plans, the team used the Green Values Stormwater Management Calculator.[xiii] With inputs like soil type, average precipitation, and impervious coverage, this calculator allows its user to apply a range of LID BMPs to a conventional site design in order to calculate the net present value (NPV) of using LID. The calculator breaks out construction costs and annual maintenance costs of both stormwater methods to present the NPV. This tool was applied to each of the sites. Each LID system proved to be more economical than the conventional counterparts.

Bioswale, Bagby Street

(Image: H-GAC)

COMMERCIAL

SITE REPORT

This commercial site is adjacent to a major highway and outside a suburban town that is experiencing rapid growth. The site is a 79.6-acre development, nearly flat, with a dense bottomland hardwood tree canopy cut by an east-west roadway easement and a north-south pipeline easement. Soils in this area are dense clay and do not drain well. East of the site is a 100-year floodplain which drains to adjacent waterways and a future planned open space and park amenity. Due to the relatively flat nature of this site, the current hydrology is composed of small pools forming at the center, flowing away from the raised highway and roadway embankments surrounding the property.

The site is slated to develop as a commercial center, requiring a minimum of one parking space for every 200 square feet of retail space. Building heights in this area are not restricted but expected to maintain a one- to two-story height average.

SITE PLANNING ASSUMPTIONS:

Parking Requirements:
One parking space per 200 Sq Ft of building area

Parking Space + Circulation Area Required:
350 Sq Ft

Detention Requirements:
15 percent of site area (less in LID version, approximately 12 percent)

CONVENTIONAL SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	79.6-Acres (3.4 Million Sq Ft)
Leasable Floor Space	396,400 Sq Ft
Parking Spaces	Required: 2,086 Supplied: 3,490
Detention	11.6 Acres (505,000 Sq Ft)
Stories	Single-Story Throughout

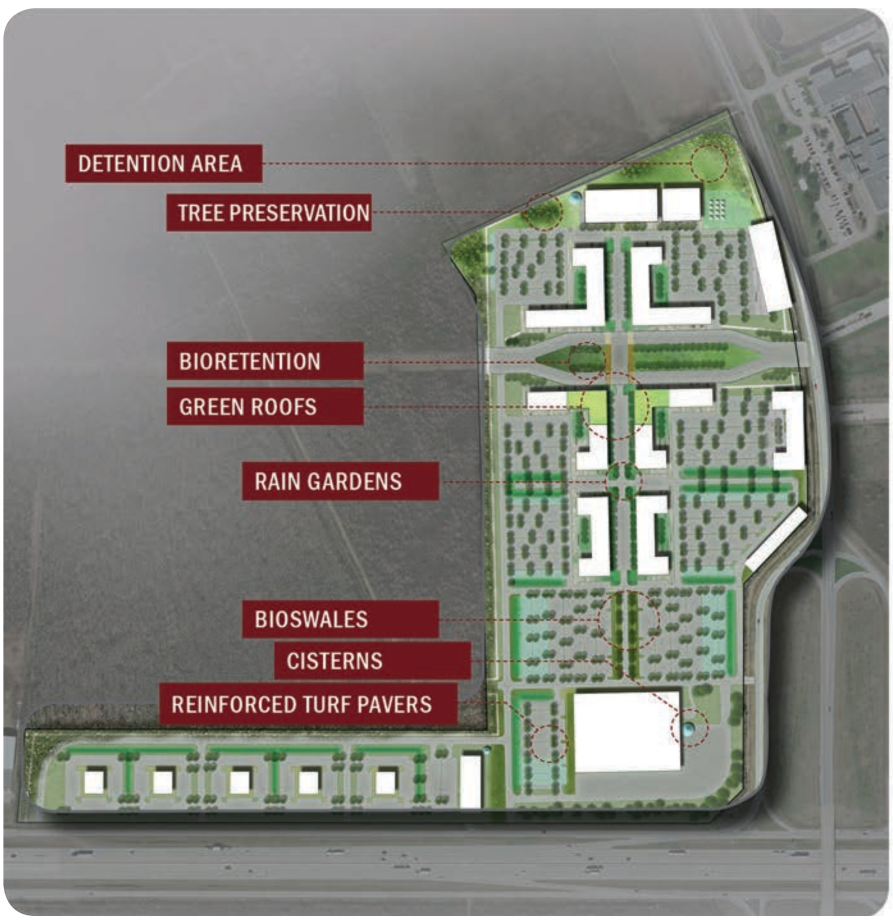
CONVENTIONAL WATER ANALYSIS

COST BENEFIT OF STORMWATER MANAGEMENT INFRASTRUCTURE

	Life Cycle Cost ($, NPV) Net Present Value			
	Conventional	**LID**	**Difference**	**%**
Concrete Sidewalk	$ 661,685	$ 661,685	$ 0	0 %
Curbs & Gutters	$ 450,731	$ 318,934	$ 131,797	- 29 %
Street	$ 4,910,461	$ 2,605,956	$ 2,304,505	- 47 %
Parking Lot	$ 14,000,628	$ 11,188,054	$ 2,812,574	- 20 %
Conventional Stormwater Storage	$ 4,490,076	$ 1,775,920	$ 2,714,156	- 60 %
Standard Roof	$ 4,470,707	$ 5,063,692	($ 592,985)	13 %
Green Roof	-	$ 602,277	($ 602,277)	
Turf	$ 3,235,742	$ 895,695	$ 2,340,047	- 72 %
Native Plants	-	$ 2,008,641	($ 2,008,641)	
Rain Garden	-	$ 732,242	($ 732,242)	
Trees	$ 193,702	$ 363,191	($ 169,489)	87 %
Swales in Parking Lot	-	$ 444,153	($ 444,153)	
Downspout Disconnection	-	$ 101	($ 101)	
Cisterns	-	$ 796,644	($ 796,644)	
Total	$ 32,413,732	$ 27,457,185	$ 4,956,547	-15 %

These numbers compare landscape development and stormwater management costs. They do not account for cost to construct buildings.

