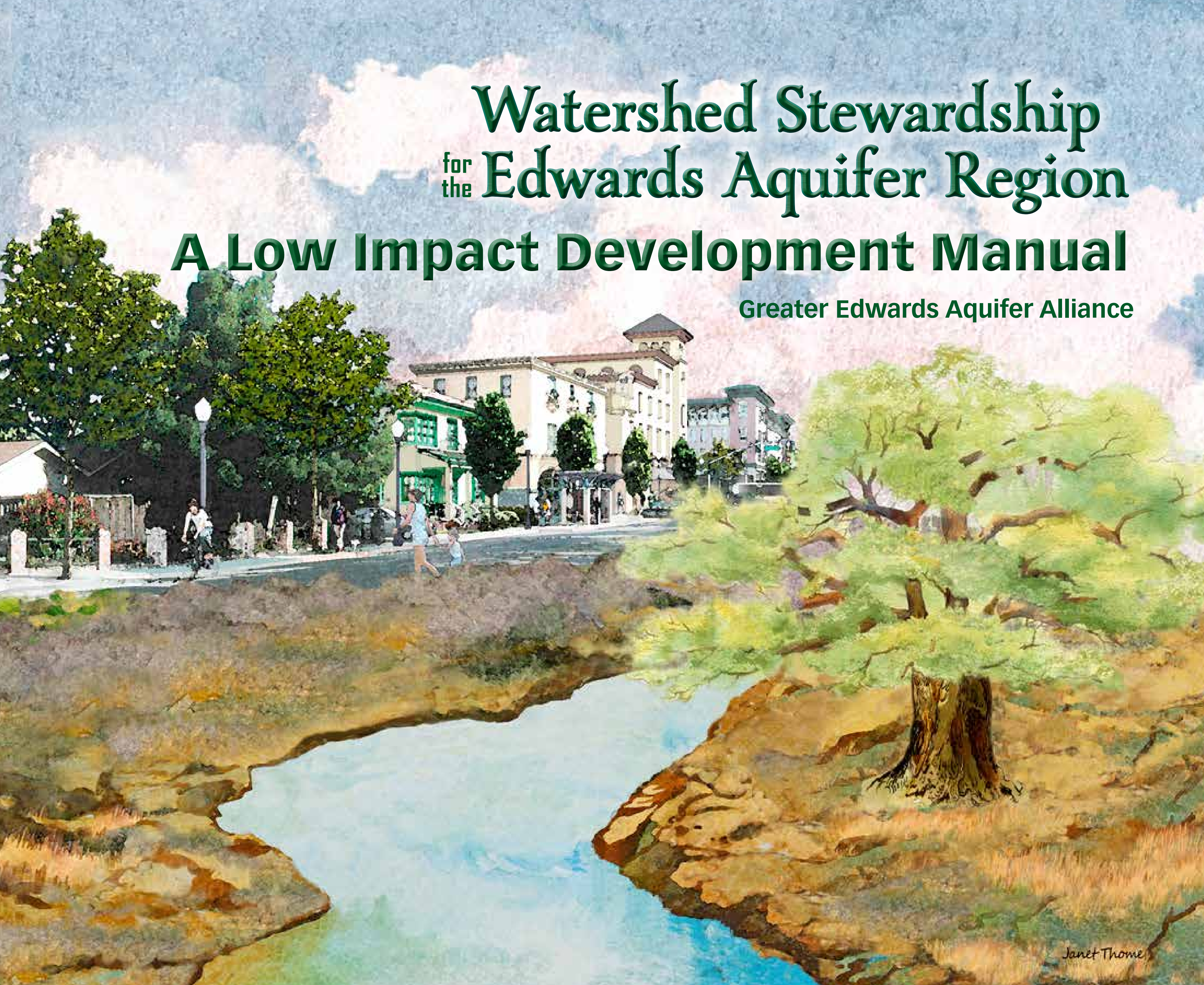
Watershed Stewardship for the Edwards Aquifer Region

A Low Impact Development Manual

Greater Edwards Aquifer Alliance



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Greater Edwards Aquifer Alliance

June 2014

This handbook is dedicated to the memory of the late George P. Mitchell, founding benefactor of the Greater Edwards Aquifer Alliance.

Mr. Mitchell's life was filled with monumental accomplishments, among them the creation of The Woodlands, north of downtown Houston, in 1974. This master-planned new town redefined the American city and is still recognized as a model for America's most livable communities. Based on the concept of designing with nature, The Woodlands became the inspiration for the Low Impact Development movement here in the United States. Dedication to applying these methods to the Edwards Aquifer region to mitigate pollution of this marvelous resource was the basis for creating this handbook.

"Given the rapid growth in the Austin/San Antonio corridor, I believe a strong case can be made for a major conservation commitment," said George P. Mitchell in 2004. "I'm also familiar with the way karst limestone aquifers like the Edwards are uniquely vulnerable to pollution and excessive pumping from urban development."

We are deeply grateful to Mr. Mitchell for the foresight that inspired all of us associated with the Greater Edwards Aquifer Alliance, and for his generous and enduring support of projects such as this one.

Annalisa Peace, Executive Director
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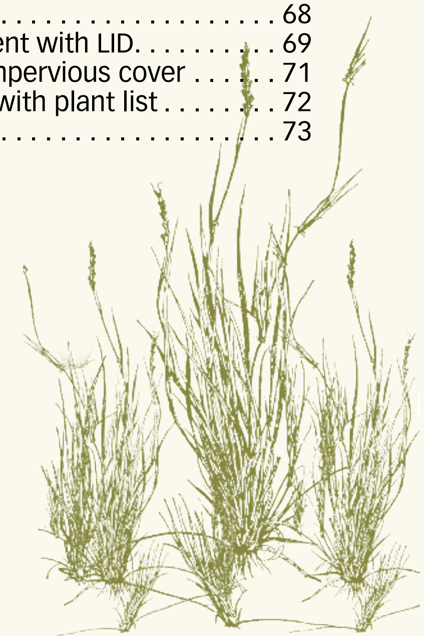


Foreword

Historically, the Edwards-Balcones system of freshwater springs, creeks, rivers, recharge features and groundwater storage has adequately supported the economies and cultures of Central Texas. It has only been in the last 60 years that land use patterns have changed in ways that threaten the Edwards Aquifer system's natural integrity and its capacity to sustainably support us.

For most of our history, we walked lightly on the Edwards Aquifer, using only the water that naturally flowed along the surface or emerged from springs. The intermittent flow that characterizes the Hill Country made it far too harsh a place for large populations. Settlements were dispersed and limited to where the water was easily accessible. Only a few unique, perennial springs could sustain a permanent population. The first Edwards wells, drilled in the late 1800's, mostly functioned by artesian flow. Pumping from wells drilled into the Edwards became common by the 1920's. By the 1950's the introduction and widespread use of powerful pumps and deep well drilling enabled Central Texans to reach into the aquifer and access significantly more water. No longer dependent on artesian flow, settlement was not restricted to proximity to perennial springs and the Edwards Artesian Zone, allowing widespread settlement over the recharge areas along the Balcones Fault Zone.

The values and laws that brought us here and facilitated expansion (property rights, strong individualism, and rule of capture) perpetuate trends and practices such as growth over the aquifer's Recharge and Contributing zones, deep well pumping, impervious surfaces that accumulate pollutants and release them in stormwater during heavy rainfall, and sewage management systems that pipe effluent through the aquifer's permeable subsurface. As a result, we face a suite of demands, impacts, and risks that the natural system was never designed to handle. Furthermore, evidence suggests that the legal, regulatory, and planning framework intended to protect and distribute Edwards water needs to be strengthened and modified to effectively manage today's risks.

The need to explore new techniques for aquifer management is punctuated by several noteworthy developments. Chief among these is the rapid growth of population within a region subject to cyclical droughts and the need to maintain springflows to protect endangered species at the springs and coastal bays and estuaries. There are numerous indications that current patterns of development are not sustainable when further applied to undeveloped land within the Edwards ecosystem. Contaminant levels associated with human activity have been detected at levels exceeding natural background in wells, springs, and sediments in creeks that recharge the aquifer. We must determine how best to accommodate increases in population without compromising the integrity of the natural system that has served us so well.

Stormwater regulation is a good example of a standard practice whose reform offers tremendous benefits for our region. Current regulations do little to restrict growth over the Recharge and Contributing zones. State mandated aquifer safeguards treat stormwater as a pollutant and consist of plugging susceptible recharge features. Because this practice erodes the aquifer's natural recharge mechanism at a time when water demand is on the rise, it makes sense to explore management practices that transform stormwater from a pollutant to a precious resource that can safely be recharged and stored.

This manual provides a practical set of tools known as low impact development (LID) specifically adapted to the Edwards region to offer options for growth and ultimately, sustainability. These new tools work with the unique features of the Edwards

Aquifer system that has sustained us to this point, recognizing that it is a system in which water travels directly from the surface into the aquifer without filtration. In fact, studies show recharge is not just limited to individually mapped recharge features. The natural system facilitates infiltration throughout the entire surface of the Recharge Zone. This means that every site is an important component of the aquifer's recharge system and should be developed with innovative LID practices that promote filtration and clean infiltration.

For this reason, this manual targets developers and planners to help lead the way in implementing development stewardship practices based on the science of maintaining aquifer integrity at each developed site. This role for developers and planners is not unique. For the past twenty years, public and private interests across the country have mimicked natural systems using LID. These practices have been slow to take hold in the Hill Country, in part because much LID technology is not designed to meet our need for water supply enhancement. Traditional LID promotes evapotranspiration, plant uptake, and green roofs to discourage infiltration—all of which fall short in augmenting water supply. This manual offers alternative approaches that facilitate recharge while achieving the water treatment benefits of traditional LID.

Recognizing that the process of transforming site management is incremental, this manual presents itself as a blueprint for innovative demonstration projects designed to investigate a variety of important questions including:

1. What are the water management best practices that optimize recharge and water quality for development areas?
2. Can we maximize recharge across the Edwards Aquifer region by applying principles of low impact development and managing for targeted plant regimes?
3. Can the natural system assimilate dispersed pollutant loads with the help of low impact development and targeted plant regimes?

While we recognize that the surest way to maintain the function of the Edwards is to permanently protect land and limit impervious cover within the Recharge and Contributing zones, we also recognize that culture, politics and the price of land conspire to thwart this goal as surely as they discourage adequate regulation of land use. We recognize that the techniques recommended in this manual do not address all of the issues that come with increased density throughout the aquifer region. For example, as innovative LID is implemented, we will need to be mindful of the impact of sewage management systems that pose a significant risk due to point-source contamination. Ultimately, the management of both surface and subsurface, point and non-point source pollution will determine the quality of the water supplies that we bequeath to future generations.

Annalisa Peace, January, 2014

Purpose

This manual is intended to fill a gap in the stormwater management measures that currently protect the Edwards Aquifer in Central Texas. This groundwater system provides drinking water for close to two million people, as well as sourcewater for many of the region's rivers and streams. The aquifer is home to prolific artesian springs as well as dozens of endangered and threatened species. A truly unique and remarkable resource, the aquifer provides drinking-quality water directly from its springs, which are among the most prolific in the U.S.

Management of groundwater for the aquifer is increasingly a topic of discussion throughout the Central Texas region, with the current historic drought lending urgency to the conversation. Low rainfall, permeable geology, and high population growth, along with nonpoint source pollution, high recreation impacts, and aging waste water infrastructure form a suite of risk factors that have triggered a mix of special laws, regulations and programs designed to address the region's unique challenges.

Foremost among regional groundwater managers is the Edwards Aquifer Authority (EAA), the regional authority charged with regulating pumping to ensure that spring flows remain adequate to protect water flows as well as endangered species. The EAA exercises limited regulatory authority, however, so in order to address water management in times of extreme drought, a new initiative has been created through collaboration of the region's largest water users. This initiative, known as the Edwards Aquifer Recovery and Implementation Program (EARIP), joins the cities of San Antonio, San Marcos, New Braunfels and other entities in a Habitat Conservation Plan (HCP) that promotes greater assurances that pumping in a severe drought will not harm endangered species (EARIP, 2011).

EARIP tools include stronger, more comprehensive pumping triggers and mitigation measures that keep springs flowing and protect water quality. While the management program set forth by the EARIP HCP is a significant step forward in establishing a consensus commitment to mitigating existing threats to aquifer sustainability, strengthened water quality measures are needed in the region to support and complement the EARIP mitigation.

This manual supports the EARIP initiative by proposing best practices for stormwater management, based on techniques of green infrastructure that have been specifically adapted to the karst hydrogeology of this region. In its broadest form, green infrastructure usually involves interagency watershed-level planning for land use as a basis for conservation. This manual is primarily designed for implementation by a local agency or development entity,

> *"There is a growing consensus that strategies based on preserving pre-development hydrology and maintaining critical vegetated areas can minimize groundwater pollution and flooding in karst regions. Green infrastructure techniques may finally provide the answer to the long-standing question of how to best manage stormwater in geologically-sensitive regions."*
>
> (Hewes, American Rivers).

for example, as a basis for development guidelines. An underlying objective to all the recommendations is reduction of impervious cover. Replacement of natural land cover with paved surfaces or rooftops reduces the volume of water available for aquifer recharge and is a significant contributor to flooding, water quality degradation, ecosystem damage, and urban heat island effect.

An approach that has received more attention recently is the use of LID. LID has been widely developed and implemented nationwide as a stormwater Best Management Practice (BMP) that relies on dispersed, onsite water management to reduce peak flows and improve water quality. Since the EARIP initiative acknowledges water quality management as a critical need for the Edwards region, the use of LID is examined more closely here with respect to the exceptional challenges of the Edwards Aquifer region. The LID section of this manual supplements the work done regionally in Central Texas, including *Complying with the Edwards Rules: Technical Guidance on Best Management Practices* (Barrett, 2005) the *San Marcos Green Infrastructure-LID Practices* booklet (Couch, 2011) and the *San Antonio River Authority Low Impact Development Technical Guidance Manual* (SARA, 2013). Links to these manuals can be found in the references or the useful links appendix.

While much stormwater management focuses on flood control, the emphasis of this manual is managing for water quality while promoting aquifer recharge. Around 75% of aquifer recharge infiltrates into the limestone through streambeds, so protecting streamflow by ensuring treated runoff reaches local streams is an important key to aquifer recharge. Incorporating new landscaped BMPs into new and redeveloped areas throughout the region can optimize the effectiveness of programs like the EARIP HCP and potentially transform the way our towns and suburbs grow. Rather than managing stormwater as a burden, we can treat scarce water as a valued resource, both for the ecology of the region and for the design of our developed places.

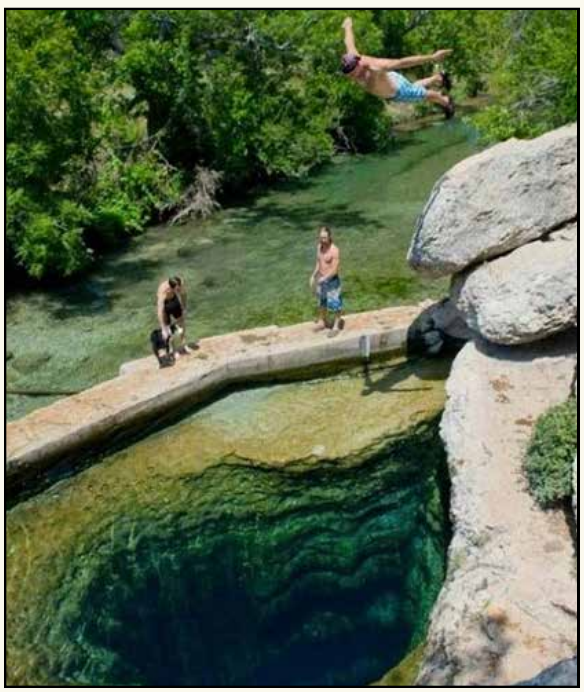
HOW DOES LID DIFFER FROM CONVENTIONAL STORMWATER MANAGEMENT?

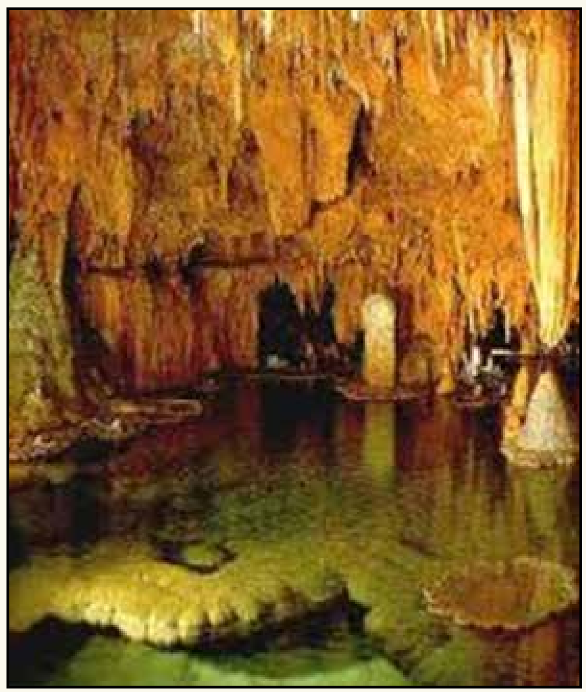
LID systems are designed to work with the natural hydrologic patterns that exist before a site is developed. Low impact designs utilize small scale networked landscape features that treat runoff on site, as opposed to conventional systems that rely on drains and culverts to rapidly convey stormwater off site. Treated runoff water can gradually infiltrate to groundwater or make its way to surface streams, where the majority of drinking water recharges.

Organization

The manual is organized into four chapters and appendices to simplify its use by a range of users, including decision makers, elected officials, planners, engineers, developers, and citizens. Chapter One is a basic overview of the Edwards Aquifer, including the ecoregional context and the special considerations for karst hydrogeology. Chapter Two describes the current regulatory picture, where multiple agencies manage the water resource for varying and often competing objectives. This chapter also discusses watershed-level protection strategies for the karst recharge area to conserve species habitat. Chapter Three presents approaches to landscape and site analysis and vegetation management to support water quality objectives while contributing to aquifer groundwater recharge.

Chapter Four, the Toolbox, illustrates and describes LID technologies together with the water quality needs met by their application. This section includes a case study that applies LID methodology to a site development scenario. The appendices provide a list of local organizations and material sources, definitions of terms used throughout the document, a plant list developed specifically for the karst landscape and tables that provide detailed background for the document text.





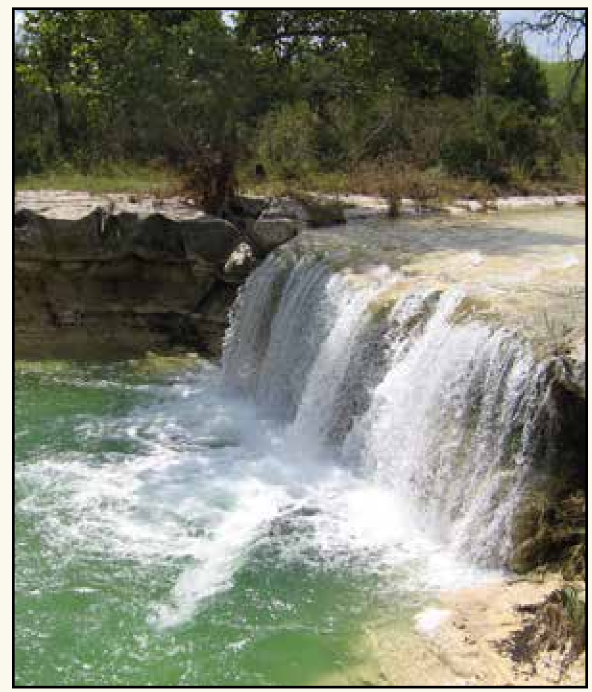


Photo by Marita Roos

A Precious Resource for Central Texas 1

Texas possesses one of the most pure and abundant natural sources of water to be found anywhere in the world—the Edwards Aquifer. The Edwards Aquifer is an unusually prolific groundwater resource, extending over 180 miles along the southern and eastern edge of the Edwards Plateau, from Brackettville in Kinney County to Austin in Travis County (Figure 1). The aquifer is the primary source of drinking water for more than 2 million people in south central Texas—water that, because of its purity, receives virtually no treatment other than chlorination and fluoridation in some areas. Wells drilled into the aquifer provide crop irrigation and industrial use that generates hundreds of millions of dollars in economic activity.

What does it mean to have a sole-source aquifer? The term "sole source" recognizes the unique, essential and irreplaceable role that the Edwards Aquifer occupies in the region. The San Antonio Segment of the Edwards Aquifer is enormous, with a 5,400 square mile watershed (most of which lies over the Contributing Zone)

> *"As I've seen in other mapping projects, developers, planners, and the public treat areas mapped as 'less vulnerable' as 'not vulnerable.' All karst is highly vulnerable, even if no karst features are apparent. All such mapping does is split hairs between different levels of high vulnerability.*
>
> (George Veni, personal communication, 2011)

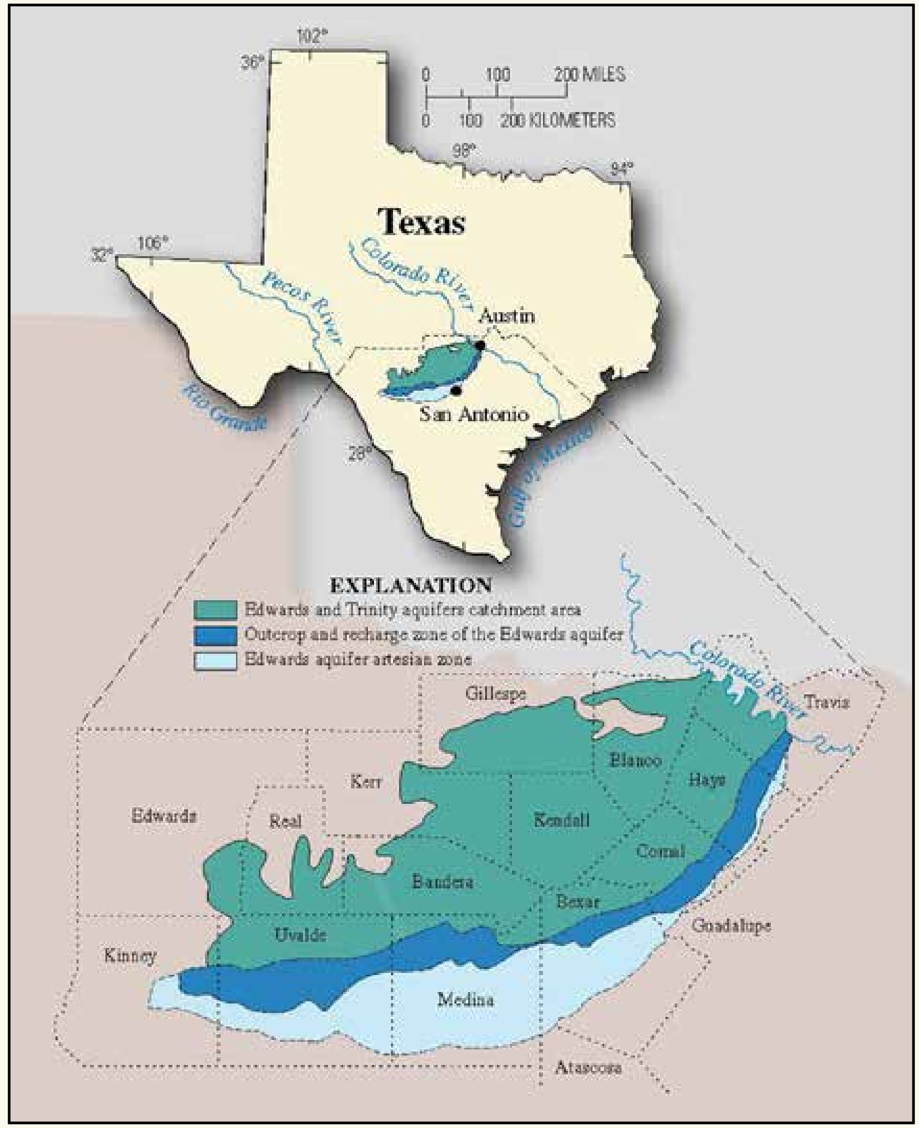


Figure 1. Distribution of the Edwards-Trinity Aquifer and catchment area (USGS, 2007).

and a 1,250 square mile area in the Recharge Zone. The Recharge Zone is particularly vulnerable to pollution since the porous limestone can transmit surface water, including stormwater runoff, directly to the underlying aquifer.

The Edwards Aquifer's Barton Springs Segment lies northeast of the San Antonio Segment (Figure 2) and supplies water for Austin's famous swimming pool in Zilker Park. This segment is much smaller, with a surface area of 247 square miles, located in Hays, Caldwell and Travis counties. A number of factors, including lower resident times, shorter flow paths, and higher density of monitoring sites because of the smaller size of the segment may cause contaminants to register sooner than they would in the San Antonio segment of the Edwards. In one well-reported instance, City of Austin sampling data documented environmental contamination, leading to the closure of the Barton Springs swimming pool for three months in 2002-2003 (TCEQ, 2003).

Due to its status as a primary drinking water source and the growing urbanization of the region (Texas Groundwater Protection Committee, 2003), the Texas Commission on Environmental Quality (TCEQ) has named the Edwards Aquifer the major aquifer in the state most vulnerable to pollution. Potential point sources of pollution include sewage leaks and industrial contaminants, and non-point sources such as agricultural and stormwater runoff from roadways and parking lots. TCEQ is the main regulatory agency charged with protecting the aquifer, but the large and diverse area, variable types of land uses and growing urbanization present a huge challenge for the agency (regulatory issues are covered later in this section). This combination of size and fragility adds particular significance to efforts to protect the Edwards Aquifer.

The aquifer is also the source of the remaining major springs in Texas—the best known being Barton, San Marcos, and Comal springs. The Comal and San Marcos springs are a source of water for the Guadalupe River. The aquifer region also is home to more than fifty unique animal species, many of which are key water quality indicators. More than ten of these are federally listed endangered species. Most of these endangered species inhabit caves and springs throughout the region, where they are highly vulnerable to both land disturbance and groundwater contamination. The habitat of these species is protected only to the extent that the surrounding terrestrial and aquatic ecosystems are protected.

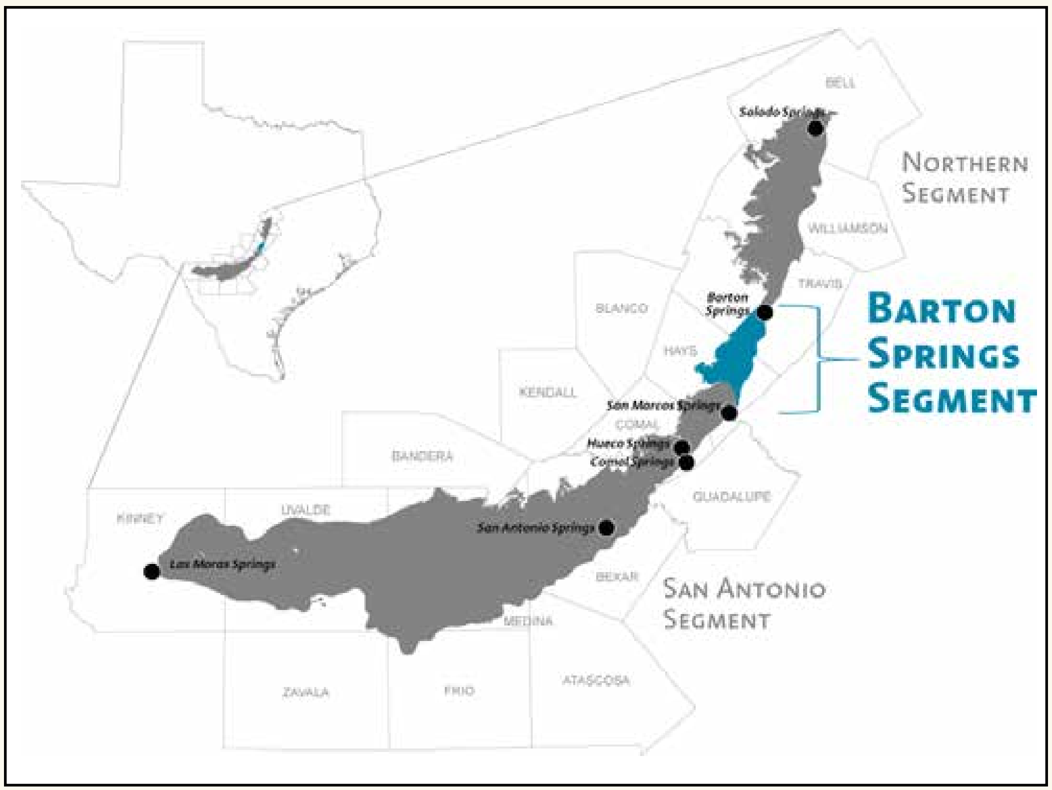


Figure 2. Location of the Barton Springs Segment of the Edwards Aquifer (Barton Springs/Edwards Aquifer Conservation District).

The connectivity of the whole Edwards Aquifer system means that a water pollution event occurring in one of the western counties, such as Uvalde or Medina, may eventually appear in a spring or well further east. The speed at which the water moves within the aquifer may vary, but land surface activities and groundwater quality are inextricably linked.

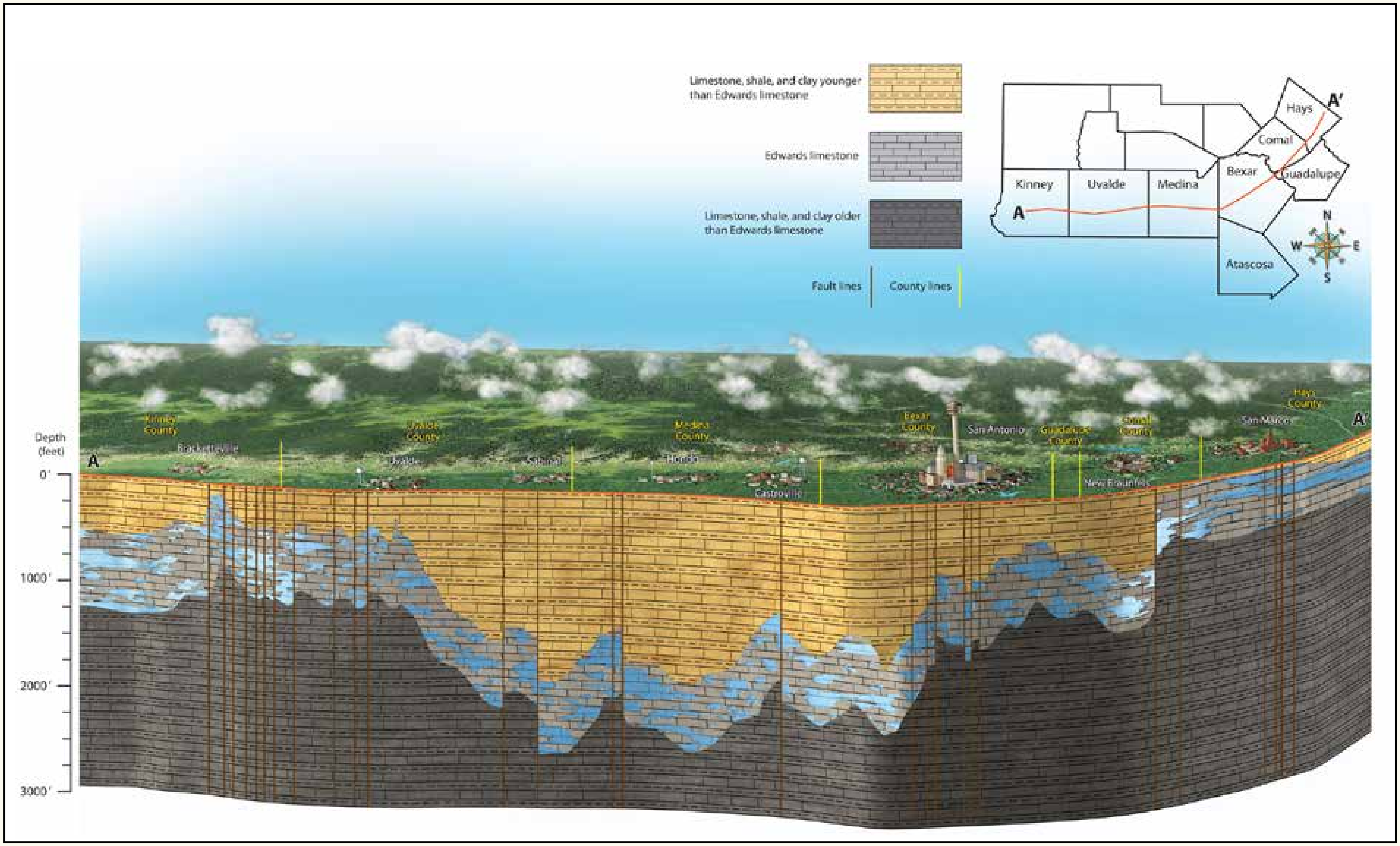


Figure 3. Edwards Aquifer Authority cross-section graphic (EAA, 2013).

Ecoregional Context

Geology and Groundwater

Figure 4. Seco Creek Sinkhole in Medina County. Recharge water flows from Seco Creek through channel cut in rock. (Photo by Geary Schindel, June 2000).

The Edwards Aquifer is located along the southern and eastern boundaries of the Edwards Plateau, a physiographic and ecological region that defines much of the distinctive landscape character of Central Texas. The land and underlying aquifer geology is generally divided into three major aquifer zones: the Contributing Zone, Recharge Zone, and Artesian Zone.

The Contributing Zone is a hilly upland area that extends across the south-central part of the Edwards Plateau. It covers some 5,647 square miles in all or parts of Bandera, Bexar, Blanco, Comal, Gillespie, Hays, Kendall, Kerr, Kinney, Medina, Real, Travis, and Uvalde counties. Numerous streams flow across the Contributing Zone, gathering springflows and runoff from rainfall and carrying it south and east onto the Recharge Zone. Most of the water in the Edwards Aquifer originates in the Contributing Zone.

The Recharge Zone is where the Edwards Limestone is exposed at the surface and water can enter the aquifer. About 75% of the water that recharges the aquifer comes from Contributing Zone streams; the remaining recharge occurs from rainfall directly on the Recharge Zone. The Recharge Zone is the most sensitive section of the aquifer. Surface water and any contaminants it carries are rapidly transmitted directly into the aquifer through streambeds, faults, fissures, sinkholes, and caves with effectively no filtration (EARIP 2012). Protecting the land on the Contributing Zone and especially the Recharge Zone, and limiting the amount of impervious cover in those areas, is essential to ensuring the quality and quantity of aquifer water for the future.

The relationship between surface water in the Contributing Zone and groundwater in the Recharge Zone is further complicated by the fact that part of the Contributing Zone for the Edwards Aquifer overlaps the Recharge Zone for the Trinity Aquifer, which is located northwest of the Edwards. In several areas, the two aquifers are connected and groundwater is transferred between the two, with the Trinity contributing water to the Edwards. The Trinity Aquifer supplies groundwater to much of the Texas Hill Country, including parts of Bexar, Bandera, Comal, Hays, Kendall, and Kerr counties.

The Edwards Aquifer's groundwater is held within the 450-foot thick layer of Edwards Limestone. This rock is broken by faults, where the rock to the south and east has generally dropped down relative to the rock on the north and west sides of the faults. The amount of drop ranges up to several hundred feet, and eventually the Edwards Limestone is buried underground. Groundwater in the aquifer is confined in that zone between impermeable rocks that lay above and below the Edwards Limestone. This is the Artesian Zone. The weight of water entering the aquifer from the Recharge Zone creates pressure on the water deeper in the aquifer, sufficient to force the water to the surface along faults or through drilled wells, creating flowing artesian springs and wells. "Artesian" refers to the water being under pressure. As shown in the accompanying map, this zone is where the aquifer's highest capacity wells and largest springs exist (Figure 7). The springs provide the basis of existence for many life forms, including humans, but also serve as early detection of water quality and quantity problems in aquifer systems.

The springs along which San Antonio was founded—San Pedro Springs and San Antonio Springs—have minimal flow today. Pumping of the aquifer has lowered groundwater levels below the elevations of these springs so they seldom flow. Water in the San Antonio River that was historically fed by these springs is now mostly supplied by reuse water from San Antonio Water System (SAWS) supporting flow through downtown San Antonio for tourism and recreational purposes. Several other springs still contribute to their respective rivers: Leona Springs (Leona River), Hueco Springs (Guadalupe River), Comal Springs (Comal River), and San Marcos Springs (San Marcos River). Comal Springs at New Braunfels and San Marcos Springs at San Marcos are by far the largest and most productive springs. The clear, consistent flows issuing

Figure 5. Cavers rappelling into Seco Creek sinkhole during normal dry conditions (Photo by Mike Harris).

from these two springs provide the water source for endangered species habitat and for the healthy flow of the Comal, Guadalupe and San Marcos Rivers.

The focused recharge, porosity of the rock layers, transmission between aquifer formations and water quality conditions make the Edwards one of the most productive groundwater reservoirs in the country and one of the most biologically diverse karst aquifers in the world. A high diversity of species are found within the aquifer and associated springs and karst formations, including blind catfish, salamanders, aquatic crustaceans, and terrestrial cave invertebrates (EARIP, 2011). The species endemic to the aquifer and its spring flows, which are protected under the Federal Endangered Species Act (ESA), include the Fountain Darter (*Etheostoma fonticola*), Texas Blind Salamander (*Eurycea rathbuni*), San Marcos Gambusia (*Gambusia georgei*), Texas Wild Rice (*Zizania texana*), Comal Springs Riffle Beetle (*Heterelmis comalensis*), Comal Springs Dryopid Beetle (*Stygoparnus comalensis*) and Peck's Cave Amphipod (*Stygobromus pecki*). Habitat management for these and other species still pending listing is addressed by the recent Edwards Aquifer Habitat Conservation Plan created through the Edwards Aquifer Recovery Implementation Program (EARIP, 2011).

The general groundwater flowpaths within the aquifer tend to move generally east in the western portion of the aquifer, and northeast or south in the northern and eastern portion, paralleling major faults (Figure 6). However, dye-tracing studies conducted by the Edwards Aquifer Authority (EAA) indicate that water also moves rapidly across any faults within the aquifer from the contiguous Contributing Zone directly upstream. Groundwater in karst aquifers like the Edwards moves at different rates, from less than one foot per day to several thousand feet per day. Consequently, some aquifer water is hundreds of years old while other water pumped today could have been recharged by yesterday's rainfall. Dye-tracing studies also stress the fact that the entire Recharge Zone, as well as parts of the Contributing Zone, is highly vulnerable to contamination, even if identifiable karst features are not apparent (Johnson et al., 2010).

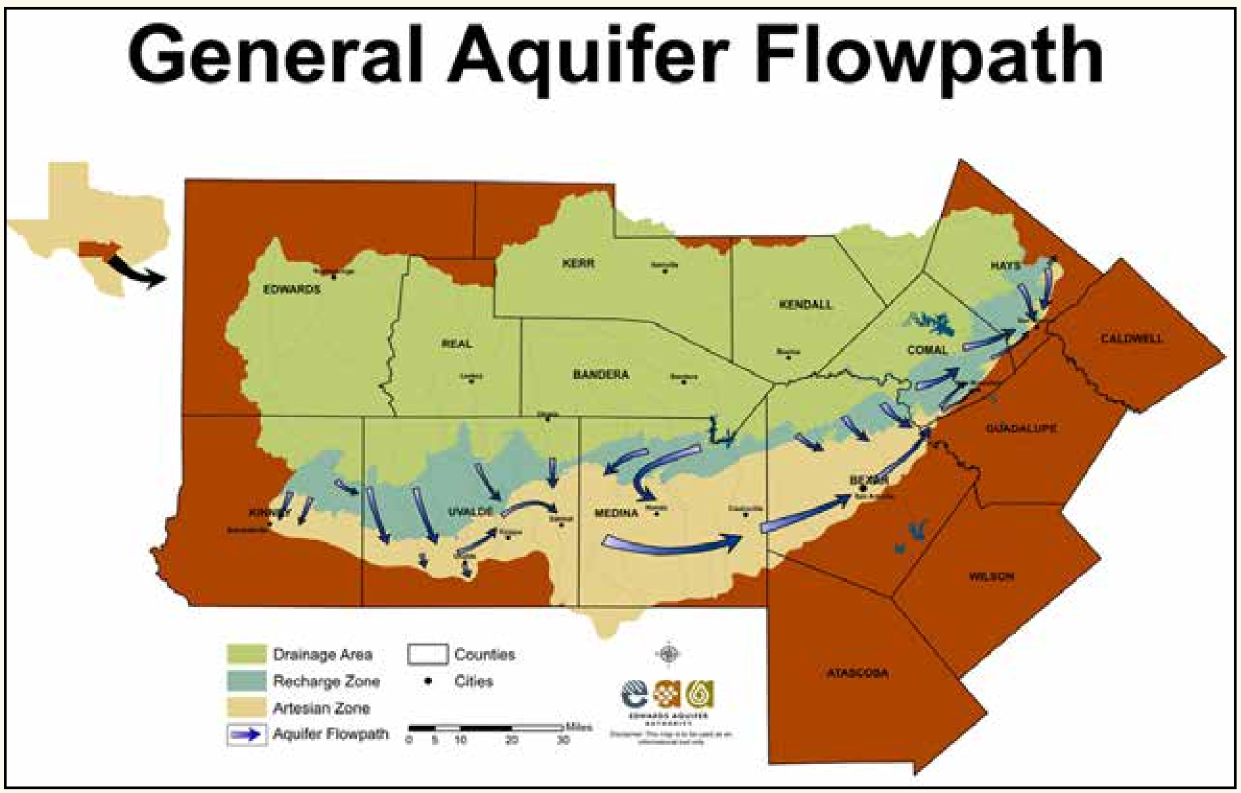


Figure 6. General Flowpaths of the Edwards Aquifer (EAA).

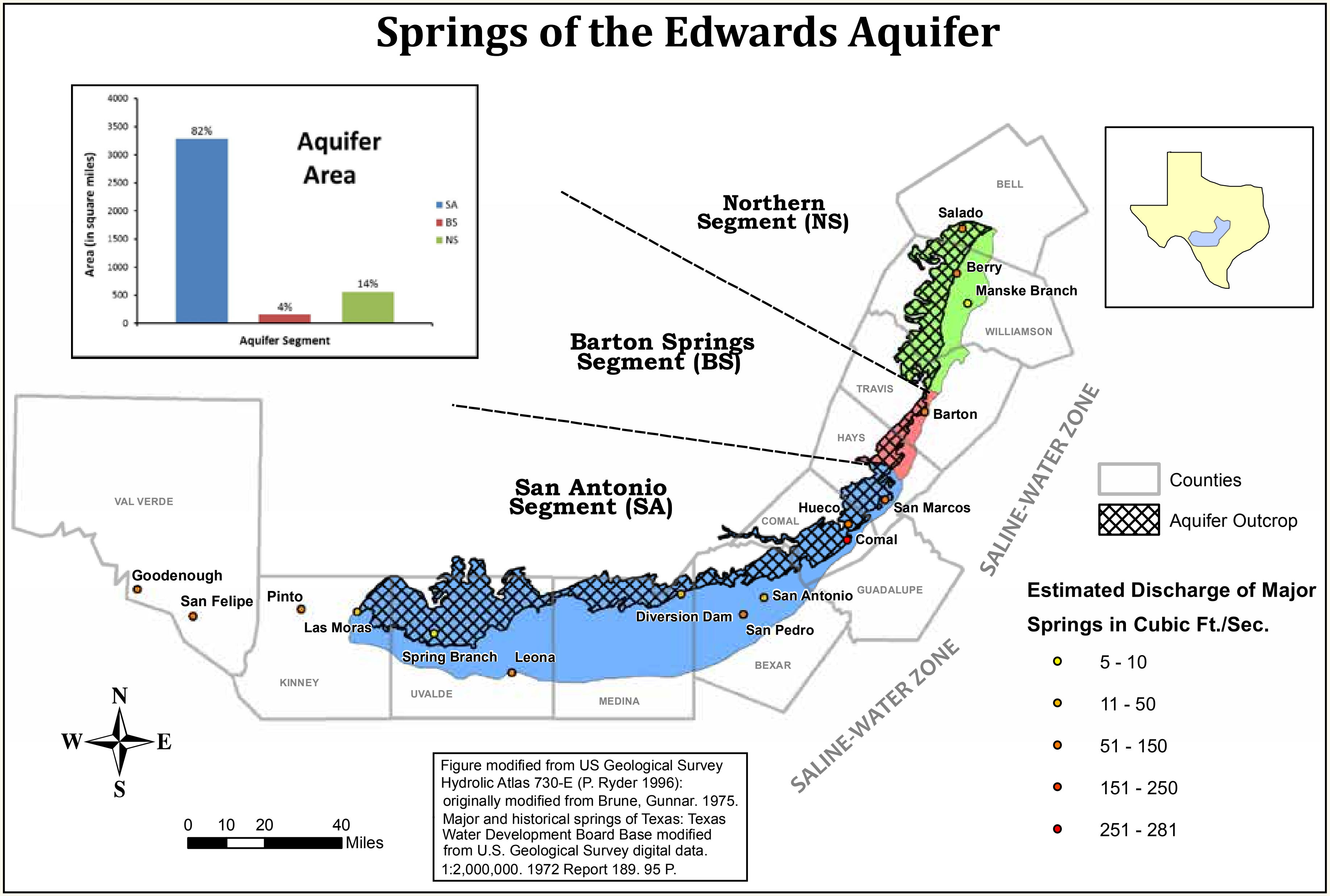


Figure 7. Major Springs of the Edwards Aquifer

Surface Hydrology

The Edwards Plateau and Balcones Fault Zone are well dissected by rivers and streams, with eight major stream basins that contribute significant groundwater recharge to the Edwards Aquifer. From west to east, they are the Nueces River, Dry Frio River, Frio River, Sabinal River, Seco Creek, Hondo Creek, Medina River and the Blanco River. The upper Nueces River and tributaries, for example, contribute much of their volume to the aquifer as they flow over the Recharge Zone in Uvalde County. Minor tributaries, such as Helotes Creek, a tributary of Leon Creek in the Medina River Basin, may contribute their entire flow to the aquifer, with the stream virtually disappearing as it crosses the exposed fault lines.

Streams are vital to replenishment of the aquifer since the aquifer gets about 75% of its water directly through streambeds that cross the Recharge Zone. Many streams lose much or all of their flow to the Recharge Zone and are mostly dry except during rainfall events. Streams are critical recharge areas, so it is vital to protect stream health by managing the riparian watersheds, maximizing the width and quality of vegetation buffers and, most importantly, controlling runoff through impervious cover limits and water quality practices.

Ecology

The Environmental Protection Agency (EPA) defines the Edwards Plateau as one of twelve ecoregions in Texas, with distinguishing patterns of geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Wiken et.al. 2011). The Edwards Plateau and its sub-ecoregion, the Balcones Canyonlands, are associated with much of the Contributing Zone and the entire Recharge Zone. The eastern Edwards Plateau, above the Edwards Aquifer, is synonymous with the Texas Hill Country, known for its rocky hills, ranches and, lately, some

Figure 8. Exposed rock layers from roadcut in northern Bexar County. (Photo by Marita Roos).

of the most prolific urban development in Texas. The karst landscape above the aquifer provides a substrate for shallow rocky soils with scattered trees and grasses.

The soils covering the region's limestone are often very shallow, ranging from totally absent to only a few feet deep. In a representative profile, the surface layer is a pale brown gravelly clay loam ranging from less than one to fifteen inches in depth. The surface of the soil is often gravelly in appearance, with angular limestone pebbles and numerous cobbles. These soils are neutral to alkaline, with a high calcium carbonate content. The thin soils, especially when considered with the hot temperatures and unpredictable rainfall, make the eastern Edwards Plateau ecosystems much more susceptible to droughts than might be predicted from rainfall accumulations alone. Additionally, the shallower soils generally have a low water storage capacity, so water that might otherwise be retained on site passes quickly through to the underlying aquifer. Importantly, the thin soils provide very little filtration for any contaminated water flowing to the aquifer below (Ross and Suh, 1997).

Historically, this landscape was a juniper-mesquite-oak savannah, with ashe juniper (*Juniperus ashei*) confined to the canyons. Its open grasslands were maintained by natural fire, bison and antelope grazing, and perhaps intentional burning by the native Americans for hunting purposes. Today, the natural character is oak and juniper woodland interspersed with grassland. Dominant trees are ashe juniper, plateau live oak (*Quercus fusiformus*) and Texas red oak (*Quercus buckleyi)*. Other woody plants include Texas persimmon (*Diospyros texana*) and Texas mountain laurel (*Sophora secundflora*). Prickly-pear cactus (*Opuntia, spp.*) is abundant and pencil cactus (*Cylindropuntia leptocaulis*) and yucca (*Yucca, spp.*) occur frequently. Grasses typical of the region include switchgrass (*Panicum virgatum*), little bluestem (*Schizacrium scoparium*), Indiangrass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*) and Canada wildrye (*Elymus canadensis*) (Fowler, 2005).

Figure 9. Characteristic oak-juniper vegetation in Stone Oak Park. (Photo by Marita Roos).

Only about two percent of the original habitat survives, and only in small, scattered pieces (Fowler, 2005). Overgrazing has fragmented the grasslands, eliminated native grassland species, and contributed to the spread of shrubs and other woody plants. The suppression of natural fires has also encouraged the growth of ashe juniper outside of its historic habitat and discouraged native grasses. Urban and suburban development around Austin and San Antonio continues to threaten the few remaining habitat fragments (Marsh and Marsh, 1995).