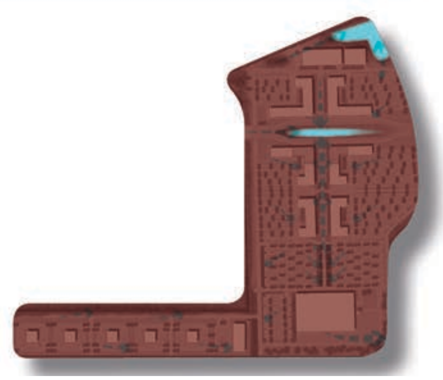
LID SITE PLAN



DEVELOPMENT SUMMARY:

Site Area	79.6-Acres (3.4 Million Sq Ft)
Leasable Floor Space	418,000 Sq Ft
Parking Spaces	Required: 2,408 Supplied: 3,046
Detention	Reduced Detention Requirements
Stories	Single-Story Throughout

LID WATER ANALYSIS



MULTI FAMILY

SITE REPORT

This 22-acre site is on a large, undeveloped property adjacent to a shopping center and a major highway. The large amount of development in this area has caused some flooding concerns, and the existing topography of the site has well-defined ridges and valleys, funneling water through two major drainages to the eastern corner of the site. The site is currently covered by well-developed tree canopy. It is located completely outside of the 100-year floodplain. The soils are dense clay soils that do not drain well.

The site is slated to be developed as a large, phased multi-family development to house about of 500 units. The parking requirement is two parking spaces for each unit. The maximum height for apartment developments in this area is four stories.

SITE PLANNING ASSUMPTIONS:

Average Unit Size: 800 Sq Ft

Percent of Building Footprint Utilized for Hallways & Utilities: 15 percent

Parking Requirements:

Conventional:	2 spaces/unit
LID:	1.5 spaces/unit

Detention Requirements:

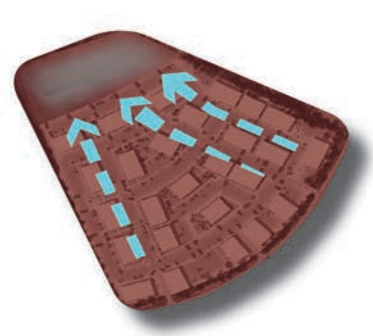
Conventional:	15 percent
LID:	12 percent

CONVENTIONAL SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	21.8 Acres (950,000 Sq Ft)
Building	All Two-Story Buildings
Units	416 Units (Avg. 800 Sq Ft Footprint, 2 Cars Per Unit)
Parking Spaces	Required: 833 Supplied: 1,002
Detention	3.25 Acres (141,570 Sq Ft)
Amenity Area	0.33 Acres (14,400 Sq Ft)

CONVENTIONAL WATER ANALYSIS



APPLICABILITY

COST BENEFIT OF STORMWATER MANAGEMENT INFRASTRUCTURE

Life Cycle Cost ($, NPV)
Net Present Value

	Conventional	LID	Difference	%
Concrete Sidewalk	$ 560,775	$ 205,524	$ 355,251	- 63 %
Curbs & Gutters	$ 10,584	$ 11,022	($ 438)	4 %
Street	$ 57,653	$ 60,038	($ 2,385)	4 %
Parking Lot	$ 3,733,194	$ 1,472,844	$ 2,260,350	- 61 %
Conventional Stormwater Storage	$ 1,139,774	$ 463,346	$ 676,428	- 59 %
Standard Roof	$ 2,099,975	$ 2,105,973	($ 5,998)	0 %
Green Roof	-	$ 121,369	($ 121,369)	
Turf	$ 1,063,246	$ 324,036	$ 739,210	- 70 %
Native Plants	-	$ 711,617	($ 711,617)	
Rain Garden	-	$ 135,064	($ 135,064)	
Trees	$ 154,962	$ 242,128	($ 87,166)	56 %
Swales in Parking Lot	-	$ 68,834	($ 68,834)	
Downspout Disconnection	-	$ 101	($ 101)	
Cisterns	-	$ 15,933	($ 15,933)	
Total	$ 8,820,163	$ 5,937,829	$ 2,882,334	- 33 %

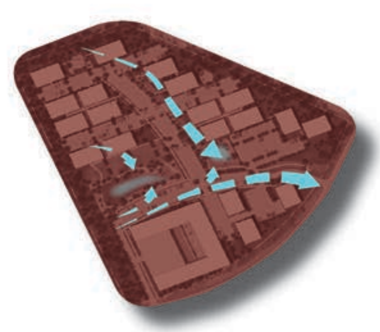
These numbers compare landscape development and stormwater management costs. They do not account for cost to construct buildings. Cost-benefit analysis does not include cost to construct parking garage, which ranges from $10,000 - $40,000 per parking space.