Wildlife abundance and distribution of species has changed dramatically over the last 200 years in response to habitat disturbance and indirect human-driven causes. Ecological change has favored species that are more tolerant to human development, such as black vultures, rather than species like the endangered golden-cheeked warbler, which are supported by larger, intact habitats. Fragmentation and disturbance of endangered bird habitat throughout the Edwards region is well understood by wildlife biologists and is not infrequently the subject of local press (e.g. McDonald, 2011). Less well publicized, and mostly unseen to the public, are disturbances to karst features through development which causes habitat degradation for endangered karst invertebrates, such as the Braken Bat Cave meshweaver (*Cicurina venii*). (For a listing of these karst species, see the Final Rule designating critical habitat for Bexar County invertebrates, Federal Register 50 CFR Part 17, USFWS, 2012).

The main karst faunal regions across northern Bexar County are extensive—over 4,000 acres—showing that critical karst habitat occurs throughout the region (Figure 10). This Geographic Information Systems (GIS) map is based on *Designation of Critical Habitat for Nine Bexar County, TX, Invertebrates; Final Rule*, which was used as a basis to establish a species recovery plan for karst invertebrates in the area (USFWS, 2012). The sensitivity of the region is evident even while it continues to undergo tremendous development and urbanization.

ECOREGIONAL CONTEXT: KEY CONCEPTS

The Edwards Aquifer is an irreplaceable resource that has been subjected to significant urban growth and development, resulting in loss of recharge due to impervious cover replacing native landscape cover.

The Edwards is a karst aquifer, a type of aquifer that is especially susceptible to contamination because pollutants from runoff, leaks, spills, lawn treatments, and other sources can reach the water table within minutes and travel quickly through the aquifer with effectively no filtration.

The need exists for an integrated approach to water management over the aquifer that will maintain the natural hydrologic regime to the extent possible, including the need to recharge the aquifer safely.

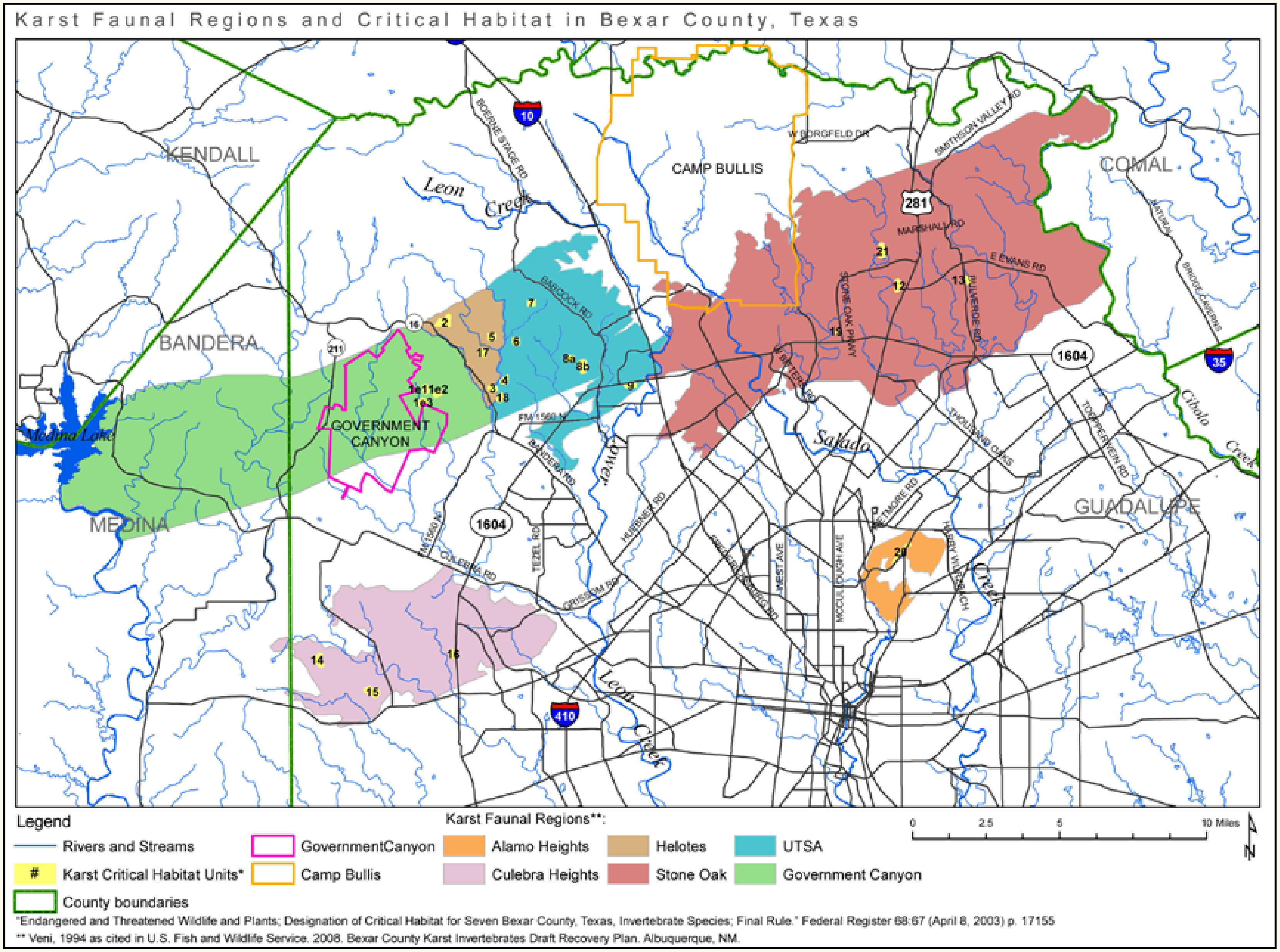


Figure 10. Karst Faunal Regions and Critical Habitat in Bexar County, Texas (Hayes and Aguirre, 2011).

Land Use and Development Over the Aquifer Zones

The 2012 report of the United States Census Bureau lists the region along the Interstate Highway 35 corridor from Round Rock to Austin as the eighth fastest growing area in the nation, with a population change greater than 37% in ten years. The census counts four counties within the Edwards region—Kendall, Comal, Hays and Travis—as among the fastest growing areas in the nation, with growth between 25 and 50% (U.S. Census Bureau, 2012). Rapid urban and suburban growth is extensive within the Contributing and Recharge zones of the Edwards Aquifer, including the southern suburbs of Austin, the cities of San Marcos, New Braunfels and Boerne, and northern Bexar County.

The pace of growth across the Edwards Aquifer region threatens to compromise not only the quantity, but also the quality of underground water supplies in the Edwards and Trinity aquifers (Marsh and Marsh, 1995). New developments increase demand for potable water, while large extents of impervious cover over the Edwards' Contributing and Recharge zones reduce the overall volume of water recharging the aquifer. The links between impervious cover and diminished water quality, as well as decreased water supply are well documented (Schueler, 1994; Brabec, 2002; Shuster et al., 2005). Impervious cover extents greater than 10-20% (depending on the type of impact measured) are shown to jeopardize watershed health by directly contaminating surface streams and groundwater with sediments, organic and inorganic nutrients, petroleum substances and bacteria. Less direct impacts to groundwater quantity and quality also occur through land cover disturbance and tree loss. Significant areas of tree clearance raise ambient air temperatures and reduce the available local moisture, which exacerbates drought cycles, such as the one that central Texas experienced during 2010 through 2014.

The two aerial photos depict the suburbs of northern San Antonio in the vicinity of Highway 281 over a period of 38 years when the landscape was almost entirely converted to residential subdivisions (Figure 11a and 11b). Large extents of recharge lands were replaced by impervious rooftops, roadways and parking areas, connected

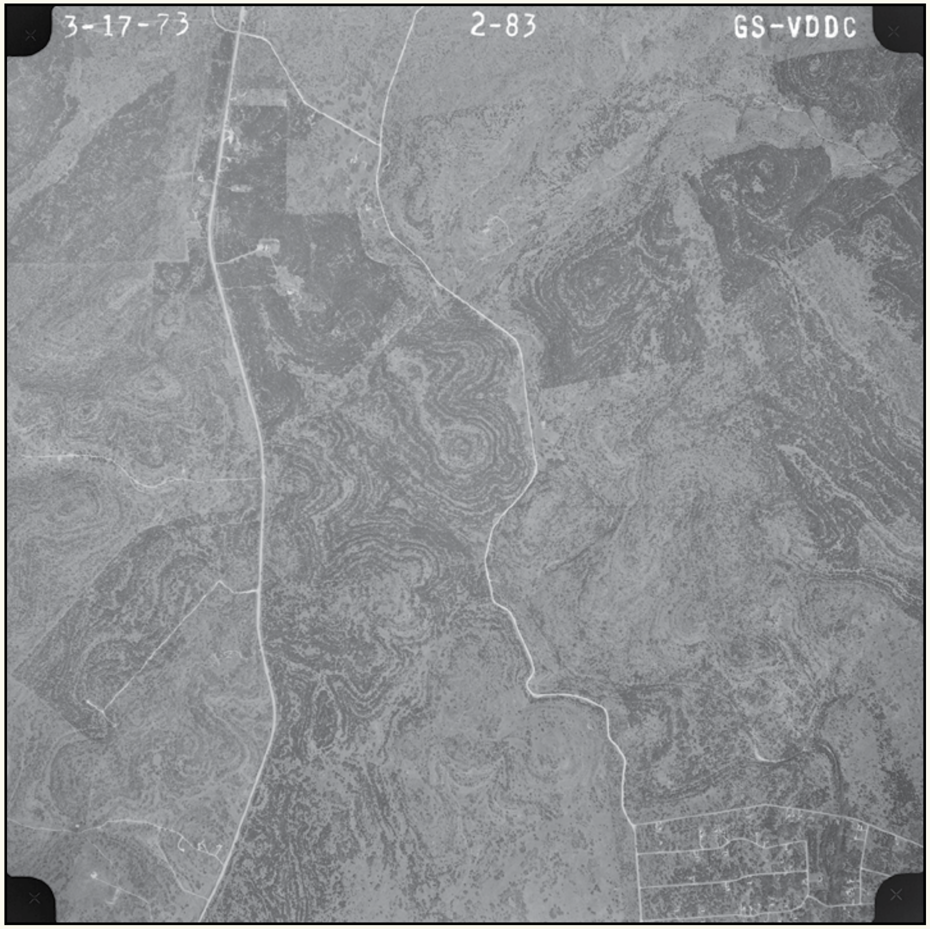


Figure 11a. Aerial photo of highway 281 near Wilderness Park, 1973.

to stormwater systems that convey most water away from the immediate area instead of into the aquifer. Stormwater runoff, whether from rooftops (contains avian fecal matter and roofing byproducts), construction sites (carries sediment), yards (pet waste, pesticides, herbicides and fertilizers) or roadways and parking areas (petroleum, debris and metals) can potentially discharge contaminants into the aquifer.

Figure 11b. Same location, 2010. Both photos: http://www.earthexplorer.usgs.gov/

In places of development, rainwater that would normally perform a recharge function is captured by a system of culverts and swales for the purpose of preventing pollutants from reaching groundwater. In some cases, that means that water is conveyed off the aquifer entirely. In other cases, the water may enter into the aquifer through surface streams or constructed recharge features. In both cases, rainwater that is now labeled as stormwater runoff is treated primarily as a regulated byproduct of development, and not as a resource to the ecosystem.

Water is an especially vital resource to this region, and we cannot afford to mistreat or lose it. The most effective way to treat stormwater is as a potential resource in the landscape, instrumental to the ecosystem which includes human habitat. The natural model is one where water is well-distributed throughout the Recharge Zone and allowed to infiltrate naturally through surface streams, which account for 75% of aquifer recharge (Ockerman, 2005). This is the scenario that low impact development (LID) seeks to emulate.

Low impact development, by itself, will not restore the natural water regime, especially since so much conventional development has already blanketed the region. This booklet intends to show how low impact development can be used in concert with improved development methods that include conservation subdivisions, protective easements and local land partnership agreements.

Our current understanding of karst aquifers tells us to be extremely careful of how we develop over the Edwards Aquifer area. Meanwhile, people continue to live in this region and are steadily developing and building over the aquifer Recharge and Contributing zones. We should note that the use of low impact development, conservation subdivisions and sustainable site design do not fully protect the aquifer. Used as part of an aquifer management plan, in conjunction with careful siting and land conservation practices, they can provide additional protection for the region's sensitive karst aquifer geology.

Aquifer Regulation 2

The Edwards Aquifer is protected by a variety of regulations from several different agencies and authorities. Most of these regulations are aimed at ensuring there is sufficient water volume in the aquifer to meet the demands of agriculture, ranching, industry, endangered species, and drinking water needs for the many communities that rely primarily on groundwater for these purposes. Regulations aimed at point source pollution and non-point sources, such as urban runoff, have been enacted to protect water quality. Since the regulations are designed to primarily protect groundwater, the unintended effect is that replenishment of surface streams from stormwater treated to a high standard is not necessarily part of the overall water quality picture.

"Water wells in the Edwards Aquifer are vulnerable to potential contaminants that infiltrate the recharge zone from stormwater runoff or contaminant spills, even in the absence of obvious karst features or fractures, as shown by the interstream area trace."

(Johnson, et al. 2010)

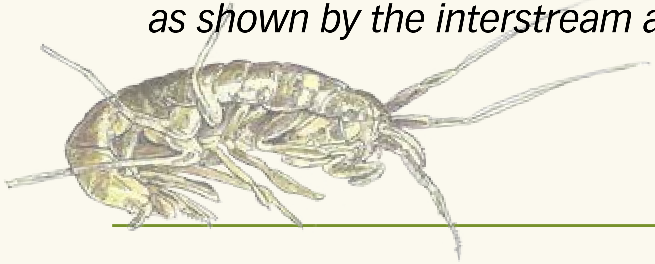


Figure 12. Discharge from a sand filter on the EARZ, Bexar County. (Photo by Annalisa Peace, GEAA)

The Edwards Aquifer Authority

The EAA, authorized by the Texas Legislature in May 1993, manages groundwater withdrawals and protects the quality of groundwater within its jurisdiction. Water quality-regulated activities include point and non-point source activities, such as pollution generated by stormwater runoff. The EAA does not regulate the entire Edwards Aquifer Recharge and Contributing zones. Its jurisdiction is limited to the eight counties designated as the San Antonio Segment, which contain much of the Recharge Zone, excluding the eastern portion in Kinney County and parts of Comal and Hays counties in the far northeast (Figure 13) (EAA website, 2012).

Texas Administrative Code Section 213, known as the Edwards Rules, aims to safeguard the groundwater supply for all users within the San Antonio and Barton Springs groundwater districts. Originally, the Edwards Rules did not include the need for stormwater controls necessitated by non-point sources such as parking lots, roadways, rooftops and other impervious surfaces. In the light of research demonstrating the link between impervious cover extents above 10-20% and degradation of surface streams (Schueler, 1994; King et.al., 2011), the EAA has decided to look more deeply into the connection between land cover change, stormwater runoff, and aquifer water quality. As of this writing, no proposed rules regarding limits on impervious cover are forthcoming.

STORMWATER and KARST

Rainwater that falls onto paved surfaces is widely considered a groundwater contaminant because it carries pollutants from impervious roadways and parking lots, which can enter and pollute aquifers. “Karst” is a type of landscape formed by the slow dissolving away of the bedrock, typically limestone. As water enters fractures in the rock, they are enlarged over millennia into conduits, sinkholes, and caves that recharge their aquifers. These karst features allow rapid and unfiltered recharge into and through the Edwards Aquifer via complicated and hard-to-predict flowpaths.

Across urbanized regions of the Edwards Aquifer, impervious surfaces plug its highly permeable karstic recharge features. As a result, substantially less water enters the aquifer in those areas while runoff increases, concentrating water volumes along streams, resulting in greater downstream flooding. The runoff that does recharge the aquifer is often of poor quality, a cause for concern due to the proximity to water supply wells. For these reasons, current regulations governing the Edwards Aquifer Recharge Zone do not permit urban stormwater infiltration, or direct discharge into the groundwater system.

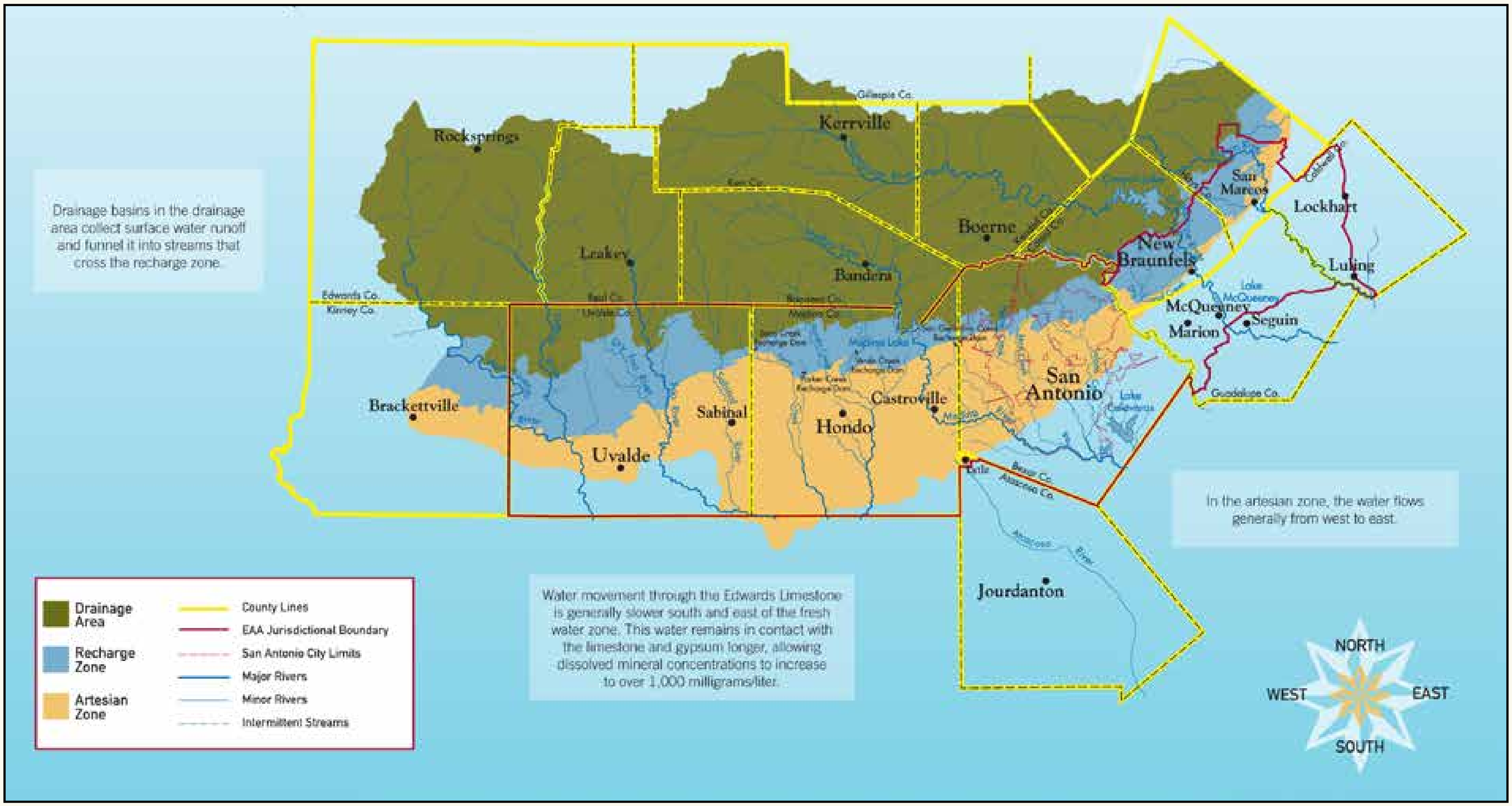


Figure 13. Edwards Aquifer Authority Jurisdictional Map (EAA website, 2012).

Texas Commission on Environmental Quality

As the impacts of stormwater on water quality degradation have become known, the Edwards Rules have been adopted to regulate water quality protection of the Edwards Aquifer. The Texas Commission on Environmental Quality (TCEQ) Edwards Rules requires land developers to prepare and submit geologic and engineering data for proposed development as part of a Water Pollution Abatement Plan (WPAP). The submittals are reviewed and copied to municipalities and the EAA for their comments. When all of the comments by the reviewing agencies have been cleared, TCEQ issues a permit to construct development over the regulated aquifer zones. It is up to the local municipalities to determine extents of impervious cover permissible in their jurisdiction, since neither the EAA nor TCEQ exercises the authority to fully regulate the location and character of development. As of this writing, Austin, Sunset Valley, San Antonio and San Marcos are the only cities over the Recharge and Contributing zones that regulate the extents of impervious cover.

In 2005, TCEQ commissioned a technical guidance report aimed at improving the effectiveness of stormwater management within the aquifer region. Complying with the Edwards Rules: Technical Guidance on Best Management Practices (*Technical Guidance Manual*, Barrett, 2005) filled a significant gap in the regulations, proposing a variety of Best Management Practices (BMPs) for stormwater controls around the Edwards Aquifer's Contributing, Recharge and Transition zones (the Transition Zone is defined for a few locations as areas between the Recharge and Artesian zones where some recharge could potentially occur). Techniques covered in the *Technical Guidance Manual* (TGM) are extensive and include site preservation, erosion and sedimentation controls during construction, landscaped BMPs, structural BMPs, integrated pest management (IPM) and maintenance prescriptions. The suite of practices is intended to work within an integrated system that includes sound land use planning at the local level in order to mimic the predevelopment site conditions of stream recharge and natural filtration.

The TGM is the guidance most often consulted by practicing engineers and developers in the region. This publication utilizes this TGM as a main reference to develop LID techniques recommended for water quality treatment across the Contributing and Recharge zones. Information pertaining to the Edwards Rules and digital files of documents in .pdf format, including the TGM, are available at the TCEQ Edwards Aquifer Protection Program website (TCEQ, 2013).

Best Management Practices

Texas state law requires that all permanent BMPs reduce sediment loads associated with development by at least 80%. Structural Best Management Practices, or BMPs, are the most widely used tool in the engineering toolbox for meeting the regulatory standards. BMPs can be structural or non-structural; the structural relies upon reinforced hardened materials for their construction while non-structural depends on either a mixture of vegetation and soils for water quality treatment, or a set of practices such as reduced fertilizer application (EPA, 2000). LID methods utilize vegetation and soil construction as a filtration system (Barrett, 2005).

Many states and municipalities rely on the same set of BMPs regardless of rainfall and climate variability, although some states, such as Maryland, California and Florida, have gone well beyond the standard set of practices by developing new guidelines based on low impact development. Several of these newer guidelines are listed in the References and Appendix A. In the state of Texas, including the Edwards region, structural BMPs are still the tool of choice; the most widespread BMP used in central Texas is the sand filter (Figure 14).

In Bexar County alone over 800 tracts use one or more permanent structural BMPs. The chief disadvantage of sand filters is that many are either not maintained or irregularly maintained. The TGM notes that without proper maintenance, sand filters are prone to clogging, which dramatically reduces performance and can lead to the problem of standing water (Barrett, 2005). A 2010 study and field investigation noted that at least 10-15% of 3,000 structural BMPs located in Bexar County were persistently non-compliant with TCEQ regulations, with trash, debris and weedy vegetation present (GEAA, 2010). Structural BMPs are typically given as little aesthetic treatment as possible and are commonly surrounded by chain link fences to prevent people, animals, and cars from accidentally falling in. As single purpose devices, structural BMPs effectively reduce sediment loads and also reduce the presence of some common urban pollutants, primarily metals and petroleum products. However, sand filters contribute nothing to site character and appear especially out of place in the rugged terrain of the Texas Hill Country. The lack of visual and functional amenities, the space required to satisfy the regulatory purpose, and the need for consistent maintenance raises the question as to whether these BMPs are the most effective solution for every development scenario.

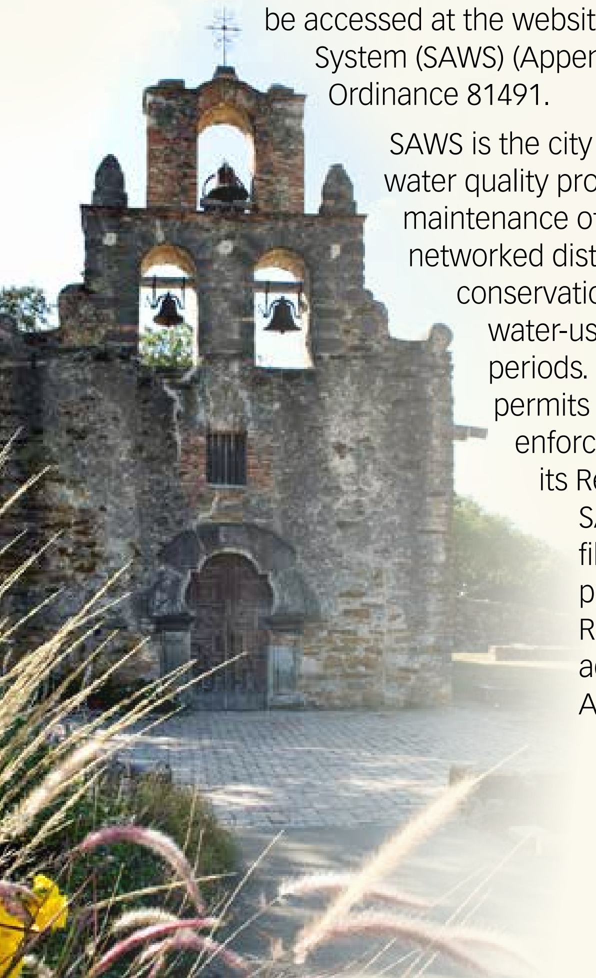
Even under the best possible scenario for management, BMPs are not a substitute for land protection ordinances and careful watershed stewardship practices. Site-specific treatment methodologies can address contaminants from limited extents of the watershed, but are only as effective as their design, implementation, and follow-up maintenance permit. Larger-scale land conservation practices that rely on inter-agency partnerships and well-crafted regulations are essential to fully address protection of the Edwards Aquifer resources.

Figure 14. Sand filter, the most common BMP in the Austin-San Antonio region (Photo by Annalisa Peace, GEAA website, 2010).

Municipal Regulations

San Antonio

Although TCEQ is the main regulatory agency, several municipalities within the Edwards Aquifer boundaries have regulations that may affect development, stormwater runoff, and water use for the aquifer region. For San Antonio, the regulations governing water quality are set by the San Antonio Unified Development Code (UDC), Chapters 34 (Article VI Division 6 - Aquifer Recharge Zone and Watershed Protection) and Section 35-504 (Stormwater Management). The UDC also sets impervious cover limits ranging from 15% for properties within the city's extraterritorial jurisdiction (ETJ), up to 85% for development within the city limits (Table 1). The regulations may be accessed at the website of the San Antonio Water System (SAWS) (Appendix A) under Aquifer Protection Ordinance 81491.



SAWS is the city agency charged with aquifer water quality protection. SAWS' primary focus is maintenance of the city water supply through networked distribution, well level monitoring, and conservation initiatives, including mandatory water-use restrictions during drought periods. SAWS reviews development permits over the Recharge Zone and enforces stormwater regulations through its Resource and Compliance Division. SAWS also requires developers to file an Aquifer Protection Plan for proposed development over the Recharge Zone, a requirement in addition to the TCEQ Water Pollution Abatement Plan (WPAP).

SAWS maintains a database of sensitive recharge features, such as sinkholes, caves, faults and crevices. These features must be identified at development sites and recorded as part of the Geologic Assessment for the WPAPs submitted to TCEQ. Recommended vegetation buffers for karst features are 100 meters so that any associated sinkholes and faults can be incorporated into protection. Since karst features are so numerous across the Recharge Zone, and often not visually obvious, many critical recharge features are not adequately protected in development plans. Several geologists have also noted that since the entire Recharge Zone is a highly permeable karst area, it is impossible to adequately protect water quality solely by protecting individual recharge features (G. Veni, personal communication, 2011).

San Antonio and many environmental organizations have done important work trying to protect the Edwards Aquifer, including a joint purchase of critical aquifer lands, such as the 12,000-acre Government Canyon State Natural Area. San Antonio and SAWS have also received national recognition for their water conservation efforts. However, monitoring data indicate that San Antonio's efforts have not been entirely effective in preventing pollution to the aquifer. It is important to keep in mind that SAWS is foremost a water provider dependent on a broad consumer base for its product and, as growth increases, so does the number of consumers, which in turn increases the demand on the aquifer.

A comparison of Austin, San Marcos, New Braunfels and Sunset Valley regulations, as well as San Antonio, is provided in the Appendix. Impervious cover limits for each city are provided in Table 1 shown on the following page.

Austin

The regulations governing water quality in Austin and its ETJ are found in the Austin City Code, Title 25 - Land Development Code (The Code of the City of Austin, 2013). Impervious cover assumptions limit the amount of impervious cover allowed on new development depending upon the size of the lot. The limits range from 2,500 square feet of impervious cover for smaller lots under 10,000 square feet (25%), to a maximum of 10,000 square feet (8%) for larger lots over 3 acres (for duplex and single-family lots). This does not apply to a commercial site development (including roadway projects), which will not exceed 8,000 square feet of new impervious cover.

Critical Water Quality Zones established restrictions on development in watersheds along waterways and lakes. An environmental assessment is required if over a karst aquifer, in water zones, or on a 15% or more gradient. Water Quality Transition Zones have been established adjacent to critical water quality zones. An environmental resource inventory must be completed as prescribed by the *Environmental Criteria Manual*.

The *Environmental Criteria Manual* contains the technical criteria necessary to accomplish the environmental protection and management goals of the Austin City Code. These guidelines address the issues of water quality management, landscaping, preservation of trees and natural areas, the underground storage of hazardous materials, and construction activity in city parks. A short introduction is included with each section identifying the applicable provisions of the Land Development Code and other applicable legislation (City of Austin, 1998-2013).

The City of Austin Watershed Protection Department uses administrative criteria (known as "rules") and ordinances to help prevent flooding, erosion, and water pollution, including programs that address storm water management and flood mitigation, riparian and streambank restoration, endangered species and invasive plants management, water and environmental monitoring, groundwater management, Master Planning, pollution prevention and reduction, and wildfire management. See Appendix A: Sources and Links for reference.

CITY REGULATIONS	SAN ANTONIO and ETJ	NEW BRAUNFELS	SAN MARCOS and ETJ	AUSTIN	SUNSET VALLEY
Impervious cover limits	Single Family 30% Multi-Family 50% Commercial 65% Commercial at transportation nodes 85% ETJ Only: All Types 15%	Considering Monthly stormwater utility fee assessed based on impervious cover on all developed property	<3 acres = 40% 3 - 5 acres + 30% 5+ acres = 20% Waterway buffer zones = 10%	Duplex and single family: <10,000 ft^2 = 2,500 ft^2 limit (25% or more) 10,000 ft^2 – 15,000 ft^2 = 3,500 ft^2 (35% - 23%) 15,000 ft^2 – 1 acre = 5,000 ft^2 (33% -12%) 1 – 3 acres = 7,000 ft^2 (16% - 5%) 3+ acres = 10,000 ft^2 maximum (8% or less) 1. Limit calculation Includes adjacent roadway ft^2 if limit is > 5,000 ft^2 2.1 acre = 43,560 ft^2	Single Family 18% Commercial 18% Monthly stormwater utility fee assessed based on impervious cover on all developed property

Table 1. Impervious cover limits on the Edwards Aquifer Recharge Zone: current jurisdictional regulations

Rules and ordinances include:

- Banning the sale and use of pavement sealants containing coal tar
- Restrict construction within 500 ft. of hazardous pipelines
- Restrict development near closed and abandoned landfills
- Protections against flash flooding
- Recommendations to improve Lake Austin Development Code Protections for Austin watershed lakes, creeks and springs

Projects proposed within the Barton Springs watershed must submit Hydrogeologic, Vegetation, and Wastewater reports. The hydrogeologic report generally describes the topography, soils, and geology of the site; identifies springs and significant point recharge features on the site; demonstrates that proposed drainage patterns will protect the quality and quantity of recharge at significant point recharge features; and identifies all recorded and unrecorded water wells, both on the site and within 150 feet of the boundary of the site. [The Code of the City of Austin, Section 13-7-28(1); Ord. 990225-70; Ord. 031211-11; Ord. 20131017-046.]

A vegetation report must demonstrate that the proposed development preserves to the greatest extent practicable the significant trees and vegetation on the site. This provides maximum erosion control and overland flow benefits from the vegetation, including prescribed inventories or surveys of existing trees on the site. [The Code of the City of Austin, Section 13-7-28(2); Ord. 990225-70; Ord. 031211-11.]

Required wastewater reports must provide environmental justification for a sewer line location in a critical water quality zone; address construction techniques and standards for wastewater lines; include calculations of drainfield or wastewater irrigation areas; describe alternative wastewater disposal systems used over the Edwards Aquifer Recharge Zone; and address on-site collection and treatment systems, their treatment levels, and effects on receiving watercourses or the Edwards Aquifer. [The Code of the City of Austin, Section 13-7-28(3); Ord. 990225-70; Ord. 031211-11.]

Sunset Valley

Sunset Valley is a small town surrounded by the City of Austin and located almost entirely in the Barton Springs Recharge Zone. The main water quality protection is a limit of 18% impervious cover for residential and 18% of net site area for commercial development. No construction or development can occur within 100 feet of an aquifer recharge feature and no untreated runoff is allowed to flow into a recharge feature. No plugging of recharge features is allowed. Engineered water quality ponds or other controls are required except for low density residential development where the lots are at least five acres. Generally development is prohibited within 150 to 700 feet from the centerline of creeks.

Other protection practices include landscape preservation during site development and limitations on fertilizer and pesticide use. Except for certain invasive species of trees, trees more than 5 or 10 inches in diameter (depending on the species) cannot be removed unless they are diseased, hazardous, prevent reasonable access or preclude all reasonable and lawful use of the property. Larger trees of particularly valued species called “heritage” or “ancestral” trees cannot be removed or damaged unless there is no way to design development of the property around the tree.

Most of the city’s intense commercial and school district facilities development either preceded these regulations or were grandfathered or partially grandfathered under state law.

Another significant program is the City’s acquisition of conservation land. Sunset Valley has so far acquired or purchased development rights to more than 5% of the land within the City limits for conservation land. This does not include the large amount of parkland surrounding Williamson Creek.

San Marcos

The San Marcos regulations governing land use and water quality protection are set by the City of San Marcos Code of Ordinances (SM Code)-Subpart B- Land Development Code which may be accessed via the City website homepage Departments tab/City Council. The SM Code requires the application of environmental and flood control standards through submission of a Watershed Protection Plans in the City limits and ETJ. These plans, as well as Aquifer Protection Plans for land in the San Marcos River Corridor, are subject to the water quality standards appearing in the TCEQ Edwards Aquifer Rules.

Erosion controls must comply with the City of Austin Drainage Criteria Manual and the City of Austin Environmental Criteria Manual (City of San Marcos Stormwater Technical Manual). Procedures to attenuate runoff include impervious cover (IC) limits ranging from 20% for gradients more than 25% and IC of 35% on slopes between 15% and 25%. Areas with highly erodible soils are subject to further limitations. Drainage basins of 120 acres or more are subject to buffer zones of 100 ft in FEMA defined floodways with impervious cover limits within buffer zones ranging from 10% IC for slopes greater than 25% to 30% IC for gradients of less than 15%.

Special provisions for excavations in the Edwards Aquifer Recharge Zone require suspension of activities within 50 feet of discovered sensitive features. Geological assessments are required to include mapping of caves and recharge features. Impervious cover limits in the EA recharge zone range from 0% where the slope exceeds 20% to 40% IC on sites up to 3 acres. Where IC exceeds 15% , BMP's must be installed. IC limits for River Corridors range from 10%-30% for slopes ranging from greater than 25% to slopes of less than 15%. Finally, the SM Code recognizes the beneficial role of trees in storm water management as well as erosion control.

The San Marcos Code also establishes water conservation measures under Subpart A-General Ordinances, Chapter 86-Utilities, Article 2-Water, Division 2-Conservation. The City is authorized to monitor daily supply conditions and issue notices to implement or terminate four drought response stages, as well as enforce drought stage restrictions and assess penalties for violations.

Figure 15. Construction of Kyle Seale Parkway, Bexar County (Photo by Annalisa Peace, GEAA 2011).

Regulatory Gaps

Current regulations are aimed at mitigating land disturbance on a parcel-by-parcel basis, but are not always effective in redistributing the overall pattern of growth away from sensitive aquifer areas. With a well-established link between development and runoff water quality, managing growth and limiting impervious cover are acknowledged as necessary steps for protecting the aquifer's water quality. In practice, earthmoving and clearing 80% or more of the native vegetation is typical of new developments over the Recharge Zone. Local ordinances provide options for developers, such as mitigation fees in lieu of preserving a stated percentage of trees; however, these protections do not actually guarantee land preservation for the aquifer's Contributing and Recharge zones. Additionally, since numerous landowners have filed plats well in advance of planned development, many developments containing greater densities were grandfathered in advance of the impervious cover regulations.

Impervious Cover - Suggested Limits

Numerous studies have shown consistent links between the extent of impervious cover and water quality degradation, with the tipping point for reduced water quality being 10-20% impervious surface (Schueler, 1994; Exum, 2005; King et al., 2011). The 10% criteria is considered most effective at the watershed level, which poses a huge challenge for urban stream quality, given that urban watersheds usually exceed 25% impervious cover. Much of the Recharge Zone of northern Bexar County is developed at levels that exceed 25% impervious surface, resulting in a decline in surface stream quality for Leon and Salado creeks. The current amount of impervious surface in Bexar County does not include a measurement of future growth, which will further impact already stressed hydrologic systems.

For areas that are not yet urbanized, consistent limits set for impervious cover extents are necessary to protect the aquifer's recharge capability and water quality. The 2010 Concept Memo prepared by EAA recommended 20% impervious cover limits for most projects, and 30% impervious cover limits if certain BMPs are used. Current standards vary depending on jurisdiction and location within the Recharge Zone, which is inconsistent with coordinated management of this essential resource. Most such limits fail to adequately protect water quality because they are misused, based on impervious cover percentages of individual properties while the research on impervious cover demonstrates the percentage must be based on the entire watershed. For such standards to be fully effective, they must require calculation of all existing impervious cover within the watershed to assure that proposed new developments do not exceed the recommended percentage. GEAA recommends an impervious cover limit of 10% in the Recharge Zone and 15% in the Contributing Zone (GEAA, 2010).

Evaluating and Protecting Karst Habitat

Balcones Canyonlands Preserve

Several programs have arisen in Central Texas to protect lands over the Edwards and Trinity aquifers, partly as a response to inadequate watershed protection at the state and regional level, but also, and importantly, to conserve the many endemic and endangered species that inhabit the Edwards Plateau karst region. In 1996, the U.S. Fish and Wildlife Service issued a permit for the Balcones Canyonlands Conservation Plan ("BCCP") for the creation of a 30,428-acre preserve system in western Travis County known as the Balcones Canyonlands Preserve ("BCP") to protect eight endangered species as well as 27 other species believed to be at risk, and secured protection for a series of karst features and rare plants throughout Travis County. The BCCP Managing Partners (Travis County, the City of Austin, and the Lower Colorado River Authority), in cooperation with the Travis Audubon Society, the Texas Nature Conservancy and private landowners, have already assembled more than 28,000 acres (or over 92%) of the total permit acreage required.

City of San Antonio Edwards Aquifer Protection Initiative

Land acquisition and protection measures for the Recharge and Contributing zones have begun in Uvalde, Medina and Bexar counties, primarily through a voter-approved initiative, the Edwards Aquifer Protection Program (EAPP). The initial program, an eighth-of-a-cent local sales tax increase, was begun in 2000 and used to collect $45 million to purchase 6,500 acres of private lands located over the Edwards Aquifer. The program was re-approved in 2005 and again in 2010, yielding an additional $180 million dollars for purchase of aquifer lands. As of 2014, the City of San Antonio website lists properties totaling 122,614 acres that are under permanent protection from development, either by outright purchase or through conservation easements (Figure 16). The bulk of these lands lie over the Recharge Zone in Uvalde County and Medina County – the program also includes Bexar County, but not Comal or Hays

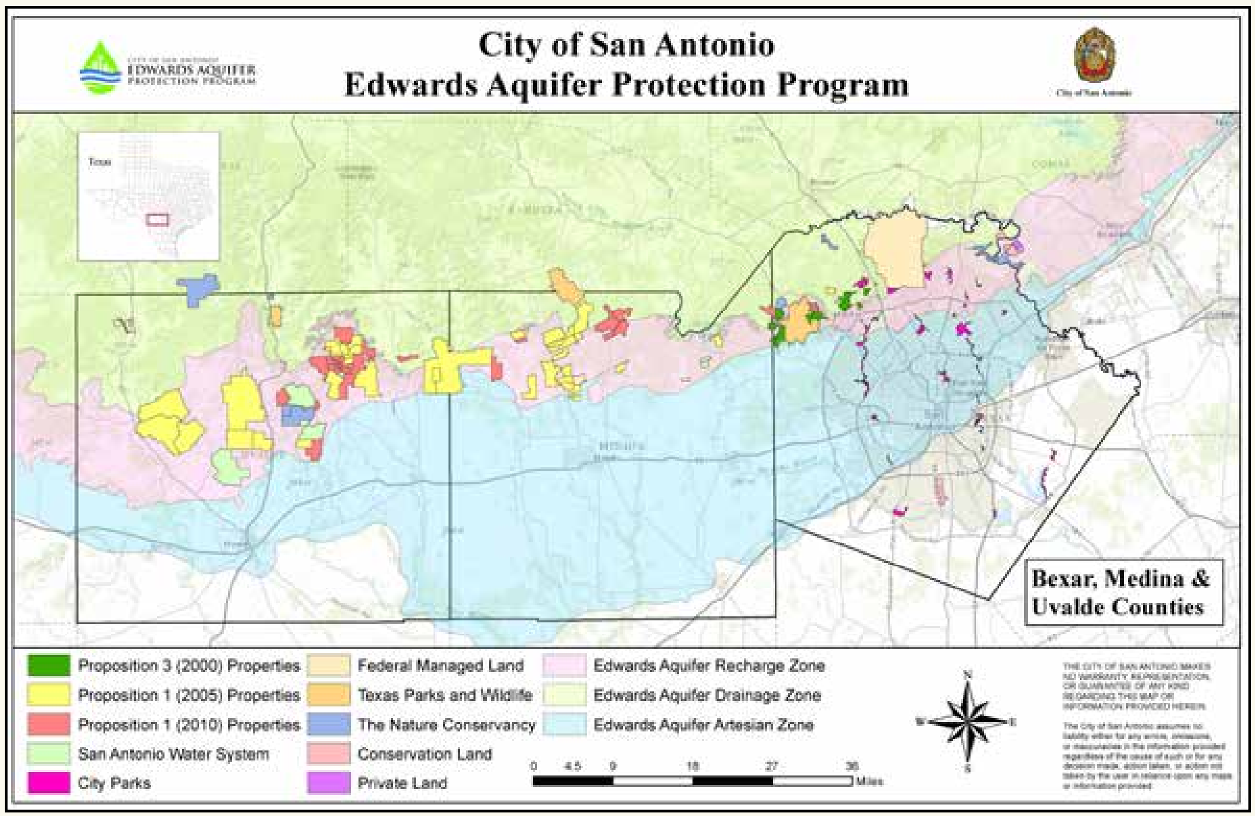


Figure 16. EAPP map, City of San Antonio.

counties, which have significant unprotected recharge lands. Because Texas counties lack the authority to conduct land use planning, protection strategies for the aquifer recharge lands rely upon federal and state endangered species laws as last-resort conservation measures.

Austin Water Quality Protection Lands Program

The City of Austin's Water Quality Protection Lands Program (WQPL) has protected 26,603 acres of land in the Barton Springs Recharge (22%) and (7%) Contributing zones through the purchase of fee simple land and conservation easements. In 1998 the citizens of Austin approved a bond for $65 million to protect the Barton Springs Segment of the Edwards Aquifer. Subsequent bonds issued in 2006 ($50 million) and 2012 ($30 million) were dedicated to protect Barton Springs' water quality and quantity. The City of Austin has secured grants for the preservation of some of these lands through the Farm and Ranch Protection Program set up by the USDA/NRCS to preserve working farms and ranches. Of the total land purchased since 1998, approximately 60% is held in conservation easements, with 40% held as fee simple land. The administration of the WQPL is funded through the Austin Water Utility.

Science has helped guide the acquisition of land into more productive geographic areas (based on recharge) and helped direct the management of these lands to further benefit water quality and quantity. Fee simple properties are managed for aquifer protection to keep the land in its natural state and ensure the function of karst recharge features. Land management focuses on ecological restoration of vegetation back to native prairie and savanna ecosystems that provide optimal water yield. These restoration actions combined with proper karst management protect both water quality and water quantity recharging through these lands. Particular attention is paid to keeping recharge features in creeks functioning and restoring the function of impaired recharge features in order to allow them to continue to provide recharge to Barton Springs. The WQPL engages the citizens of Austin in these restoration efforts, with volunteer events scheduled during many weekends throughout the year.

Although the primary purpose of the WQPL is to protect land to benefit Barton Springs, public access through volunteering, education activities and two publicly accessible trails are available. Trails must follow guidelines established through a public process, but have allowed citizen organizations to take on the task of designing, building and then maintaining and operating such trails.

Edwards Aquifer Habitat Conservation Plans

Endangered species are specifically protected under the Edwards Aquifer Habitat Conservation Plan (EA-HCP), a consensus-based stakeholder driven process begun in 2006 as the Edwards Aquifer Recovery Implementation Program, known as EARIP. The EARIP process was groundbreaking in that it was the first truly collaborative plan to address the water quality of critical Edwards springs, primarily San Marcos Springs and Comal Springs. Over forty organizations and agencies convened over five years to address complex issues related to the survival of eight of the endangered species that inhabit the Comal and San Marcos Springs and river ecosystems (EARIP 2011). The EA-HCP makes recommendations for groundwater withdrawal adjustments during critical periods to ensure the endangered species are protected. The plan also addresses measures for ecosystem restoration and management, directed primarily at maintaining instream flows.

In 2013, Hays County received approval for a Regional Habitat Conservation Plan (RHCP) to protect the Golden-cheeked Warbler (*Dendroica chrysoparia*) and the Black-capped Vireo (*Vireo atricapillus*), which could also protect as many as 56 additional species considered rare or threatened, including a number of karst species that could receive collateral protection (http://www.hayscountyhcp.com/). Comal County has also applied for a RHCP to protect these two bird species. The Comal RHCP would also cover seven karst invertebrates as Species of Concern, which are sufficiently rare and/or endemic within Comal County that they may be listed in the future.

Another attempt to preserve endangered species habitat through conservation of aquifer recharge lands was convened in 2009, with a focus on evaluating land parcels for potential habitat protection. A consensus plan, the Southern Edwards Plateau Habitat Conservation Plan (SEP-HCP) was produced in 2011 and serves as a roadmap for regional conservation of important land, water and habitat sites (www.sephcp.com). Endangered species covered under the plan include the two endangered birds in the RHCP, the Golden-cheeked Warbler and the Black-capped Vireo, and nine endangered karst invertebrates, primarily spiders and beetles (Loomis, 2011). All are threatened by habitat loss driven by urban growth in the San Antonio region.

Land parcels are evaluated for inclusion in the SEP-HCP based on several factors: geologic permeability for aquifer recharge, vegetation and biological habitat for karst invertebrates, parcel size and adjacency to other protected parcels. The evaluation process uses GIS data to sift through potential conservation lands so that protection funds are appropriately targeted. A Conservation Advisory Board vets top candidates before landowner negotiations are begun. Implementation of the SE-HCP, which is still in draft form, is limited to the geographic extent of six Texas counties: Bexar, Bandera, Blanco, Comal, Kendall, and Medina. As of this writing, Kerr County has opted out of the plan; in addition, the plan is undergoing revisions and is not expected to be implemented before 2015 (Richard Heilbrun, TPW, personal communication 2013).

REGULATIONS: KEY CONCEPTS

State, regional and local regulations concerning the Edwards Aquifer deal primarily with allocating water use. Water quality standards have lagged and are not sufficiently tied to site preservation and overall impervious cover restrictions.

Structural Best Management Practices are the accepted regional method for addressing water quality; these are implemented as part of development practices but are not consistently monitored for compliance.

Impervious cover restrictions are now recognized as essential to protecting the health of the Aquifer Contributing and Recharge zones. Most communities and municipalities over the aquifer do not set restrictions on impervious cover, and those that do set them improperly on percentages of individual properties instead of total impervious cover in watersheds.

Permanent preservation of land through land purchases, easements and habitat conservation plans is optimal. Since it is unlikely communities can afford this level of protection everywhere it is needed, adequate regulation is critical.

Landscape Management for Aquifer Recharge 3

Integrated Approach to Landscape and Water Management

Effectively protecting the Edwards Aquifer requires a multi-faceted and coordinated strategy. At present, there is not a single regulatory framework that fully protects the aquifer's water quality, though several agencies contribute in part to the protection framework. As noted, each agency has a particular focus, which can lead to gaps and overlaps in the overall protection of the aquifer. Water quality regulations have focused on protecting drinking water, but current development practices where large extents of impervious cover are permitted still contribute to depletion of the resource. Understanding the aquifer as a biological system integrated with its landscape is a relatively novel perspective to many water managers who are accustomed to viewing water as a physical commodity. Treating the aquifer as a complex, constantly changing living system is essential if we are to move forward with effective management of this critical resource.

The aquifer's Contributing and Recharge zones should be managed to support and restore the landscape above the aquifer, as well as protect the riparian systems it naturally supplies. As an example of this, the Edwards Aquifer Recovery Implementation Program (EARIP) draft Habitat Conservation Plan (HCP) has proposed through its Ecosystem Restoration Subcommittee restoration measures for the Comal and San Marcos rivers. These measures are specifically targeted to habitat enhancement of the eight endangered aquatic species that inhabit the springs. Restorative landscape management should be undertaken for critical natural areas, including stream buffers. However, more landscape and biological protection measures should be implemented to protect the quality of the water entering the aquifer. These measures would be enacted in the Recharge Zone and would directly

Stormwater Planters (Photo by Troy Dorman).

protect the aquifer as well as the downstream biology that relies on the aquifer's springs and rivers.