LID SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	21.8 Acres (950,000 Sq Ft)
Building	Two-Story Buildings, with Three-Story Wrap Around (Garage)
Units	486 Units (Avg. 800 Sq Ft Footprint, 1.5 Cars Per Unit)
Parking Spaces	Required: 730 Supplied: 762
Detention	Reduced Requirement and Increased Per/Unit Value with Inclusion of Detention Park Space
Amenity Area	1.86 Acres of Amenity Area (81,000 Sq Ft)
Plants	Native Plantings Throughout

LID WATER ANALYSIS



SINGLE FAMILY

SITE REPORT

This 28-acre site is located in a suburban setting, between existing residential development and a busy highway. It is a nearly flat and undeveloped greenfield site with excellent tree canopy cover.

Waterways exist to the north and south, but none cross the site. Water generally pools inward on-site, away from road and home embankments. Soils here are somewhat sandy and drain well, making them suitable for deep infiltration.

The site is zoned for single-family development and will likely be built by a single developer/builder combination. Per city regulations, cul-de-sacs may not exceed 400 feet in length, and sidewalks must be provided throughout the development.

SITE PLANNING ASSUMPTIONS:

Average Parcel Size:

Conventional:	60 ft x 120 ft
LID:	50 ft x 100 ft

Parking Requirements:
Included in building footprint

Detention Requirements:

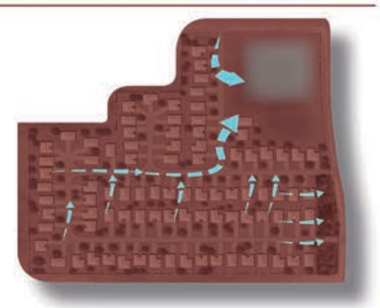
Conventional:	15 percent
LID:	12 percent

CONVENTIONAL SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	23.7 Acres (1.03 Million Sq Ft)
Units	89 Single Family Homes Lots: 60 x 120 Ft Footprint: Avg. 2,400 Sq Ft Type: Single-Story
Setbacks	40-foot Avg.
Detention	3.8 Acres (165,528 Sq Ft)
Roadway	Total Area: 140,400 Sq Ft 3,510 Linear Ft Roadway Profiles: 30 Ft Sidewalks: 5 Ft (both sides)

CONVENTIONAL WATER ANALYSIS



COST BENEFIT OF STORMWATER MANAGEMENT INFRASTRUCTURE

Life Cycle Cost ($, NPV)
Net Present Value

	Conventional	LID	Difference	%
Concrete Sidewalk	$ 114,572	$ 180,846	$ 66,274	58 %
Concrete Driveway	$ 794,421	$ 320,154	($ 474,267)	- 60 %
Curbs & Gutters	$ 116,887	$ 125,848	($ 8,961)	8 %
Street	$ 1,082,403	$ 1,542,427	$ 460,024	43 %
Parking Lot	$ 316,057	$ 0	$ 316,057	- 100 %
Conventional Stormwater Storage	$ 987,525	$ 598,108	($ 389,417)	- 39 %
Standard Roof	$ 2,344,257	$ 1,988,762	$ 355,495	- 15 %
Permeable Pavement- Pavers	-	$ 54,573	($ 54,573)	
Turf	$ 1,572,590	$ 323,065	$ 1,249,525	- 79 %
Native Plants	-	$ 709,485	($ 709,485)	
Rain Garden	-	$ 197,136	($ 197,136)	
Trees	$ 125,906	$ 106,536	($ 19,370)	- 15 %
Downspout Disconnection	-	$ 101	($ 101)	
Rain Barrels	-	$ 5,573	($ 5,573)	
Total	$ 7,454,618	$ 6,152,614	$ 1,302,004	- 17 %

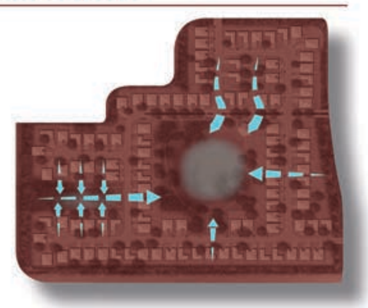
These numbers compare landscape development and stormwater management costs. They do not account for cost to construct buildings.

LID SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	23.7 Acres (1.03 Million Sq Ft)
Units	105 Single Family Homes Lots: 50 x 100 Ft Footprint: Avg. 1,700 Sq Ft Type: Two-Story
Setbacks	20-foot Avg.
Detention	Reduced Detention Requirement
Roadway	Total Area: 132,400 Sq Ft 4,137 Linear Ft Roadway Profiles: 30 Ft Sidewalks: 5 Ft (both sides)
Tree Canopy	Tree Canopy Preservation Easement Preserves 4.5 Acres of Canopy

LID WATER ANALYSIS



APPLICABILITY

INSTITUTIONAL

SITE REPORT

This 15.8-acre site is on a university campus. The growth of the student body requires the development of a new dorm facility and expanded recreational fields. The site planned for development is surrounded by existing university recreational facilities, dorm facilities, and adjacent multi-family housing. East of the site is a large drainage ditch and floodplain which drains into the bayou. The soils on this site drain poorly.

As owner of the property, the university has flexibility in developing the site. At a minimum, they are seeking to provide at least 250 new dorm units and parking for 1.5 cars per unit.