Current storm water management systems consider runoff a pollutant and move it off-site and downstream, away from recharge features, in an effort to protect our groundwater supplies. As the region manifests its 20-50 year growth projections, every drop of clean water will be needed to support economic growth and the affordable lifestyle that attracts people to this region. New stormwater management strategies are needed now in order to recycle and use the runoff to help meet future water supply needs.

Site Analysis and Planning

Site planning and analysis is required by local governments and TCEQ as part of the development process. Special regulations are in force over the Recharge Zone to protect sensitive karst features and endangered species habitats. These regulations require surveys by qualified geologists and biologists prior to site disturbance or tree clearing. Careful development that is attuned to the site's natural hydrology and vegetation patterns will help to increase understanding in the integrity of a site and its importance to the region's natural systems and patterns (Figure 17).

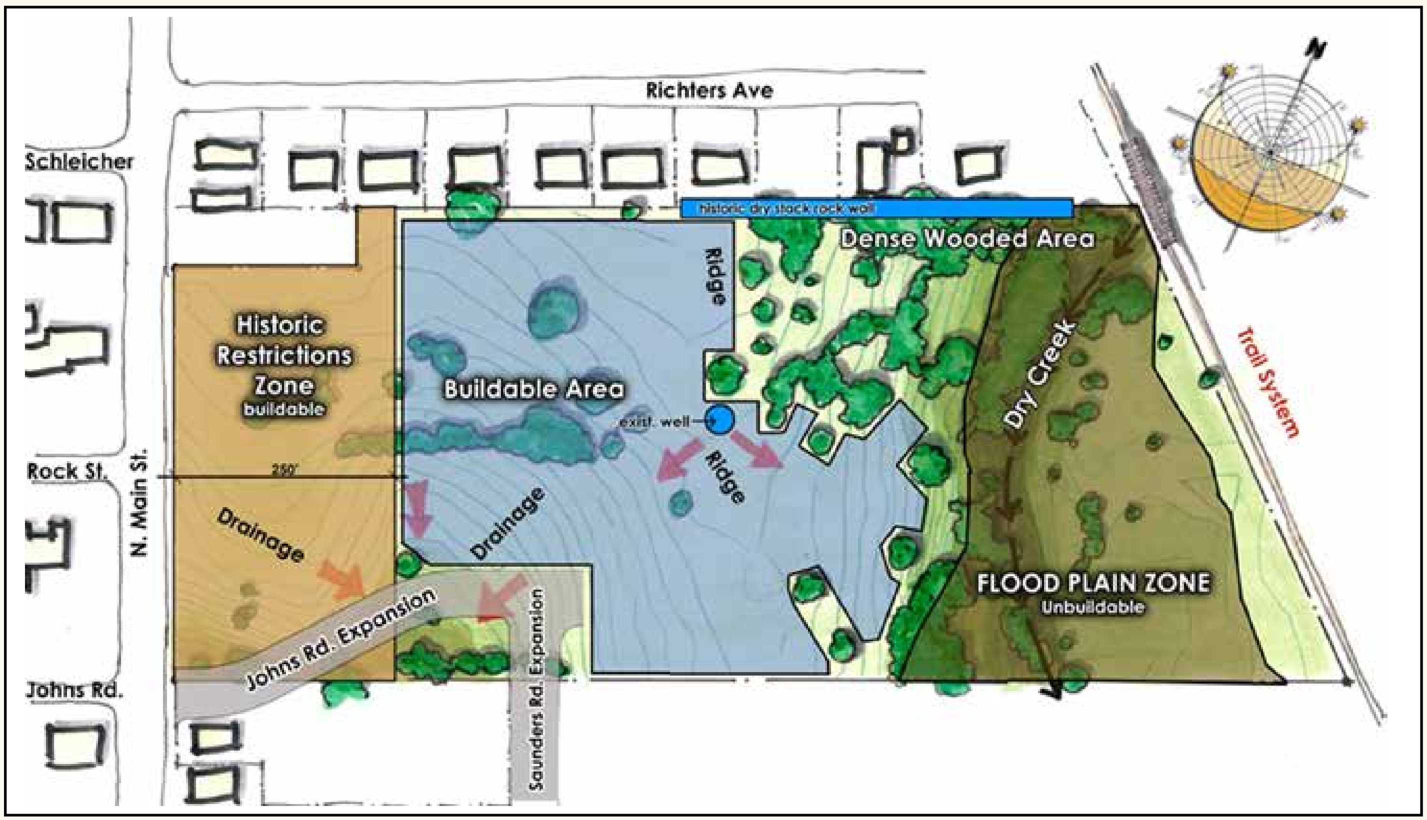


Figure 17. Site Analysis Plan developed for Patrick Heath Public Library, City of Boerne, Texas (Barwick, 2010).

The *Technical Guidance Manual* contains a chapter on Comprehensive Site Planning (Section 2.2) that should be read by anyone contemplating development over the aquifer (Barrett, 2005). The manual emphasizes a concept called “natural engineering” which attempts to preserve as many of the site’s natural features as possible to reduce the need for manmade drainage structures, engineered soils, and plantings. Although it is common practice to provide a single plan at the site development scale during this stage, a more responsive approach is to provide several plans at different scales in order to support the natural engineering concept fully and accurately. The following plans and scales are recommended:

Site Analysis Plan. Shown at a relatively large topographical scale (1″ = 200′, e.g.) and including parts of adjacent properties, the site analysis plan captures the essentials of the regional drainage system including streams and floodplains, major topographic features such as slopes and plateaus, key geologic features including Contributing and Recharge Zone boundaries, soils, and major vegetation patterns including plant community types. A Site Analysis Plan can point to features that are often overlooked at more focused scales, such as the importance of the site within its particular viewshed or a downstream feature that requires special consideration.

Site Preservation Plan. This plan is typically shown at the development scale (1″ = 100′ or less) and identifies regulated environmental factors, such as cultural/historic features, required floodplain and stream buffer widths, specific karst features, and endangered species habitat. This plan may include set-backs and buffers for karst features, endangered species habitat, and riparian areas, as well as heritage trees of a specified tree caliper or tree groupings flagged for preservation. Federal, state, and local codes will dictate what should be provided on a Site Preservation Plan, but it is important that this plan is considered as part of a responsible approach to development, and not solely as a regulatory compliance path.

Site Assessment Plan. Shown at the same scale as the Site Preservation Plan, this assessment should be the foundation of the site engineering program. The natural features uncovered during the site analysis process can be examined in greater detail to assess their condition (e.g. undisturbed vs. degraded) and assess which features (e.g. drainage swales) can feasibly be used to support the eventual site development plan.

Proposed Site Hydrology Plan. This plan can be more detailed if necessary and is developed to show how the proposed site drainage will interact with the site’s natural hydrologic patterns. The plan differs from more typical engineering plans in that the purpose is to mimic the site’s natural hydrology and keep as much water as possible on the site. Proposed LID features, such as bioswales, rain gardens, ponds, and permeable pavements will be incorporated into this plan along with engineered drainage structures.

Proposed Landscape Plan. This plan supports all of the plans listed above by ensuring that proposed plantings will function as part of a native ecosystem. Plants should be considered as part of the natural habitat and hydrologic system, used as part of landscape designs that support the ecological context. Though it is not essential that plants be entirely native, they should never be invasive and should always support an environmental sense of place (Figure 18).

Many authoritative references on the topic of site analysis and planning exist. A great general text, now in its fifth edition, is *Landscape Planning: Environmental Applications* by William M. Marsh (Marsh, 2010).

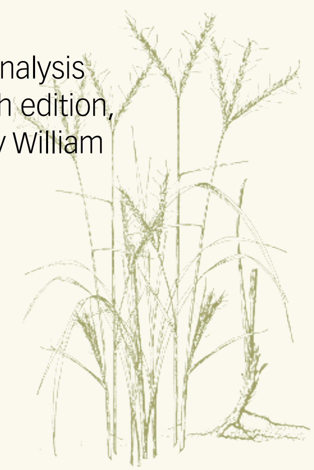


Figure 18. Landscape Plan for Patrick Heath Public Library, City of Boerne, Texas (Barwick, 2010).

Sustainable Site Design

Sustainable site design is simply a conservative approach to developing sites that reduce impacts on sensitive areas by integrating tree and landscape preservation, on-site stormwater management, and native vegetation and ecological landscape maintenance. The aim of sustainable site design is to reduce the environmental "footprint" of the site while retaining and enhancing the owner/developer's purpose and vision for the site. As envisioned by a recent set of guidelines, The Sustainable Sites Initiative or SITES™ (www.sustainablesites.org), sustainable site design concepts can reduce the cost of infrastructure while maintaining or even increasing the value of the property relative to conventional designed developments.

The Sustainable Sites Guidelines and Performance Benchmarks is a comprehensive rating system developed by the American Society of Landscape Architects (ASLA), Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the United States Botanic Garden. The guidelines formulate a detailed point system for sustainable site development that includes benchmarks for site selection, site planning, site design for water, soil and vegetation, responsible material selection and sustaining human health and wellbeing. A revised guide is scheduled for release in 2014.

The section on managing water utilizes a target value for runoff based on the water storage capacity of sites in different climatic regions, instead of the more commonly applied design storm target. Based on the Stormwater Management Model (SWMM), this approach allows stormwater engineers to use a standard stormwater methodology to more closely calculate stormwater volumes based on rainfall and hydrologic characteristics of their region (SSI, 63-77).

SITES™ BENCHMARKS

Do no harm: make no changes to the site that will degrade the surrounding environment

Support a living process: continuously re-evaluate assumptions and values to adapt to change

Precautionary principle: examine a full range of options prior to making irreversible decisions

Use a systems thinking approach: re-establish the essential relationship between natural ecosystems and human activity

Design with nature and culture: create and implement designs that respond to economic, environmental and cultural conditions

Use a collaborative and ethical approach to communication and problem-solving

Utilize a decision-making hierarchy of preservation, conservation and regeneration

Foster environmental stewardship: responsible management of ecosystems to improve the quality of life for present and future generations.

(American Society of Landscape Architects, et.al., 2009).

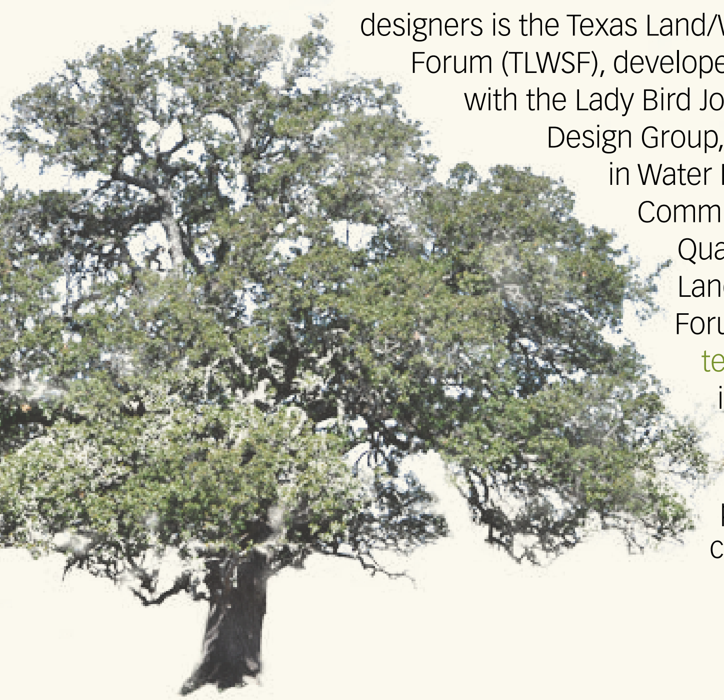
The Sustainable Sites rating system is still in the pilot project phase and is not yet part of construction codes around the US. However, it gives an excellent set of site benchmarks for sustainable design, and has the advantage that it can be adapted to local rainfall conditions and soil types, making it especially useful in the Edwards Aquifer region.

Low Impact Development

Low impact development (LID), also known as light imprint development, is a philosophy of stormwater management that seeks to mimic the natural hydrologic regime in urbanized watersheds. A basic tenet of LID is to capture and disperse stormwater within the site parcels where runoff is generated, maintaining it onsite for longer periods to reduce peak storm flows and decrease overall runoff volumes.

LID can best be understood as a set of design principles rather than a prescriptive approach. Many sources for LID principles and technologies exist in print and on the web. The Low Impact Design Center offers programs and technical publications; EPA's Wet Weather Program assists communities with implementing LID and green infrastructure, providing technical advice and funding. The toolkit section of this manual provides detailed descriptions of LID techniques appropriate for the Edwards Aquifer region, together with their rated effectiveness for water quality filtration.

A new resource for Texas water resource managers, planners and designers is the Texas Land/Water Sustainability Forum (TLWSF), developed as a collaboration with the Lady Bird Johnson's Ecosystem Design Group, Center for Research in Water Resources, the Texas Commission on Environmental Quality, and the Houston Land/Water Sustainability Forum. The TLWSF (http://texaslid.org/) features information on completed LID projects, publishes research, and promotes local chapter competitions to increase hands-on education and recognition for LID practices suitable for Texas. Notable principles of LID are described below:



Treat stormwater as a resource. Conventional site development relies on a network of pipes and inert structures to collect runoff and convey it off-site as quickly as possible. LID manages smaller storms on site to provide a host of benefits, including landscape features and irrigation. Instead of treating water as a nuisance, LID recognizes water as essential to a living site, generating multiple benefits for people and the landscape.

Manage rainwater at its source. LID duplicates natural hydrologic regimes as closely as possible. Since all developed sites contain impervious surfaces that produce runoff, LID techniques are usually sized to capture initial storm flows—termed the first flush. Collecting and managing runoff close to its source provides a preliminary level of treatment that reduces the concentrations of pollutants.

Retain and reuse water on site. LID employs a variety of methods for capturing and reusing stormwater runoff, as described in this section. Several of these methods emphasize reuse options, such as ponds, habitat, irrigation or graywater recycling for building uses. All of these methods provide benefits in addition to stormwater volume and peak flow reduction. A significant benefit of bioretention-based LID methods is natural water quality treatment, which occurs when water remains in contact with soils and plants for a period of around 48 hours.

Work with the site, not against it. LID methods should be thought of as a natural extension of site topography and hydrology. In the Edwards Aquifer region, for example, the rolling topography produces natural swales and basins that can be adapted as part of the site stormwater system. William and Nina Marsh (1995) refer to this as "micro-topography" and point to locally high infiltration rates and natural drainage basins that can be identified through a careful analysis of the site. As part of a responsive site development plan, application of this principle preserves local character and features closely associated with the Texas Hill Country landscape.

Vegetation Management

Historically, the landscape of the Edwards region was a likely a more open oak-savannah with mature live oaks and Ashe juniper and an understory of primarily native grasses (Fowler, 2005). Practices of clearing and regrowth have generated extensive patches of brushy, second-growth Ashe juniper, which can cover ground densely and are believed to uptake water that might otherwise contribute to groundwater. A brush management concept—managing springflow and aquifer recharge by clearing excessive brush and understory trees has been studied through models and field testing, notably through a long-range brush removal program conducted in the Honey Creek watershed north of San Antonio (Banta and Slattery, 2011).

For the study, brush removal was done by cutting the Ashe juniper near ground level with hydraulic tree shears attached to a skid-steer loader. This method, which is recommended where soil erosion is an issue, kills the tree with minimal soil disturbance compared to conventional practices of bulldozing trees. Locations were chosen to ensure that the habitat and nesting season of the endangered Golden-cheeked Warbler were not adversely affected, since this bird typically nests in mature Ashe juniper woodlands (Banta and Slattery, ibid). About 70% of the Ashe juniper present on site was removed using selective clearing method of leaving desirable plants standing while removing other trees (Phillip Wright, cited in Banta and Slattery, ibid).

Removing Ashe juniper and allowing native grasses to reestablish in the area as a brush management conservation practice does increase streamflow to some extent, the study concluded. The difference is not large, but it is statistically significant and gives useful guidance for land managers looking to decrease runoff and increase potential groundwater recharge. Recommendations for vegetation management for groundwater recharge are listed below.

Whatever the removal method, the newly restored habitat should be maintained wherever feasible with periodic controlled burns. Prescribed fire, or controlled burning, can be used as a primary control method in certain areas, or as a follow-up to chemical or mechanical treatment. Following up a mechanical treatment with a prescribed burn will lengthen the effectiveness of that treatment (Rasmussen, et.al. 1986). Prescribed burning must comply with National Resources Conservation Management practices as well as local codes and ordinances.

Partial funding for brush control for enhanced site management is available through the Edwards Aquifer Authority's (EAA) Range Management Cost Share Program, funded by the EAA and U.S. Natural Resources Conservation Service (NRCS). Landowners can receive funding for over 75% of Ashe juniper removal if they enroll in the NRCS Environmental Quality Incentive Program (EQIP) and/or Wildlife Habitat Incentive Program (WHIP) and their property is within EAA's jurisdictional boundaries (www.edwardsaquifer.org).

Recommended practices for vegetation management for groundwater recharge (EAA Range Management Cost Share Program brochure) include:

1. Enroll in EQIP and/or WHIP and develop an approved plan for brush management, with assistance from NRCS.
2. Identify and delineate potential Golden-cheeked warbler habitat with assistance from Texas Parks and Wildlife (TPW).
3. Perform brush management in compliance with the NRCS approved plan, using a certified contractor.
4. To maximize groundwater recharge, vegetation management should utilize selective clearing and replanting with native grasses to avoid soil disturbance.
5. Follow up with brush control maintenance with assistance from NRCS, using a mechanical method or prescribed burning.

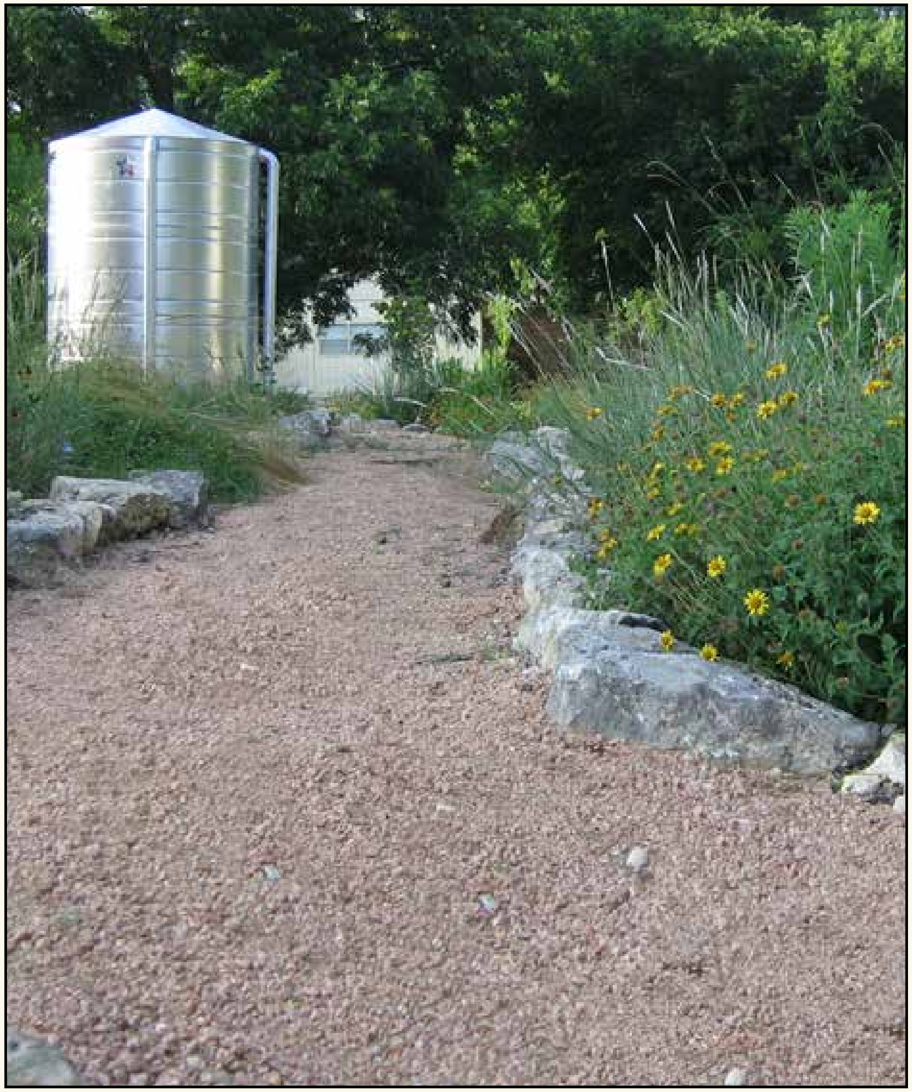
Photo by Janet Thome

This section focuses on a set of LID practices that are appropriate to the Edwards Region for aquifer recharge and replenishment of surface streams. The focus is deliberately on vegetated methods that mimic a functioning ecosystem, instead of engineered techniques such as sand filters or proprietary systems such as storm filters. Several well-known national practices, including green roofs and constructed wetlands, are not presented in detail here, primarily because the focus of this LID document is on recharging water into the aquifer system. Green roofs and constructed wetlands are also more appropriate in environments where no makeup water is required to sustain the installation.

Vegetated techniques, such as rain gardens and bioswales, require some design, construction, and maintenance. These techniques are therefore considered to be structural methods in the overall low-impact lexicon, versus non-structural methods. Non-structural LID techniques include landscape preservation, tree protection, and preservation of riparian areas and stream buffers. Another set of non-structural techniques, based on methods of Integrated Pest Management (IPM) reduces the applications of pesticides and fertilizers (Barrett, 2005, chapter 2).

Contributing Zone Strategy

Onsite infiltration near the point of origin is the optimal strategy across the Contributing Zone, assuming the soils are sufficiently permeable. This approach relies on dispersing and distributing stormwater to multiple smaller bioinfiltration sites, taking advantage of micro-topographic opportunities that exist on the landscape surface. Relatively “clean” runoff from building rooftops can be directed to rain gardens for rapid recharge through modified or



Cistern and rain garden at the Mendard Public Library installed by Texas A&M AgriLife Extension Service, and Texas Master Gardener and Texas Master Naturalist volunteers. Photo by Justin Mechell engineered soils (see section on Rain Gardens later in this chapter). Parking lot and roadway runoff must meet the Edwards Rules requirements for detention time prior to infiltration through native or engineered soils. The City of Austin Environmental Criteria Manual (Austin ECM) requires a treatment time of 48 hours, a typical period for water quality improvement (Austin ECM, Section 1.6.2, 2012). Maximizing infiltration across the Contributing Zone will slow peak discharge and minimize the need for downstream detention facilities.

Recharge Zone Strategy

The optimal treatment strategy for stormwater runoff across the Recharge Zone is "capture, treat and recharge." Due to the sensitivity of this area, not all runoff is treatable to safe recharge standards. Therefore it is critical to monitor water quality in lined treatment facilities before it is directed to an infiltration facility or a local stream channel, where much recharge occurs. Some water will be lost to evaporation from lined treatment ponds or bioswales, which will not contribute to aquifer recharge. Evaporation loss needs to be considered when implementing LID techniques.

General Design Guidelines

- Size LID treatment facility to capture a minimum volume of 0.5 inch of stormwater runoff
- Capture and hold runoff for 48 hours before release (may vary according to local regulations)
- Route off-site runoff contribution around low impact development treatment facility
- Install impermeable liners for bioretention facilities for the Edwards Aquifer Recharge Zone

Infiltration

Though the current TCEQ regulations do not allow infiltration over the Recharge Zone, properly sized bioretention methods will treat roof runoff to TCEQ water quality standards. TCEQ rules sometimes allow LID coupled with infiltration as an innovative practice. Substantial documentation of treatment effectiveness, including water quality monitoring, is required for consideration of a variance to the Edwards Rules.

The bioretention and filtration methods described in the following section will treat water to the level required by the Edwards Rules by removing 80% of Total Suspended Solids (TSS). Most LID practices will treat water to this standard, as described in Table 2. Since standing water will evaporate, lessening the volume of water available to infiltration, drainage layers of crushed stone and perforated underdrains are necessary for bioretention facilities (see Bioretention Systems in this section, or the *Technical Guidance Manual*, Section 3.2.6).

BARTON SPRINGS

The City of Austin Environmental Criteria Manual (Austin ECM) is the regulatory document for low-impact development in Austin, including the Barton Springs Recharge and Contributing zones. For projects within the City of Austin, this manual should be used only for general information purposes, not as a handbook for design of low impact development features. Section 1.6.7 covers design guidelines for water quality management, including biofiltration ponds, porous pavement for pedestrian use, vegetative filter strips, retention-irrigation systems, rainwater harvesting and rain gardens. Maintenance requirements are incorporated in the water quality design guidelines of the Austin ECM (City of Austin, Section 1.6.3).

Stormwater Treatment Train Concept

The stormwater treatment train concept is engineers' shorthand for describing an integrated plan for onsite stormwater management, employing a range of LID techniques and best management practices. The basic concepts are:

- create and sustain a long flow path for captured rainwater,
- slow water velocity to reduce erosive force,
- infiltrate water in appropriate locations following treatment,
- allow for evaporation of excess volumes through retention, and
- discharge treated water to streams for aquifer recharge.

LID techniques are usually employed in a combination or sequence in the treatment train, building a redundant system where no one LID method stands alone (Figure 19). For example, vegetated swales are often used as the first component of a LID system that manages roadway runoff, where water is directed to a bioretention feature and eventually to a stream, where it may be recharged to the aquifer. In a building environment, roof runoff water may be directed to a cistern, then to a stormwater planter or rain garden for water quality treatment, then discharged to a stream or reused as site irrigation.

LID methods used as part of a stormwater treatment train are advantageous for the Edwards region, since the water quality benefits are multiplied to achieve the necessary Total Suspended Solids (TSS) load reduction. The rationale and equations for using LID BMPs in series are provided in the *Technical Guidance Manual* (Section 3-32) and illustrated in this manual in the Case Study Section (Barrett, 2005).

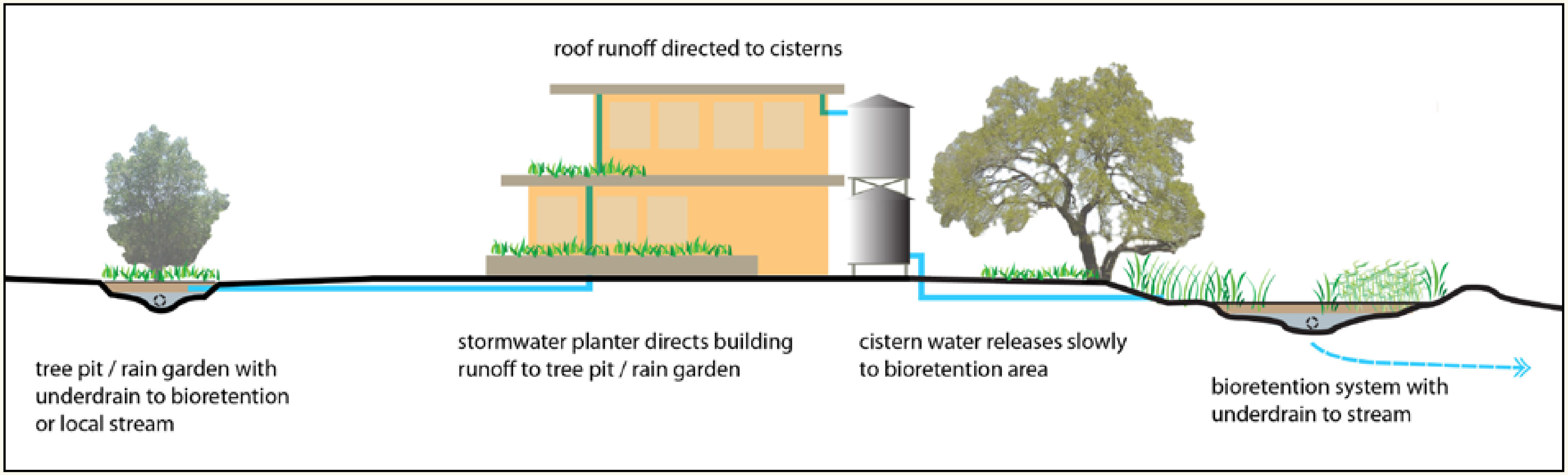


Figure 19. Diagram of stormwater treatment train with captured and treated runoff conveyed to streams for base flow or recharge.

Selecting LID Methods

Low impact development methods are selected depending on the slope of the site, size of drainage area, available space on site once the building elements are established, and whether the LID system is dispersed or centralized in location. The Austin ECM illustrates an approach to determining which LID methods are most appropriate for a site (Figure 20).

When assessing low impact options for the site, the first option is always to reduce impervious cover as much as possible. The second step is to reduce runoff directly at the source through rainwater harvesting, which benefits a project by collecting rainwater for reuse on the site.

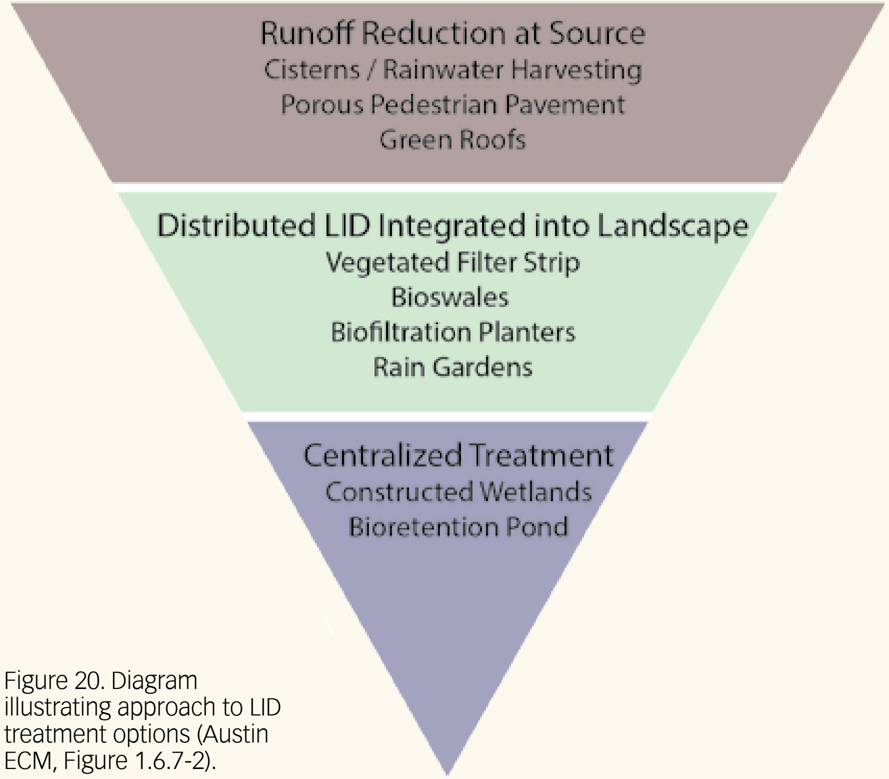


Figure 20. Diagram illustrating approach to LID treatment options (Austin ECM, Figure 1.6.7-2).

Low impact development methods should be designed together with planned impervious surfaces. For example, pedestrian walkways constructed of porous pavement increase local groundcover permeability and filter pollutants. Breaking up large expanses of pavement into smaller paved areas which drain to LID features will also disperse runoff throughout the site, allowing water quality treatment nearer the source. Opportunities for connecting LID features, such as vegetated filter strips and bioswales, should be studied to maximize water quality treatment. Once these possibilities are exhausted, remaining stormwater can be discharged to a centralized biofiltration pond or wetland facility. While these larger facilities have a significant site footprint, they are planted with native vegetation and will provide wildlife benefits that traditional detention facilities do not.

Table 2. A list of LID techniques along with their respective applications, benefits in water reduction and quality improvement and landscape values, and the maintenance required (Source: EPA Office of Water (2000).

LID BMP	APPLICATIONS	VOLUME REDUCTION	WATER QUALITY	LANDSCAPE VALUES	MAINTENANCE
BIORETENTION, BIOSWALES	Medium Sites, Parking Lots	Peak volume reduction	TSS Reduction 90%, Heavy Metals 90%, Nutrients 25-75%	Water, Plant Diversity, Habitat	Plant and Mulch Replacement, Soil Replacement (5-10 yrs), Medium Cost
BIOFILTRATION PLANTERS	Sidewalks, Street Edges	Peak volume reduction	TSS Reduction 90%, Heavy Metals 90%	Urban Greening, Air Quality Improvement, Climate Amelioration	Weeding, Replanting Mulch Replacement, Medium Cost
CONSTRUCTED WETLANDS	Large Sites, Residential Septic	Storage and peak reduction	TSS Reduction 90%, Heavy Metals 90%, Nutrients 50%	Water, Plant Diversity, Habitat (surface wetlands)	Higher Cost of Construction, Soil Replacement, Periodic Plant Replacement
DRY DETENTION BASINS	Medium-Large Sites, Developments	Storage and peak reduction	TSS Reduction 90%	Grassland Open Space	Occassional Mowing
FILTER STRIPS	Roadways, Agriculture	Minimal to none	TSS Reduction 85%, Heavy Metals 90%	Habitat, Air Quality Improvement	Mowing, Periodic Seeding, Low Cost
GREEN ROOFS	Building Roofs	Peak volume reduction	Heavy Metals 90%	Urban Greening, Air Quality Improvement	Replanting, Weeding, Low to Medium Cost
INFILTRATION TRENCHES	Rooftop Runoff	Peak volume reduction	TSS Reduction	Aquifer Recharge	Replanting, Weeding, Low to Medium Cost
POROUS PAVEMENT	Parking Lots, Alleys, Walkways	Storage and peak reduction	TSS Reduction 80%	Urban Greening (depending on type)	Periodic (annual) Sweeping, Low Cost
RAIN GARDENS	Small Sites, Residences	Mimimal peak reduction	TSS Reduction 90%, Heavy Metals 90%	Residential Landscapes, Backyard Habitat	Replanting, Weeding, Medium Cost
RETENTION-IRRIGATION	Large Sites, Golf Courses Parking Lots,	Storage and peak reduction	TSS Reduction 100%, Heavy Metals 90%, Nutrients 90%, Bacteria > 70%	Designated Landscapes, Turf Maintenance	Irrigation System Servicing, Weeding, Soil Replacement, High Cost
VEGETATED SWALES	Roadways Large Sites	Some if used with check dams	TSS Reduction 85%, Heavy Metals 90%	Urban Greening, Air Quality Improvement	Mowing, Low Cost
WET BASINS		Storage and overall volume reduction	TSS Reduction 90%, Heavy Metals 90%, Nutrients 50%	Habitat, Scenic Values	Periodic Sediment Removal

Note: This list is more comprehensive than the techniques discussed in detail in the following section. Readers should consult sources in the listed references and for more detail on green roofs, retention irrigation and other methods not described fully in this manual.

Bioretention Systems

The concept of bioretention, basic to many techniques for low impact design, is a land-based practice that uses chemical, biological and physical properties of plants, microbes and soils to mitigate stormwater volumes and provide water quality treatment within the landscape. Rainwater runoff is captured in one or more shallow basins or specially designed planters, filtered through a soil medium, and infiltrated into surrounding soils or directed through conveyance pipes to nearby streams. Bioretention is especially effective at treating the "first flush," generated by the initial half-inch of rainfall, where the majority of common pavement pollutants enter the surface water.

Bioretention is the underlying concept in LID methods that rely on water being held for a specified period of time, in contact with soils and vegetation, which do the work of water quality treatment. Several types of bioretention systems are covered in this chapter, including bioretention ponds, bioswales, biofiltration planters and rain gardens.

Figure 21 is a diagram of the basic components of a bioretention basin. The bioretention soils layer is only as deep as necessary for plant roots to thrive, generally between 18 inches and 36 inches for grass species.

Bioretention Ponds

Bioretention areas or ponds differ from retention ponds, which are designed to hold, or retain, a large volume of runoff water for an indefinite period of time. Bioretention ponds provide water quality treatment through a biofiltration media containing native plants adapted to both wet and dry conditions. The ponds are designed to incorporate many of the pollutant removal mechanisms that operate in natural marsh habitats. As often as not, they will appear as dry depressions in the landscape that will fill up with water during rain events.

Physical mechanisms by which bioretention works:

Interception: collection and capture of rainfall or runoff by plant leaves and stems or soils.

Infiltration: downward movement of water through soils, providing treatment and groundwater replenishment.

Evaporation: water taken back into the atmosphere from plants, soil surfaces and shallow pooled water.

Transpiration: water taken up by the plants and released to the atmosphere, providing air moisture and cooling.

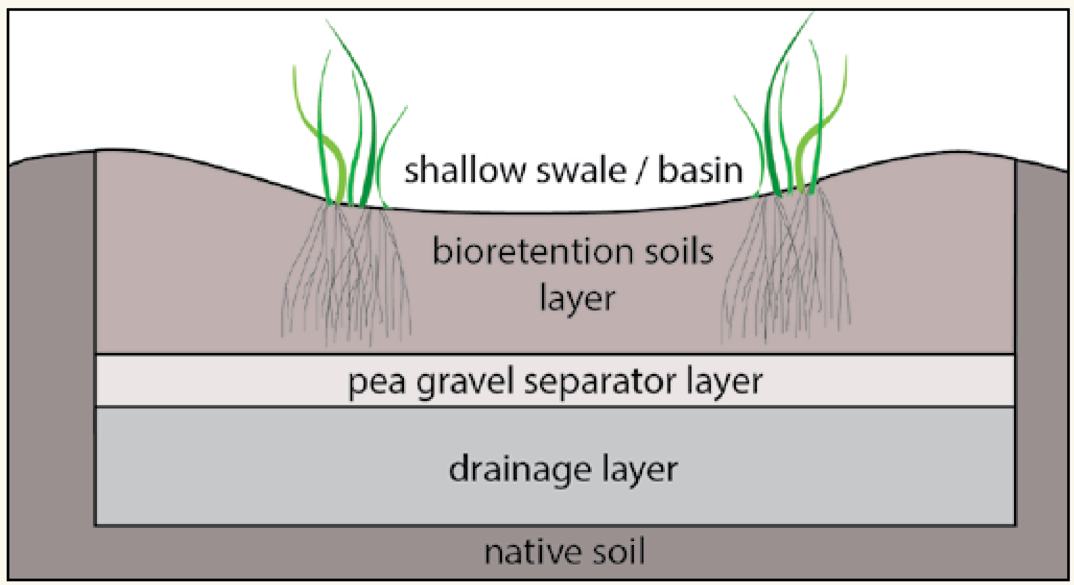


Figure 21. Diagram of typical bioretention layers.

Under the TCEQ Edwards Rules, bioretention ponds must have both an underdrain and liner when in use over the Recharge Zone (Barrett, 2005). Liners are not required for the Contributing Zone, so bioretention ponds can serve to infiltrate water into the underlying soil layers. In an unlined bioretention system, captured runoff filters through an engineered or modified soil mix, is collected in a perforated underdrain and returned to the drainage system, where it can be released through swales into creeks and streams. Unlined bioretention systems are planted with adaptable native vegetation that tolerates standing water but can also adapt to the dry periods common to Texas.

Forebays, vegetated swales or sedimentation basins, extend the life of bioretention ponds by pre-treating runoff in order to protect the biofiltration media from becoming clogged prematurely by sediment. Forebays are sized smaller than the main bioretention area, since their function is simply to allow sediment to settle before water flows to the main basin (Figure 22). They play a vital role in water quality treatment, reducing total suspended solids and associated pollutants such as metals and oils. Including a forebay and vegetated swale as components of the bioretention treatment chain also reduces the area needed for the main facility. Forebays should be designed to allow removal and replacement of accumulated and/or contaminated sediment.

Key considerations for use in the Edwards region are the type of underlying soils and geology, whether the system can infiltrate or requires a liner and underdrain system, and the selection of plants that can tolerate a foot of water for 48 hours, as well as lengthy periods of drought. Biofiltration facilities used for water quality treatment in new developments are not accepted as stand-alone devices in central Texas, as of yet, but are very appropriate for use in retrofit scenarios if space is available.

Sizing Bioretention Systems

The size of the bioretention system depends on its watershed, or catchment area, and the volume of runoff the system is required to address. Bioretention volumes are calculated differently than those of retention or detention basins, since bioretention systems are designed to only capture smaller storms, essentially the 1 to 1 ½ year frequency event, or the first half-inch of runoff (Austin ECM, Section 1.6.2).

Section 3-3 of the *Technical Guidance Manual* spells out the procedure for calculating bioretention volumes based on the net increase of impervious surface from development. Bioretention systems will meet minimum TCEQ requirements for BMPs with a TSS removal performance of 80% so they can be used as standalone BMPs. However, bioretention systems will perform better over time if used with a filtration BMP, such as a grassy swale, which can function as pretreatment and sediment capture for retention-based BMPs. The addition of a small upstream sediment basin, or forebay, to the main bioretention area will perform the same function. It is important to oversize the bioretention system by 20% to accommodate sediment deposition that occurs between maintenance activities (Barrett, 2005).

For stormwater volume calculations for the Edwards region, see the *Technical Guidance Manual*, Section 3-3, pages 3-26 to 3-37 (Barrett, 2005).

Bioretention Pond Design

As bioretention and biofiltration have become more widely accepted methods to meet water quality regulations, water quality and volumetric calculations should be performed by a licensed water quality engineer or hydrologist. Most jurisdictions also require a professional engineer's seal on stormwater management and erosion control plans. Rough designs and functions of the pond system for planning purposes have been adapted from the Austin ECM and are available below (Figure 22). For a definitive design, consult a licensed engineer or hydrologist.

The diagrams show a sedimentation basin receiving runoff, either from a grassy swale, from sheet flow, or directly from an impervious surface. Larger ponds receiving significant volumes of water should have a control device located at the upper end of the basin. This device, called a splitter, or flow separator, splits large flows into an overflow pipe and separates fast moving water into several flows so that water does not concentrate and form channels. Sedimentation

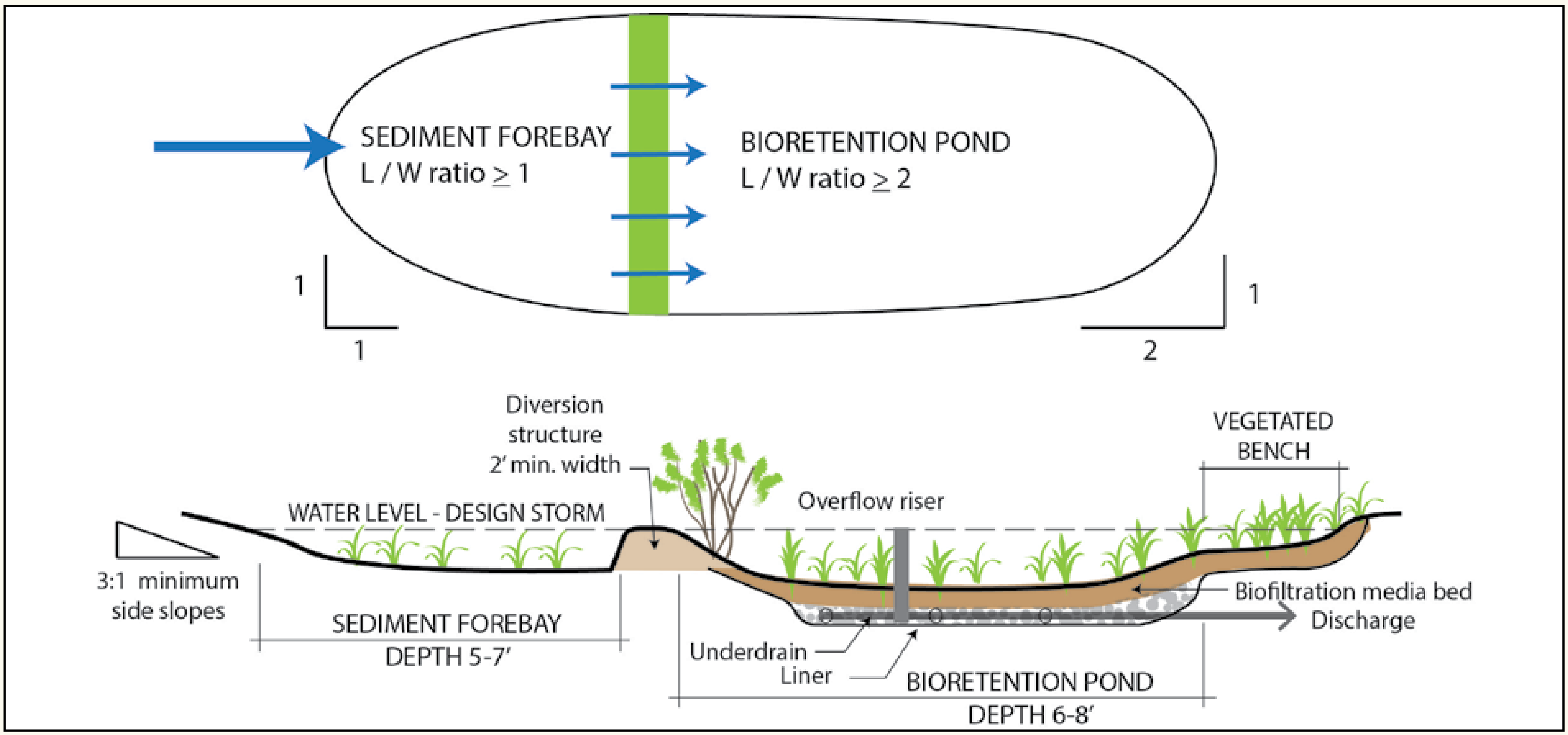


Figure 22. Schematic diagram and section showing typical bioretention pond (Austin ECM, Section 1.6.6 and 1.6.7).

basins are separated from the biofiltration pond by a diversion structure, which can be a gabion or earthen berm. A planted hedgerow on the pond side for additional stabilization is optional (Austin ECM, Section 1.6.7.C).

The bioretention pond is usually larger than the sedimentation basin and is the primary water quality treatment area (Figure 23). An underdrain piping system is suggested to ensure drainage over the Contributing Zone and is required for the Recharge Zone. Liners for ponds must be either a 12" thick clay liner, a concrete liner or a 30 mil geomembrane liner (Barrett, Table 3-6 p.3-38, 2005). Clay liners should be designed for site-specific conditions by a geo-technical engineer.

The pond is surrounded by a vegetated bench, which is typically 5-15% of the pond area and planted with standing water-tolerant plants. The top of the vegetated bench is designed to be at the level of the permanent pool, or design storm. Appropriate plants for the vegetated bench can be found in the Plant Selection Guide to follow.

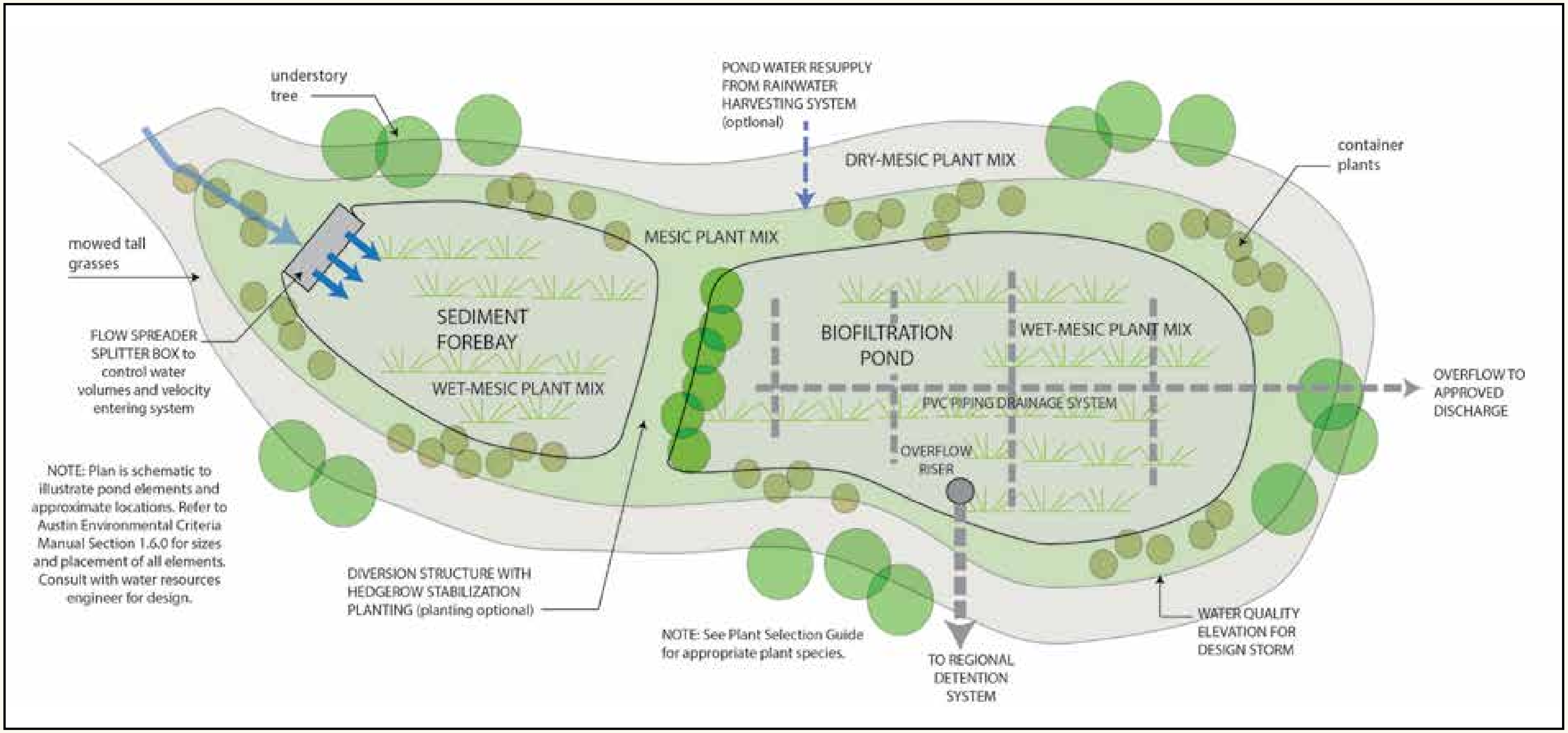


Figure 23. Typical plan of a bioretention pond (Austin ECM, Section 1.6.7.C and Bioretention Manual for Prince George's County, Maryland).