SITE PLANNING ASSUMPTIONS:

Average Unit Size: 600 Sq Ft

Percent of Building footprint utilized for hallways & utilities: 15 percent

Parking Requirements:
1.5 spaces/unit

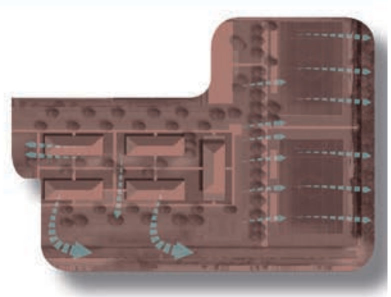
Detention Requirements:
Conventional: 15 percent
LID: 12 percent

CONVENTIONAL SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	18.8 Acres (688,600 Sq Ft)
Buildings	2 Two-Story Dorm Facilities 1 Three-Story Dorm Facility
Units	196 Student Dorm Units (Avg. 600 Sq Ft, 1.5 Cars Per Unit)
Parking Spaces	Required: 294 Supplied: 344
Amenity Area	2 Full Size Soccer Fields
Detention	2.25 Acres (141,570 Sq Ft)

CONVENTIONAL WATER ANALYSIS



COST BENEFIT OF STORMWATER MANAGEMENT INFRASTRUCTURE

Life Cycle Cost ($, NPV)
Net Present Value

	Conventional	LID	Difference	%
Concrete Sidewalk	$ 444,698	$ 180,848	($ 66,274)	58 %
Parking Lot	$ 1,283,597	$ 320,154	$ 474,267	- 60 %
Conventional Stormwater Storage	$ 485,688	$ 598,108	($ 389,417)	- 39 %
Standard Roof	$ 914,882	$ 995,052	($ 80,170)	9 %
Green Roof	-	$ 57,348	($ 57,348)	
Turf	$ 1,334,386	$ 198,988	$ 1,135,418	- 85 %
Native Plants	-	$ 436,955	($ 436,955)	
Rain Garden	-	$ 49,935	($ 49,935)	
Trees	$ 62,953	$ 52,268	($ 9,685)	- 15 %
Downspout Disconnection	-	$ 101	($ 101)	
Vegetated Filter Strips	-	$ 125,471	($ 125,471)	
Total	$ 4,526,184	$ 2,805,652	$ 1,720,532	- 38 %

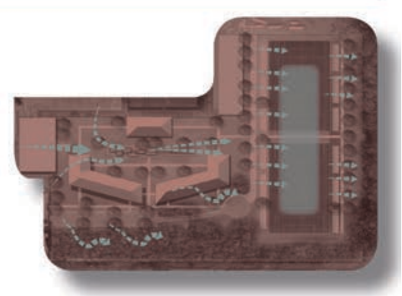
These numbers compare landscape development and stormwater management costs. They do not account for cost to construct buildings. Cost-benefit analysis does not include cost to construct parking garage, which ranges from $10,000 - $40,000 per parking space.

LID SITE PLAN

DEVELOPMENT SUMMARY:

Site Area	15.8 Acres (688,600 Sq Ft)
Buildings	3 Three-Story Dorm Facilities
Units	209 Student Dorm Units (Avg. 600 Sq Ft, 1.5 Cars Per Unit)
Parking Spaces	Required: 314 Supplied: 336
Amenity Area	2 Full Size, Sunken Soccer Fields
Detention	Sunken Soccer Fields to Provide Reduced Detention Requirements

LID WATER ANALYSIS



ROADWAY

APPLICABILITY

SITE REPORT

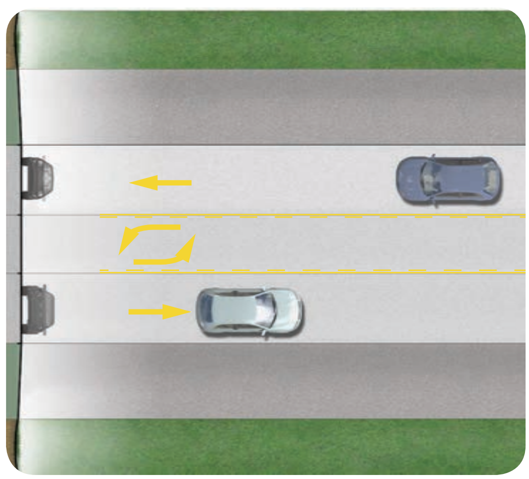
This planned roadway would extend 0.5 miles through a rural area, improving connectivity to a growing residential area. Along its route, it crosses a stream.

The hills of this region form a local watershed which generally drains to the stream crossing the site. This is planned as a future greenbelt and recreational amenity. Soils are more permeable than many areas of the region and could likely infiltrate runoff. There is little tree canopy, as much of the area was previously agricultural. The northern extent of the road utilizes an old roadway base and will be constructed as a retrofit, rather than a full reconstruction.

The roadway is planned with 80-foot ROW width to carry a moderate amount of traffic between single family homes and a farm to market road to the north.