Appropriate uses for bioretention ponds

- Onsite water quality ponds serving sites of 10 acres or less, especially where habitat creation is desirable.
- As part of a treatment train for larger sites (not sole treatment source).
- Locations where peak storage of stormwater volume and slow release is needed, such as urban or suburban watersheds with limited downstream floodplains.
- Areas in need of green infrastructure benefits such as noise reduction, climate mitigation, shade, pollution reduction, or landscape interest.
- Schools or environmental education locations as a living ecology demonstration.

Limitations of bioretention ponds

- Ponds cannot be placed on steep slopes.
- TCEQ Edwards Rules require liners and underdrains for bioretention ponds over the aquifer Recharge Zone.
- Not a sole treatment source for sites with significant impervious areas.
- Not suitable where the water table is within 6 feet of the surface and in unstable geology or sinkhole areas.
- Construction cost of bioretention systems somewhat higher than other LID practices due to the cost of liners, underdrain systems and control structures (required by TCEQ in the Recharge Zone).

Water quality benefits of bioretention ponds

- Effective removal of total suspended solids (TSS) reported in range of 86% to 98%.
- Effective removal of 90% of heavy metals - copper (Cu), zinc (Zn), and lead (Pb) prevalent in urban environments. Nearly all heavy metal removal occurs in top few inches of organic layer.
- Phosphorous (P) and organic nitrogen (N) removal are most effective in ponded facilities and also most effective with soil depths of 2-3 feet.
- Removal of bacteria (*E. coli*, etc.) will occur, but bioretention alone will not remove bacteria to human contact standards.

Costs of bioretention ponds

- Main costs for a bioretention pond are excavation, soil media, liner, underdrain, inlet and outlet control structures, and plant material.
- The Low Impact Design Center suggests a budget between $10-$40 per square foot, depending on the engineering materials required and the extent of planting.
- Costs can be offset as part of required site landscape for new developments.
- Design and engineering costs (8-12% of installation) should be factored in, unless included in an overall site planning process.

Maintenance considerations

- Media replacement every five-ten years needed to remove accumulation of sediments.
- Test soils prior to disposal to ensure contaminants are disposed of properly (Table 3).

Bioretention Media Mixes

Bioretention media mix design is essential to the performance and longevity of biofiltration systems. While the mix must contain enough fines and organic material to sustain vegetation and slow down infiltration rates, too much of these components may cause systems to clog prematurely, reducing or eliminating water quality benefits. Also, organic material percentages in the range of 10-20%, common elsewhere in the nation, are high for this region and may encourage weed growth over the native vegetation which is adapted to low nutrient soils. Locally sourced materials are strongly suggested to maintain similar nutrient profiles. The topsoil should be the same type as the native soils on the site and obtained as close to the installation as possible, preferably within 75 miles. Soil tests are suggested to ensure that the final mix conforms to the percentages of organic material found in native soils.

A LID handbook prepared for the City of San Marcos suggests considerations of alternative media mixes using local materials in place of sand as the filtration component:

These [alternative media design options] include crushed limestone, crushed (and recycled) glass, or manufactured sand. These additional options are acceptable to use as they function similar to sand and provide a more sustainable media as they are locally sourced, and often recycled. However, if using one of these media types such as crushed glass, it is important to include a small amount of organic matter for the vegetation. [Couch, 2011, Section 2.3.4(5), p23].

There is no one media mix appropriate for every situation across the Edwards region (Table 4). A suggested general guideline is to use an engineered mix where more rapid drainage is desirable, and to use a modified native soils mix where some water retention for native vegetation is desired. The engineered mix could be used for a stormwater planter (see section below), while a modified native soils mix might be more appropriate for a bioretention pond or a rain garden. The City of Austin has its own low-organic biofiltration media mix with detailed soil specifications, which could also be used throughout the region (Limouzin et al., 2011).

Maintenance Checklist for Bioretention Systems

DESCRIPTION	METHOD	FREQUENCY	TIME OF YEAR
Establishment Watering	By Hand	Daily During Establishment Period	Spring, Fall
Inspect and Repair Erosion	Visual	Monthly	Monthly
Replenish Mulch Layers	By Hand	Annual	Fall
Remove and Replace Dead/ Diseased Vegetation	Mechanical or by Hand	2 Times a Year	Spring, Fall
Inspect and Treat Diseased Plants	Varies	Quarterly	As Needed
Soil Replacement	Mechanical	Once Every 5 Years	Spring

Table 3. Maintenance checklist for bioretention systems.

Media Mixes for Biofiltration and Bioretention Systems

ENGINEERED SOILS MIX FOR BIOFILTRATION
BIOSWALES, BIOFILTRATION PLANTERS, RAIN GARDENS
75-90% Clean Sand
0-4% Organic Material
10-25% Screened Locally Sourced Topsoil
MODIFIED NATIVE SOILS MIX FOR BIORETENTION
BIORETENTION PONDS
50% Clean Sand
25% Crushed Local Stone with Fines
25% Locally Excavated Soil

Table 4. Media mixes for biofiltration / bioretention systems.

Rain Gardens

Rain gardens are essentially small-scale bioretention facilities designed to disperse and filter water from micro-watersheds, such as roofs. Rain gardens are frequently installed in residential backyards, accepting drainage from downspouts or adjacent paving into a landscaped depression. The soil mix is designed to convey water within a few days into the underlying soils for infiltration. Multiple rain gardens are sometimes dispersed across a residential subdivision and incorporated into the landscape as natural features. In areas where concern for aquifer contamination is an issue, rain gardens should drain into underdrain system for conveyance to a biofiltration system for further treatment before discharge to surface streams.

Rain gardens are designed specifically for water quality purposes that help meet mitigation requirements for development, and are subject to local regulations much as a conventional stormwater device. The Austin ECM accepts a number of LID techniques, including rain gardens, biofiltration and vegetated strips, as Innovative Water Quality Controls (IWQCs). With regard to Austin, an unlined rain garden is not acceptable as a primary method for controlling pollution from stormwater runoff within the Barton Springs Recharge Zone and Barton Springs Contributing Zone. If a rain garden is proposed for use in the Barton Springs zones, a liner is required and discharge managed as per city ordinance (Austin ECM, Section 1.6.7).

Rain gardens as part of commercial developments should manage water for catchment areas under one acre, holding water for 24-48 hours, which will necessitate use of a liner and underdrain system over karst. Rain gardens used this way, as part of a system that disperses stormwater collection prior to conveying it to a larger retention feature, will decrease downstream treatment volumes, lessening the burden and cost of the overall system.

Figure 24. Rain garden at the Lower Colorado River Authority Redbud Center. (Source: Austin Land Design).

Rain Garden Sizing Guidelines

Rain gardens for residential properties are often sized according to the available space in the landscape and typically deal with relatively small volumes, generated by part of a house rooftop, for example (Figure 25). Wisconsin Department of Natural Resources has a publication, *Rain Gardens: A How-To Manual for Homeowners* (Bannerman and Considine, 2003), that provides helpful direction for small-scale rain gardens, between 100-300 square feet. The key issues concern depth of garden, type of soils, and how much rooftop area drains to the garden. The main concepts are summarized here:

How deep should the garden be?

- Typically four to eight inches deep, deep enough to pond water for a short, 24-48 hour period of time.
- 3-5 inches deep for flat sites up to 4% slope (1 foot drop for every 25 feet length).
- 5-7 inches for slopes between 4% and 7% (1 foot drop for every 15 feet length).
- 7-8 inches for slopes 8-12% (1 foot drop for every 8.5 feet length).
- Slopes above 12% pose difficulty for creating a level rain garden.

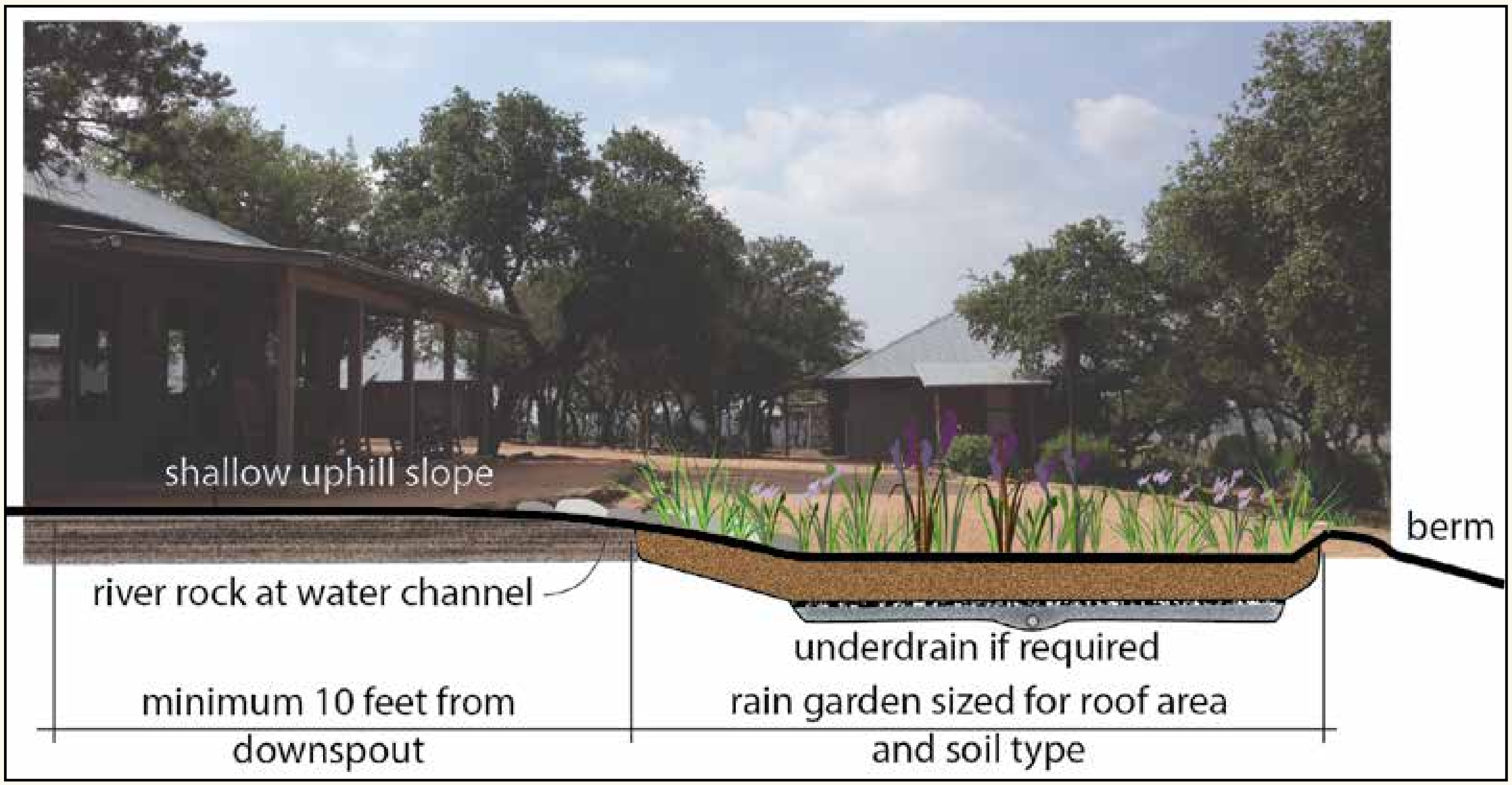


Figure 25. Typical rain garden location for residential or small commercial use.

How big should the garden be?

- Determine the square footage of rooftop area draining directly to the garden and the distance from the downspout to the garden.
- Determine the type of soils on site; visible sand or large particles indicate a sandy soil while clumping, thick soils usually indicate clays.
- Use the soils factor table (Table 5) to determine the garden's size factor by comparing soil type to depth. Clayey, poorly drained soils will require a larger area, while well-drained sandy soils will require less space.
- Multiply the size factor by the rooftop drainage area. This number will be the recommended garden size.
- If the size is much greater than 300 square feet, break up the rain garden into smaller areas.

Soils Factor for Determining Size of Rain Garden

GARDEN <30 FEET FROM DOWNSPOUT				GARDEN >30 FEET FROM DOWNSPOUT	
	3-5″ Deep	6-7″ Deep	8″ Deep		All Depths of Soil
Sandy Soil	0.19	0.15	0.08	Sandy Soil	0.03
Silty Soil	0.34	0.25	0.16	Silty Soil	0.06
Clay Soil	0.43	0.32	0.2	Clay Soil	0.1
Source: *Rain Gardens: A How-To Manual for Homeowners, pages 4-9.*					

Table 5: Desired soil profile for a rain garden.

Plant Selection Guidelines

Rain gardens for the Edwards area are designed as low-nutrient environments, duplicating the surrounding karst-based soils. Low-nutrient demanding native plants will thrive in a low-organic soil mix. Grasses and native shrubs are recommended; grasses especially have large root systems to facilitate biofiltration. Small trees with shallow root systems, like the Texas persimmon (Diospyros texana) are ideal, as the bio-retention soil volume is not occupied by roots.

Garden configuration can be determined by available space and aesthetic preferences. Many gardens use a kidney shape to fit into the landscape contours, which allows for two slightly different depressed areas and a center swale stabilized by boulders. Taller grasses and forbs can be planted in the center areas, with shorter plants around the outer edges.

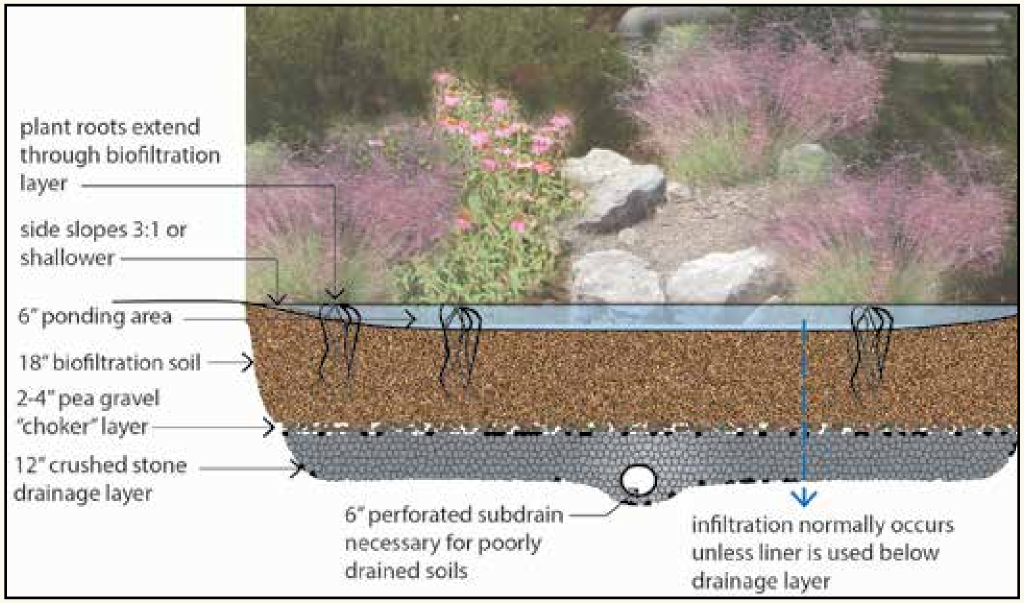


Figure 26. Rain garden soil profile suggested for this area, with a minimum of 18″ biofiltration media mix (Table 4). Below the growing media, a choker layer of pea gravel separates the media from a drainage layer. Geotextile fabrics can serve this purpose, however these are prone to clogging.

Given the high evaporation rates in Central Texas, rain gardens will be dry much of the time. Wetland plants that thrive mainly in standing water will not do well, so choosing grasses and forbs that are adapted to a range of conditions is essential, especially if the rain garden is expected to infiltrate water (Figure 27). The Plant Selection Guide provided at the end of this section lists plants according to the range of conditions they tolerate. Appropriate plants will be adapted to moist or mesic conditions.

Appropriate uses for rain gardens

- In the Contributing Zone of the Edwards Aquifer for water quality treatment and peak flow reduction during rain events.
- In the Recharge Zone as part of overall dispersed treatment systems that reduce the burden on retention or detention systems.

Limitations of rain gardens

- Only for initial treatment and conveyance over the Recharge Zone due to potential for aquifer contamination from fertilizer or herbicide runoff from adjacent lawns.

Water quality benefits of rain gardens

- Effective at removing total suspended solids and metals; less effective at removing organic pollutants due to the desired rapid draindown time.

Costs of rain gardens

- Vary depending on the excavation and soil amendments needed; underdrains and liners will increase cost.
- Residential systems cost $8-15 per square foot; underdrain system not included.
- Commercial systems cost $10-40 per square foot; assume some subsurface conveyance is needed.

Maintenance considerations

- Periodic weeding and plant replacement are the only maintenance requirements for residential rain gardens.
- Larger scale rain gardens may require removal of soil volumes if the contributing area carries and deposits sediment in the garden.

Figure 27. Residential rain garden planted with Penstemon ‘Huskers Red’, black-eyed Susan (not in bloom) and blue flag iris. (Photo by Marita Roos).

Bioswales

Bioswales are carefully graded, vegetated swales designed to convey water slowly across the land. They can capture low flows of water for infiltration or carry runoff from heavy rains to storm sewer inlets for gradual release directly to surface streams. Bioswales can also be designed with a series of check dams in steeper terrain (greater than 4%), providing essentially the same function as a sequence of small bioretention ponds (Figures 27a and 27b). Ideally, natural channels can be enhanced and utilized as bioswales; in these instances, it is important to preserve as much existing vegetation as possible.

Bioswales should have a shallow (1-3%) linear gradient, to promote infiltration and prevent erosion from rapidly moving flows. A parabolic or trapezoidal shape is recommended with side slopes no steeper than 3:1 and ideally much shallower, 10:1 or 20:1. Swales should be sized to convey a 10-year storm, about 6 inches in 24 hours for south central Texas. Limiting compaction during construction will help preserve soil infiltration functions and reduce the flows during heavy storms.

Bioswales are very similar in function to grassy swales, which are discussed later on in this section. The main difference is that bioswales often provide additional stormwater retention time for water quality treatment, and are planted with a diverse range of forbs, shrubs or trees in addition to grasses.

If a bioswale is designed to convey water from a parking area or roadway, it will be assumed to carry contaminated water. Bioswales over the Recharge Zone will require a liner to eliminate the risk of contaminated runoff directly infiltrating into the aquifer. In this scenario, the bioswale should drain into a biofiltration pond for additional treatment prior to discharge into a natural area.

Appropriate uses for bioswales

- Alternative to culverts or storm sewers to convey runoff across the landscape.
- To convey and treat roadway runoff where space exists along wider roadway verges.
- Sites where landscape enhancement is desirable, such as near schools or residential developments.

Limitations of bioswales

- Require greater widths than culverts, hardened swales or grassy swales.
- Will not effectively drain very flat areas and are at risk of eroding on steeper sites.

Figure 27a. Potential site for LID bioswale on The University of Texas at San Antonio main campus.

Water quality benefits of bioswales

- Effective removal of total suspended solids (TSS) in range of 90%.
- Heavy metals reductions similar to bioretention ponds.
- Water quality benefits increase if water is ponded behind check dams.

Costs of bioswales

- Generally less expensive when used in place of underground piping.
- Costs vary greatly depending on size, plant material, and site considerations.

Maintenance considerations

- Often incorporate a mowed edge to create a defined biofiltration zone and neater appearance.
- Require less water than turf swales, and fertilizers are not recommended for native plantings
- Deep-rooted native plants are recommended for infiltration and reduced maintenance.
- Can be mowed; native plants should not be mowed less than six inches to retain plant base and avoid disruption to root systems.

Figure 27b. Same site with example check dams and vegetation for additional bioretention treatment.

Biofiltration Planters

Biofiltration planters, also called biofilters, flow-through planters or stormwater planters, are structured planters, often linear in form, that capture rainwater runoff from adjacent surfaces—rooftops, sidewalks, streets or parking areas (Figure 28). Biofilters are planted with vegetation that can take a wide range of moisture, since they are completely dry between rain events. Like bioretention systems, biofilters treat water using plants and soil medium, releasing treated water through subsurface drainage systems connected to adjacent landscape areas or local streams (Figure 29).

Unlike bioretention systems, biofiltration planters do not pond water for extended time periods and are designed to drain within 48 hours or less. Flow-through planters are a specific type of biofiltration planter and are designed to collect roof or surface runoff and filter sediment and pollutants as the water infiltrates through the planter. Excess water collects in a perforated pipe at the bottom of the planter and drains to a treatment train system or a bioretention pond. Flow-through planters are recommended for the Edwards Recharge Zone and Barton Springs Contributing and Recharge zones due to the lack of natural drainage in the soils and sensitivity of the underlying aquifer.

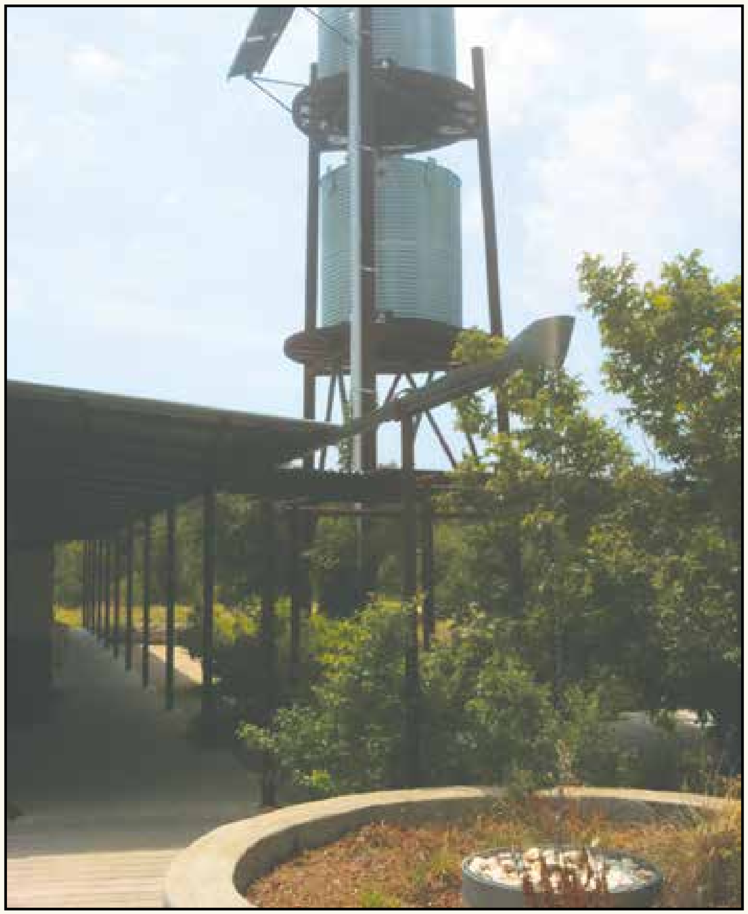


Figure 28. Biofiltration planter with rain chain conveyance at Government Canyon State Park, Texas.

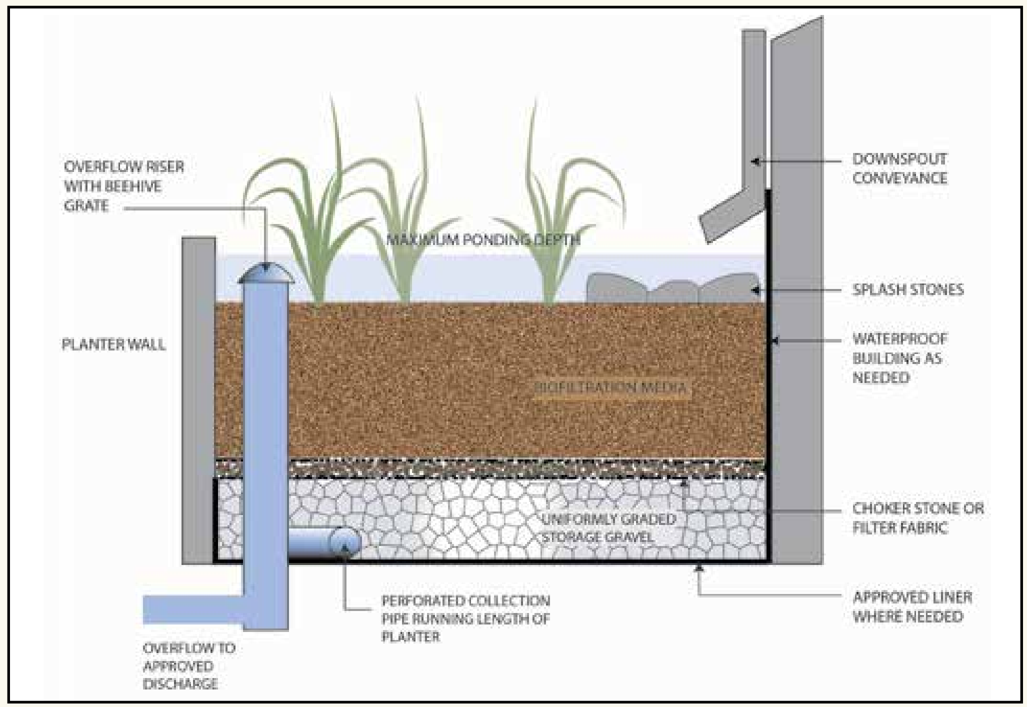


Figure 29. Detail diagram illustrating how biofiltration planter works. (Adapted from Stormwater Reference Manual, Eugene OR 2008).