CONVENTIONAL SITE PLAN

SITE PLANNING ASSUMPTIONS:



Road Profile	Road Surface:
10' SWALE	PERMEABLE
13' SHOULDER	IMPERVIOUS
12' TRAVEL LANE	IMPERVIOUS
10' TURN LANE	IMPERVIOUS
12' TRAVEL LANE	IMPERVIOUS
13' SHOULDER	IMPERVIOUS
10' SWALE	PERMEABLE

DEVELOPMENT SUMMARY:

Road Type:
35 MPH Connector Roadway Between Farm to Market Road and Expanding Single-Family Home Development

ROW: 80 Ft

Surface:
Permeable 25 %
Impervious 75 %

Length 0.5 Mi

CONVENTIONAL WATER ANALYSIS

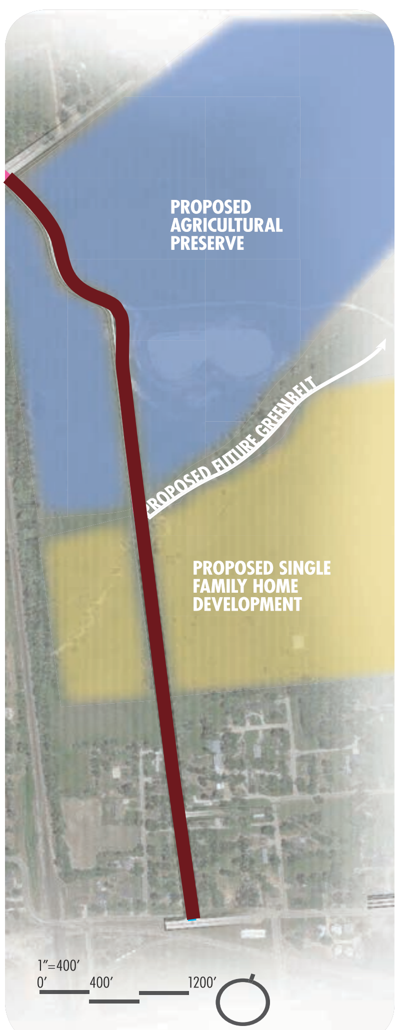
COST BENEFIT OF STORMWATER MANAGEMENT INFRASTRUCTURE

Life Cycle Cost ($, NPV)
Net Present Value

	Conventional	LID	Difference	%
Curbs & Gutters	$ 67,984	$ 67,984	$ 0	0 %
Street	$ 1,110,977	$ 555,488	$ 555,489	- 50 %
Conventional Stormwater Storage	$ 297,208	$ 297,208	$ 0	0 %
Bioswale	$ 157,514	$ 403,629	($ 248,115)	156 %
Trees	$ 0	$ 63,922	$ 63,922	
Total	$ 1,633,683	$ 1,388,231	$ 245,452	- 15 %

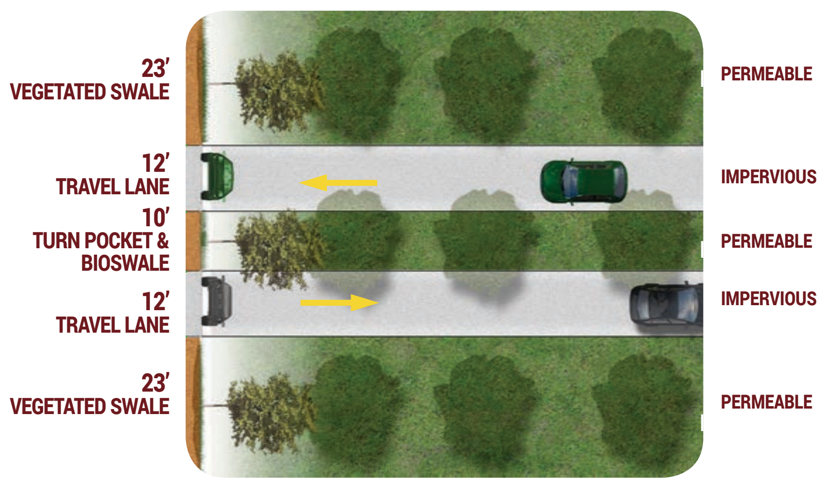
These numbers compare landscape development and stormwater management costs. They do not account for cost to construct buildings.

LID SITE PLAN



SITE PLANNING ASSUMPTIONS:

Road Profile **Road Surface:**



DEVELOPMENT SUMMARY:

Road Type:
35 MPH Connector Roadway Between Farm to Market Road and Expanding Single-Family Home Development

ROW: 80 Ft

Surface:
Permeable 63 %
Impervious 37 %

Length 0.5 Mi

LID WATER ANALYSIS

SWEETBAY MAGNOLIA

Sweetbay Magnolia is a small to medium sized tree that grows near water and is tolerant to periods of inundation. As a native plant, these trees can grow upright and develop a stable root system that provides stability and helps prevent erosion.

The most common LID tools that incorporate the Sweetbay Magnolia are rain gardens and constructed stormwater wetlands.

CASE STUDIES

LID IN ACTION

Public and private entities in the Houston-Galveston region are incorporating LID practices into different types of projects. Some developers are integrating these features into new developments, while others are retrofitting previously-developed properties to improve their functionality. Municipalities and other public agencies have built pilot projects to evaluate the effectiveness of LID practices at managing stormwater. The public and private sectors can learn from these completed projects when developing new sites or modifying regulations.

The following six case studies are existing, successful LID projects from around the Houston-Galveston region:

- **Queenston Manor Apartments**
  Bioswales, Rain Gardens, Permeable Paving, Underground Cisterns
- **Birnamwood Drive**
  Bioswales, Underground Storage Tanks
- **City of Houston: Fire Station 90**
  Cisterns, Permeable Paving, Rainwater Harvesting, Native Plantings
- **Ghirardi Family WaterSmart Park**
  Rain Garden, Bioswale, Permeable Paving, Green Roof, Rainwater Harvesting
- **Sugar Land Conference Center**
  Bioswale, Underground Cistern
- **Kempwood Manor Subdivision**
  Bioswales, Rain Gardens, Permeable Paving

Native Plantings & Bioswale, Birnamwood Drive

(Image: Harris County Public Infrastructure Department)

CASE STUDIES

(Image: EHRA)

QUEENSTON MANOR

UTILIZING LID FEATURES TO CREATE ADDITIONAL DEVELOPMENT OPPORTUNITIES

LOCATION	Houston, TX
LAND USE	Multi-Familly Residential
COST	$ 799,483 (LID Systems)
PRACTICES USED	Bioswales Rain Gardens Permeable Paving Underground Cisterns
CONSULTANT	EHRA

Conventional stormwater management practices may require a lot of space, reducing the amount of land available for development.

When the site plan for Queenston Manor was initially prepared, a detention pond was proposed to manage the site's runoff. This feature consumed a large area, making multi-family development financially infeasible. Redesigning the site with LID practices increased the amount of land available for buildings, allowing the developer to construct 48 additional units within the multi-family residential project. While the installation of LID systems did not result in cost savings, the 48 extra units generate an additional $642,812 in revenue each year.

Rain Garden, Queenston Manor

(Image: EHRA)

Different LID practices were distributed throughout the site.

RAIN GARDENS AND BIOSWALES

A system of rain gardens and bioswales are located between buildings. Native species are planted in engineered soils, creating a functional and attractive landscape for residents.

This system was designed to allow water to drain within 24 hours. The use of engineered soils and other strategies ensures water does not stand for long periods, preventing these features from becoming breeding areas for mosquitoes.

PERMEABLE PAVING

Parking spaces are surfaced with permeable pavers. Stormwater seeps directly though the pavers into the underground storage system.

UNDERGROUND CISTERNS

After flowing through permeable pavers, rain gardens, and bioswales, stormwater percolates through engineered soils into an underground system of rain tanks.

Permeable Pavers and Underground Storage Tank, Queenston Manor

(Image: EHRA)

(Image: H-GAC)

BIRNAMWOOD DRIVE

RETHINKING TRADITIONAL ROADWAY DESIGN TO INCORPORATE LID

LOCATION	Spring, TX
LAND USE	Roadway
COST	$ 3,500,000
PRACTICES USED	Bioswales Underground Storage Tanks
CONSULTANT	RPS Klotz Associates, Knudsen LP

Public and private entities are interested in using LID practices but may be unsure of their performance in certain applications.

The construction of Birnamwood Drive was a pilot project by Harris County to evaluate the viability of incorporating LID practices into the design of its major thoroughfares. To manage stormwater runoff, a system of LID features was installed in the roadway's median:

Building Birnamwood Drive with LID practices cost $3.5 million. If it had been built as a conventional four-lane divided roadway with curb and gutter connecting to a storm sewer, the project would have cost an estimated $3.8 million. Incorporating LID practices into the design eliminated the need to build an extensive storm sewer system and purchase additional property for a detention pond. As Harris County continues to experiment with these practices and determine which are the most effective at managing stormwater, the cost of LID features used in subsequent projects may decrease.

The bioswale and other features were designed to minimize maintenance, decreasing the roadway's upkeep costs. Once established, the site's native plants do not need to be regularly watered. A temporary sprinkler system was installed when the bioswale was first planted, but has since been removed. While most roadways in Harris County are mowed quarterly, Birnamwood Drive only needs to be mowed twice a year. Rain tanks require less maintenance than detention ponds, since the biofiltration system helps prevent them from being clogged with trash, sediment, and other debris. Over time, lower construction and maintenance costs will deliver significant savings to taxpayers.

Monitoring stations are installed within the bioswale to help researchers determine how effectively LID features can manage stormwater and improve water quality.

Since completion of Birnamwood Drive, Harris County has incorporated LID practices into the design of several roadway construction projects, including Slojander Road near Baytown and Holzworth Road in Spring.

LID BMPs used in this project are:

BIOSWALES

Native species are planted in gently-sloping vegetated swales. Diverse plantings are installed along different segments of the roadway, depending upon hydrologic conditions. **Check dams** within the bioswale reduce the velocity of stormwater flowing through the system and increase the amount of runoff that can be stored.

Bioswale and Underground Storage Construction, Birnamwood Drive

(Image: Harris County Public Infrastructure Department)

UNDERGROUND STORAGE TANKS

Bioswales connect to modular rain tanks buried beneath gravel and engineered soils able to increase filtration to 100 inches per hour. Stormwater is held within the rain tanks and slowly released at two outfall locations.

These features are able to accommodate all runoff flowing from the roadway, making off-site detention unnecessary.

(Image: Asakura Robinson)

CITY OF HOUSTON: FIRE STATION 90

USING LID PRACTICES TO REDUCE WATER USE

LOCATION	Houston, TX
LAND USE	Institutional
COST	$ 5,400,000 (Total Cost)
PRACTICES USED	Permeable Paving Rainwater Harvesting Native Plantings
CONSULTANT	Asakura Robinson, English Associates

Irrigating urban landscapes requires a significant amount of water.

In Texas, an estimated 46.6 percent of water consumed in urban areas is used to irrigate lawns and other landscapes.[xiv] To reduce the expense and environmental impacts of excessive irrigation, the City of Houston used a variety of LID practices and other techniques to minimize outdoor water use at Fire Station 90:

NATIVE PLANTINGS

Large expanses of native, drought-tolerant plants surround the building.

Native Plantings, Fire Station 90

(Image: Asakura Robinson)

RAINWATER HARVESTING

Six 1,000-gallon cisterns collect rainwater that runs off the building's roof. This water is used in a low-flow drip irrigation system.

PERMEABLE PAVEMENT

To manage stormwater on-site, parking stalls are surfaced with permeable concrete. Pores allow water to seep through the pavement into the underlying soil instead of ponding and running into nearby storm sewers.

These features have reduced the amount of potable water used for irrigation by more than 80 percent.

A vegetated detention area stores stormwater, with a mix of trees and shrubs removing pollutants. These water conservation and stormwater management techniques helped the building earn LEED Gold Certification from the U.S. Green Building Council, which recognizes projects that incorporate environmentally-friendly materials and practices into their design.

Rainwater Harvesting Cisterns and Rain Garden with Native Plantings, Fire Station 90

(Image: Asakura Robinson)

(Image: H-GAC)

GHIRARDI FAMILY WATERSMART PARK

UTILIZING PUBLIC SPACES TO MEASURE THE EFFECTIVENESS OF LID PRACTICES

LOCATION	League City, TX
LAND USE	Park
COST	$1,010,000 (Total Project Cost) $90,109 (Installation of LID Features)
PRACTICES USED	Rain Garden Bioswale Permeable Paving Green Roof Rainwater Harvesting
CONSULTANT	TBG

Communities nationwide, including some in the Houston-Galveston region, are experimenting with the use of LID practices on public property.

In 2011, the City of League City began developing the Ghirardi Family WaterSmart Park as a demonstration site for LID. This park is designed to show developers, residents, and local officials how these features function and can be incorporated into landscapes.

Not only was the park designed to manage stormwater in an environmentally-friendly way, but it also minimizes the use of potable water for landscape purposes. Water collected in the site's cistern is used for irrigation. Native plants were installed throughout the park. Since they are well-suited to the region's climate, natives generally require less water than other species once established.

To ensure their long-term effectiveness, LID BMPs must be properly maintained. The park's maintenance crew received training on appropriate management techniques, along with a maintenance handbook.

Since the park's completion in early 2014, the Texas Coastal Watershed Program has been studying how these features impact local water quality. Data collected has demonstrated the ability of LID practices to capture pollutants. All of these features have been effective at removing harmful bacteria, such as *E. coli,* from runoff. The site's bioswales have the most positive overall impact on water quality, removing significant amounts of nitrogen (97.4%), phosphorus (79.1%), and suspended solids (92.1%). Continued monitoring will help determine the long-term effectiveness of these practices. [xv]

Different LID techniques were used throughout the site:

RAIN GARDENS AND BIOSWALES

Curb cuts allow water to flow from parking areas into rain gardens planted with native species. Engineered soils promote infiltration.

Some of the site's runoff is directed to vegetated swales which serve as an attractive landscape feature.

PERMEABLE PAVEMENT

Parking areas are surfaced with concrete pavers. Joints between these pavers allow water to infiltrate into the soil.

GREEN ROOF

The park's pavilion features a green roof, with plantings contained in a system of removable trays.

RAINWATER HARVESTING

Cisterns collect rainwater that runs off the roof of the park's pavilion.

Signage highlights these features and provides information on how they function.

Native Plantings, Ghirardi WaterSmart Park

(Image: H-GAC)

Actual Installation Costs for Select LID Techniques at Ghirardi Family WaterSmart Park [xvi]

Technique	Cost per Square Foot *
Rain Garden	$ 5.90
Bioswale	$ 1.72
Pervious Pavers	$ 9.78
Vegetated Buffers	$ 2.26
Green Roof	$ 51.42

* Excluding Grading & Installation

(Image: H-GAC)

SUGAR LAND CONFERENCE CENTER

RETROFITTING AN EXISTING PARKING LOT TO INCORPORATE LID PRACTICES

LOCATION	Sugar Land, TX
LAND USE	Commercial
COST	$ 80,000
PRACTICES USED	Bioswale Cistern (Underground)
CONSULTANT	Steve Albert, PE for Aguirre & Fields, LP

Not only can LID practices be incorporated into new development, but reconstruction projects as well. The Sugar Land Conference Center had an expansive concrete parking lot, which carried runoff quickly to the nearest storm drain. Since the concrete surface did not allow infiltration, puddles would form in some locations and last for days. The lack of landscaping left a poor impression on visitors.

To improve the site's appearance and functionality, a network of bioswales was installed throughout the existing parking area. Runoff from the building's downspouts is directed into bioswales, and curb

Bioswale

(Image: H-GAC)

Parking Lot Bioswales

(Image: H-GAC)

openings allow stormwater from adjacent parking spaces to enter these landscaped areas. Bioswales carry the site's runoff approximately 400 feet to an area with engineered soil media which allows stormwater to seep into an underground cistern. Up to 3,500 gallons of water are stored in the cistern, providing about half of the site's annual irrigation needs.

Plants within the bioswales filter runoff, improving water quality. Native Texas plantings remove 90 percent of sediment carried by the site's runoff, along with most heavy metals and other harmful pollutants. As the plants' roots soak in water, they also reduce the amount of runoff reaching the storm sewer. Since the project was completed in 2012, the plantings have matured and created an attractive environment for workers and visitors.

Stormwater Runoff Reductions
LID Retrofit at Sugar Land Conference Center [xvii]

Design Storm: 2-year, 15 minutes	
Peak Flow Rate Reduction	97 %
Total Runoff Reduction	17 %
Extreme Short Storm: 100-year, 15 minutes	
Peak Flow Rate Reduction	90 %
Total Runoff Reduction	16 %
Long Duration Pond Storm: 2-year, 24 hours	
Peak Flow Rate Reduction	53 %
Total Runoff Reduction	13 %
Extreme Pond Design Storm: 100-year, 24 hours	
Peak Flow Rate Reduction	27 %
Total Runoff Reduction	7 %

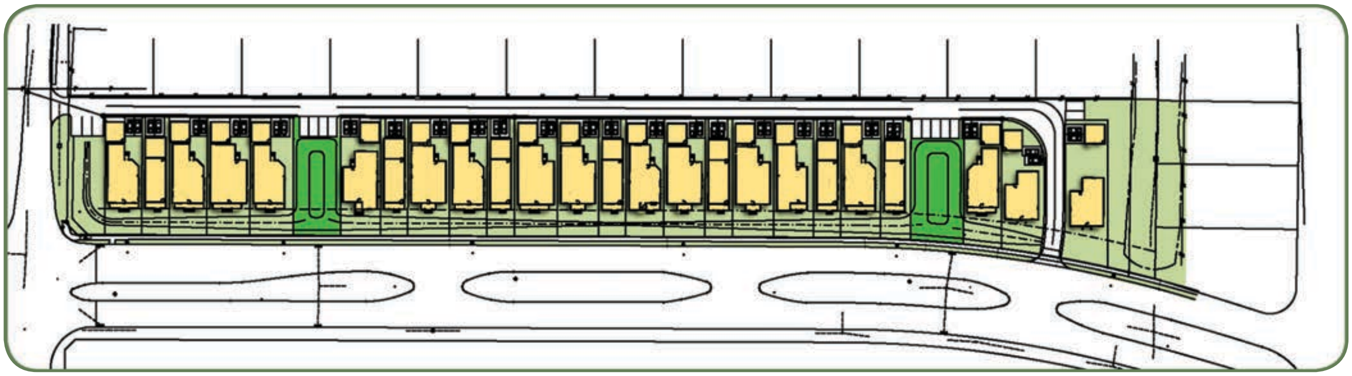
(Image: EHRA)

KEMPWOOD MANOR

INCORPORATING LID PRACTICES INTO A DENSE SINGLE-FAMILY INFILL DEVELOPMENT

LOCATION	Houston, TX
LAND USE	Single-Family Residential
COST	$104,107 (LID only)
PRACTICES USED	Bioswales
	Rain Gardens
	Permeable Paving
CONSULTANT	EHRA

On infill sites, space is often limited, making it difficult to accommodate conventional stormwater management practices. Kempwood Manor is on a narrow 3.2-acre site in Northwest Houston, bound by a major thoroughfare and existing residential development. The original plan for the project included 21 individual lots and a large detention basin. By revising the design and incorporating LID practices, the developer was able to create three additional lots.



Site Plan

EHRA

Rain Garden following rain event

(Image: H-GAC)

Permeable Paving

(Image: H-GAC)

This project was one of the first residential developments that adhered to Harris County's *LID and Green Infrastructure Design Criteria for Stormwater Managemen*t. Adopted in 2011, this document establishes guidelines for developers using LID practices to satisfy local requirements for stormwater management.

The final design, which was ultimately constructed, features several LID techniques:

RAIN GARDENS AND BIOSWALES

Rain gardens in two pocket parks create a landscaped amenity for residents.

PERMEABLE PAVING

While all of the homes face Kempwood Drive, their garages are accessed by a rear alley. The alley and visitor parking areas are surfaced with permeable pavers with joints allowing stormwater to seep into the ground.

APPENDICES

DEFINITIONS

BIOFILTRATION
Biofiltration is a technique that removes pollutants from water using living material to capture and biologically degrade pollutants.

CHECK DAM
Typically constructed of gravel, sandbags or straw bales, a check dam is a small, temporary structure constructed across a swale designed to slow the velocity of runoff flows. Check dams are used to control for soil erosion.

DEPRESSION STORAGE
Depression storage refers to small low points in rolling terrain that store stormwater that would otherwise become runoff.

DETENTION
A detention facility is designed to receive, temporarily store, and completely release stormwater slowly into a receiving channel.

ENGINEERED SOIL MEDIA
Engineered soil media is a manmade mix of soils.

EVAPORATION
Evaporation is the process of water changing from a liquid to a gas or vapor.

HEAT ISLAND EFFECT
The heat island effect is an urban area in which significantly more heat is absorbed and retained than in surrounding areas, resulting in a "warm island" among a cooler "sea" of lower temperatures.

INFILTRATION
Infiltration is the seepage of water into the ground.

RETENTION
A retention facility is designed to retain stormwater on a more permanent basis.

STORMWATER MANAGEMENT
Stormwater management refers to all natural or engineered control devices and systems designed to control and/ or treat stormwater.

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