Biofiltration planters are coming into much greater use in the urban green streets movement (Figure 30). Green streets promote walkability in downtowns and residential areas, contributing to economic development and cleaner urban environments. Biofiltration planters are a relatively low cost way to treat smaller volumes of roadway runoff (Figure 31) and offer multiple benefits for community greening. Biofiltration planters are described in detail in a recent reference for the southwest U.S., *Green Infrastructure for Southwestern Neighborhoods* (MacAdam, 2010). The book provides details of street biofilters and a unique methodology for sizing the planters based on limited available right-of-way.

It is important to note that biofiltration planters by themselves will not provide adequate treatment for use over the Recharge Zone, since they cannot sufficiently treat roadway runoff to required treatment standards. Their recommended use here is as part of a stormwater treatment train connected to a larger biofiltration system, so that water can be held and treated for longer periods of time.

Appropriate uses for biofiltration planters

- Urban sites with limited room, especially within street right-of-ways and places where pedestrian or landscape interest is needed.
- In combination with streetscape planting, including canopy trees for shading and air pollution mitigation.
- Without containment curbs to handle sheet flow, for example in parking lot islands.
- Infiltration or flow-through planters; flow-through planters have underdrain systems beneath soil beds.

Limitations of biofiltration planters

- Not used to control large volumes of rainwater; biofilters usually manage first flush, or the initial half-inch of runoff after a storm event.
- Stone placement is needed where water enters planter to prevent erosion of mulch layers.
- Biofiltration planters require a liner and underdrain over the Recharge Zone.

Figure 30. Roadway biofiltration planter located in street right-of-way, Tucson AZ.

Figure 31. Roadway biofiltration with stormwater inundation. (Photos courtesy of Watershed Management Group).

Water quality benefits

- Removal of TSS and heavy metals is similar to bioretention systems (Table 6).
- Nutrient removals are less effective due to space limitations for ponding water.

Costs of biofiltration planters

- Pricing should consider savings that may accrue as contributions to water quality mitigation credits, or credits against development impact fees or municipal stormwater fees.

Maintenance considerations

- Annual mulch and plantings inspection, with replacement as needed.
- Media replacement every five years to remove accumulation of sediments; more frequent replacement may be needed if planters are adjacent to streets due to greater accumulation of urban pollutants.
- Test soils prior to disposal to ensure contaminants are disposed of properly.

Sizing Flow-Through Stormwater Planters

STEPS IN SIZING PLANTERS (FLOW -THROUGH)	FORMULA (FROM TECHNICAL GUIDANCE MANUAL SECTION 3.3, BARRETT 2005)
CALCULATE WATER QUALITY VOLUME	WQV = Rainfall depth x Runoff Coefficient x Area
Enter rainfall depth of 0.05 inches representing first flush of runoff. Convert 0.5 inches to feet by dividing by 12.	SQV = (0.5/12) x Runoff Coefficient x Area
Use standard runoff coefficient table for impervious cover areas. Typical roof runoff has coefficient of 0.98, meaning that nearly all water will runoff.	WQV = 0.042 x 0.98 x Area
Enter area of impervious surface. Example is a 5,000 sf roof.	WQV = 0.042 x -.98 x 5,000 sf
WATER QUALITY VOLUME IN CUBIC FEET	WQV = 204 cubic feet

Table 6. Calculating water quality volume for stormwater planters.

Filtration Methods

Filtration methods are an important component of LID treatment trains and are normally used in combination with bioretention systems. Their primary use is conveyance vs. final treatment, since filtration methods do not possess the capacity to retain water for the period of time needed for biofiltration. Filtration techniques treat the first flush of water from impervious surfaces by removing sediments and total suspended solids. Generally removing at least 80% of the TSS, filter devices in good condition provide excellent water quality benefits in combination with allowing reduction in the size of bioretention basins.

Filter Strips

Filter strips are vegetated areas gently sloped to slow stormwater velocity, filter sediment and associated pollutants, and provide limited infiltration of runoff. They are successfully used to receive sheet flow runoff from roadways and parking lots, providing pretreatment before runoff enters another LID facility. Filter strips perform a similar function as stream buffers, which are natural areas of riparian vegetation adjacent to surface waterways and creeks, often part of the natural stream floodplain.

Filter strips are extremely useful in any situation where adjacent lands produce large volumes of runoff, such as agricultural lands, turf lawns, and impervious areas. Filter strips are cost effective alternatives to storm drains and piping systems since they disperse runoff as well as provide initial treatment. A team from the University of Texas and Texas A&M conducted tests that show filter strips are very effective as pretreatment measures along Texas state highways, with most treatment occurring in the first 18" of width (Barrett et al., 2006).

Filter strips are good candidates for seeding instead of planting due to their relatively large surface areas and consistent slope. Stabilization mulch or erosion control fabric is required as part of the initial installation. Crimped straw or fabric that biodegrades in one year is suggested, and Texas Department of Transportation (TXDOT) regulations require the use of a binder or blanket for slopes greater than 15%. Figure 32 illustrates their basic design. Native plant and wildflower mixes are strongly recommended to increase local biodiversity and climate tolerance. The LBJ Wildflower Center can suggest a mix appropriate to the particular site conditions; another good source is Native American Seed of Junction, Texas (see Appendix A for links to these and other sources).

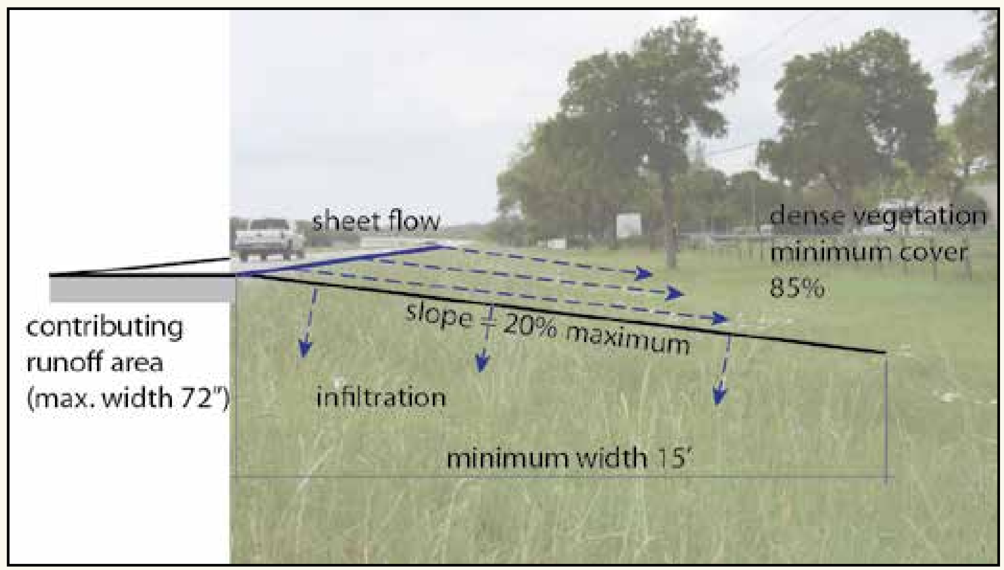


Figure 32. Schematic diagram of roadway filter strip. (Adapted from Couch, 2011).

Appropriate uses for filter strips

- Manage sheet flow from impervious surfaces, such as roadway and driveway edges, and parking lots.
- Manage sheet flow from agricultural fields and turf lawns.

Limitations of filter strips

- May require a level spreader or some method of spreading runoff evenly across the filter strip; care should be taken while grading to avoid potential gullying and erosion.
- May provide limited benefits in slopes >20%.

Water quality benefits of filter strips

- Initial pretreatment, including reduction of total suspended solids and heavy metals.

Costs of filter strips

- Seeding with crimped straw mulch = $0.92 per square yard or $4,450 per acre.
- Seeding with cellulose fiber mulch (applied with hydroseeder) = $0.30 per square yard or $1,450 per acre (TXDOT, 2013).

Grassy Swales

Grassy swales are probably the most common LID method in use given their cost effectiveness and applicability to many development scenarios, including retrofits. Grassy swales are shallow planted linear trenches that slow concentrated flows prior to releasing them downstream or to the aquifer. Swales are great candidates for use in a stormwater treatment train, for example, conveying water from a hardscaped area to a bioretention facility. Grassy swales provide several important benefits, including slowing stormwater velocity, infiltration of small amounts of runoff volumes, and pretreatment of stormwater runoff prior to discharge into a stream or another LID facility.

As with filter strips, grassy swales should be planted with native vegetation wherever possible to maximize biodiversity and habitat benefits. Swales may require check dams if the longitudinal slope exceeds 2%, depending on the erosive tendency of the underlying soils, and are a necessity if the slope exceeds 4%. Side slopes should not exceed 3:1 (3’ vertical distance to 1’ horizontal distance) or about 18% (Figure 33).

A civil engineer should be consulted if grassy swales are intended to carry substantial flows, since knowledge of hydraulic engineering is needed to ensure that water does not overwhelm or erode the swale. A general rule of thumb for sizing is that swale surface area ought to be no less than 1% of total catchment area (University of Florida, 2008).

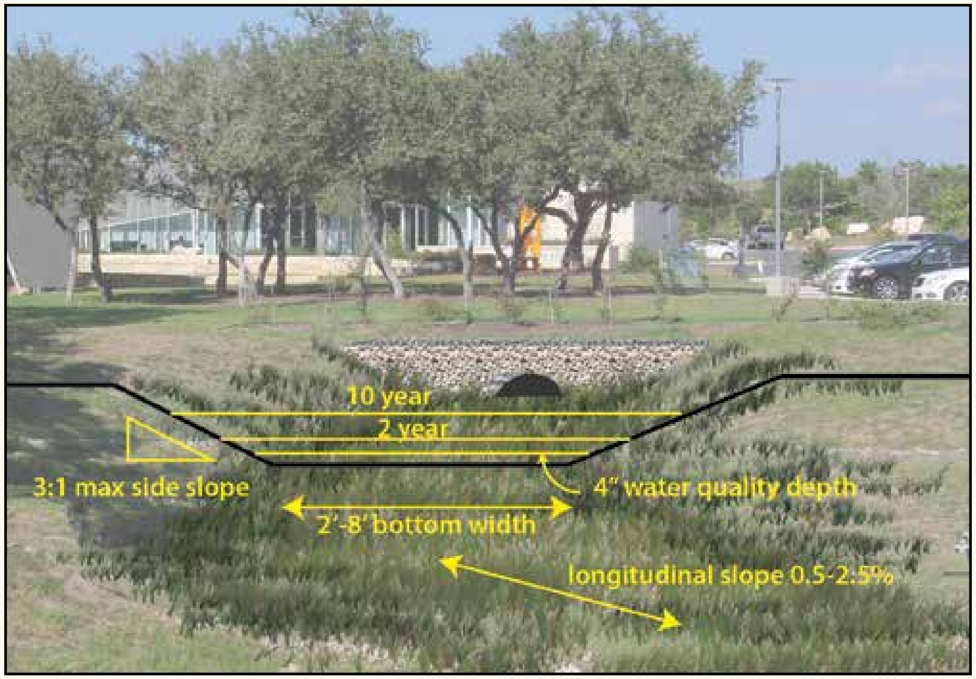


Figure 33. Typical diagram of grassy swale. (Source: Huber, 2011).

General criteria for grassy swales include (TGM Manual 3-52)

- Channel length sufficient to provide a minimum water residence time of 5 minutes.
- Channel slope at least 0.5% and no more than 2.5%.
- Side slopes do not exceed 3:1 (H:V).
- At least 80% vegetated cover to provide adequate treatment of runoff.
- Maintain water contact with vegetation and soil surface by selecting fine, close-growing, water resistant grasses.

Appropriate uses for grassy swales

- Conveyance devices as part of a stormwater treatment train.
- Replacements for curbs and gutters where conditions permit.
- Standalone LID BMPs where catchment areas are smaller and where soils do not infiltrate readily.

Limitations of grassy swales

- Erosion in steep areas and water ponding in flat areas.
- When used as standalone devices over karst, may infiltrate pollutants into aquifer, since they are not designed for sufficient pollutant uptake.
- Should not receive construction stage runoff to prevent sediment overloading.

Water quality benefits of grassy swales

- Similar to filter strips: sediment removal and heavy metals, depending on length of swale (200 feet is often considered a minimum for pretreatment benefits).

Costs of grassy swales

- Slightly higher than for filter strips, particularly in erosion-prone sites where erosion blankets will be required.
- Grass plugs cost more than seed but establish cover much more quickly; costs for deep-rooted nursery-grown plugs are less expensive than plant pots, typically less than $1.50 apiece, and offer substantial benefits in terms of establishment time and plant vigor.

Maintenance considerations

- Mowing is the accepted maintenance practice; steeper slopes should be managed with a grass trimmer.

Grass Mix

Short native grasses adapted to a range of moisture conditions are recommended. Douglas King Company offers several native seed mixes formulated with the LBJ Wildflower Center. Bagged mixes are Habiturf™ Lawn Mix or King's Short Native Grass Mix, available from Douglas King Company (see Appendix A). Note that grass seeds are fluffy and will require a carrier during seeding.

Native grass species typically used in the mixes:

- Buffalograss—*Buchloe dactyloides*
- Blue grama—*Bouteloua gracilis*
- Sideoats grama—*Bouteloua curtipendula*
- Curly mesquite—*Hilaria belangeri*
- Little bluestem—*Schizachyrium scoparium*

Pervious Pavement

Pervious or permeable pavement is an open graded pavement application that allows water to flow directly through the pavement mix—usually asphalt or concrete—into one or more sub-base layers and eventually into the soil matrix underneath (Figure 34). Pervious pavement is a fairly well developed set of techniques that has been in use for over twenty years in the US, generally for low traffic areas such as parking spaces, driveways, and similar uses. Several websites, including the EPA's menu of Best Management Practices, have specifications and test examples of pervious pavement performance (EPA, 2000). Originally engineered for light duty traffic, newer applications include highways and industrial applications. TXDOT has begun to use permeable asphalt extensively for its noise reduction and safety benefits, since the danger of spray and hydroplaning is substantially reduced.

Grass paver systems consist of concrete, metal, or plastic grids of squares or rings that are filled with well drained soil mixes and planted with tough grass species. These systems are more popular in small installations with light traffic, such as small commercial parking areas (Figure 35), or fire lanes for campuses and industrial parks. Soil and subgrade preparation, plant selection, type of use and maintenance are important factors to consider when considering this type of pavement.

Pervious pavements used in larger areas often drain to stone filled recharge beds below grade, which are sized to capture a specific volume of local stormwater. Usually the recharge beds contain an underdrain that conveys overflow water to nearby storm drains, so the recharge bed contains sufficient void space to infiltrate the initial storm event only.

Permeable pavements may not be appropriate when land surrounding or draining into the pavement exceeds a 20% slope, where pavement is down-slope from buildings or where foundations have piped drainage at their footers. The key is to ensure that drainage from other parts of a site is intercepted and dealt with separately rather than being directed onto permeable surfaces.

The City of Austin limits the use of pervious pavement to pedestrian surfaces only, out of concern for aquifer contamination from direct infiltration (Austin ECM).

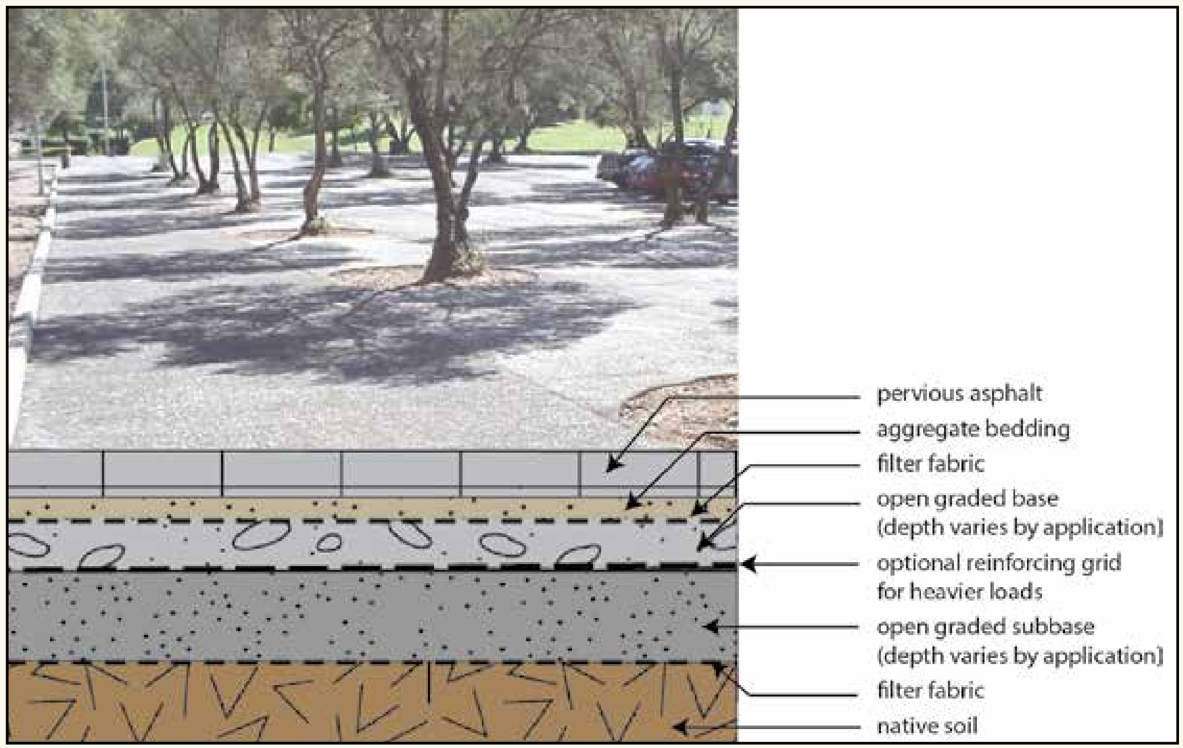


Figure 34. Typical section of pervious pavement. (Diagram adapted from Huber, 2011).

Appropriate uses for pervious pavement

- Best used in larger site designs as part of capture and conveyance to a bioretention or other treatment facilities such as swales, roof rainwater collection, catchments, and strategic landscaping with native vegetation.
- Light duty permeable pavements, such as pavers and thinner asphalt and concrete applications, are suited for low-traffic areas, such as supplemental parking lots and pedestrian walkways.

Limitations of pervious pavement

- Not suitable for direct infiltration above the Edwards Aquifer.
- Best suited for well drained sand and gravelly soils and is not suited for expansive soils such as heavy clays or for use directly over bedrock.
- Requires a flat site, 1-2% grade, so that stormwater doesn't simply run off.
- Should be used to capture rainwater, not stormwater runoff, from adjacent sites.

Costs of pervious pavement

- For pavement layers: asphalt $0.50-1.00/sf; concrete $20/sy; grass geoblock $2.00-$3.00/sf. Costs are for installed surface layers, since subbase layers are similar to conventional pavements.
- Substantial costs will occur if additional storage or recharge beds are needed, since these require excavation up to three feet, underdrains, filter fabric, and stone to fill the beds.
- Costs for permeable paving should be considered in the context of overall stormwater infrastructure, since water volume captured by pervious pavements can reduce the need for expensive stormwater infrastructure such as curbing, storm sewers, and additional treatment facilities, creating net savings.

Maintenance of pervious pavement

- To prevent clogging, porous concrete and asphalt systems must be periodically vacuumed or pressure washed to remove fine debris—typically no more than once per year for most uses.
- Grass paver systems require careful design, planting and maintenance so that they drain sufficiently, grasses have sufficient time to become established, and traffic is not concentrated or excessive.

Figure 35. Permeable pavers in San Antonio parking lot. (Photo by David Dods).

Cisterns

Cisterns or rain barrels are simply a means to capture roof runoff or air conditioning condensate and store the water for reuse on site or in building graywater systems. Cisterns are well represented as part of the agricultural landscape of central Texas, along with windmill-driven pumps. As an LID technique, cisterns provide storage and slow release of water to bioretention facilities or landscape irrigation systems. If used as part of an onsite water quality treatment plan, cisterns should be sized to drain within 120 hours (Austin ECM, Section 1.6.7.D). It should be noted that cisterns alone do not provide water quality treatment.

The green building movement has taken a great liking to cisterns in the Austin-San Antonio region and they are fairly ubiquitous on LEED-rated buildings. Cisterns come in many sizes, depending on their purpose. A municipal building in San Antonio has three 3,000-gallon sized cisterns that hold air conditioning condensate for landscape irrigation (Figure 36); the Pearl Brewery complex has five cisterns as of this writing, including two 7,500 gallon refurbished beer brewing tanks (Figure 37). A recommended source for overall rainwater harvesting guidance is the *Texas Manual on Rainwater Harvesting* (Texas Water Development Board, 2005).

Figure 36. Cisterns capture air conditioning condensate for reuse, San Antonio city administration building.

Cisterns are excellent for use as part of the overall LID treatment train. Since they can be integrated into the building design, and used to capture only clean roof runoff, they could potentially be used for direct aquifer recharge. Under this scenario, cisterns might drain into permeable stone seepage pits or dry wells without lined bottoms. No regulations exist to permit this use at the time of this writing, but it may be worth considering for larger building developments.

Calculating Cistern Volumes

The following method for determining cistern volumes is adapted From *Rainwater Harvesting For Drylands and Beyond* (Lancaster, 2006)

Let's say we want to size our cisterns to capture the volume of water for a two-inch storm event, which occurs on average about once a year in the Edwards region. We have a building that measures 100 feet long and 40 feet wide at the drip line. To determine the runoff from such a rain event, divide the 2 inches of rainfall by 12 inches of rainfall per foot to convert inches to feet for use in the equation. Since the roof is a rectangular area, use the following calculation for catchment area:

Figure 37. Cisterns at Pearl Brewery in San Antonio capture roof runoff for landscape irrigation.

Volume = length (ft) x width (ft) x rainfall (ft) = maximum runoff in cubic feet

Multiply cubic feet x 7.48 = maximum runoff in gallons = cistern volume needed.

Example: Building roof area (100 ft x 40 ft) x rainfall (2 in ÷ 12 in/ft) = maximum runoff (cubic feet). Multiply result by 7.48.

4,000 ft2 x 0.167 ft x 7.48 = 4,996 gallons

In this example, a 5,000 gallon cistern will capture much of the water needed to supply a rain garden or bioretention facility of about 600 square feet, assuming an underdrain is provided. If no underdrain is used and soils are clay, the rain garden area would need to be increased to manage longer retention volumes. See the Rain Garden section for using soil factor to calculate garden sizes.

Case Study – A LID Site Development

Site and Building Program

A 7,200 square foot office building with parking for 36 cars, plus 10 car overflow, is planned for a 4.0 acre site in Comal County. The site is over the Edwards and Trinity aquifers' Contributing Zone and the proposed impervious cover will total 28% of the site. Although Comal County does not currently restrict impervious cover, nearby San Marcos restricts impervious cover to 30% for sites between 3-5 acres. The developer decides to voluntarily limit impervious cover to the San Marcos standard and additionally to utilize LID to protect water quality.

The site is undeveloped with no impervious cover and no offsite runoff contributing to the site water balance. The property is rolling topography with oak-juniper cover and thin soils over gravelly rocky substrate. No streams or wetlands exist and no sensitive karst features are known to exist on the site. Several live oaks over 30" caliper are present in the south part of the site, so the developer decides to concentrate development elsewhere on the property (Figure 38).

Figure 38. Site plan showing office development with LID. Blue arrows indicate general direction of flows. Dashed lines indicate pipes; solid lines are surface flows.

Reducing Total Suspended Solids Under TCEQ Rules

The main regulatory requirement for water quality is the TCEQ rule that the site BMPs capture at least 80% of Total Suspended Solids (TSS). The developer is considering a combination of LID techniques to achieve the required treatment for the volume of water that is discharged from the site impervious surfaces. LID techniques used in combination yield better treatment efficiencies than used alone, so a bioretention swale system used in combination with a dry shallow detention basin for overflow yields an efficiency of 93%, compared to 89% for bioretention alone (calculated separately).

The first step in designing the stormwater system is to calculate the runoff capture volume needed to achieve a TSS reduction of 80%. For this calculation, two inputs are needed, the net increases of proposed impervious area and the average annual rainfall for the county. Impervious area is calculated by adding up the square feet of paving and rooftop and converting to acres to simplify the subsequent calculations.

BEST MANAGEMENT PRACTICE	TSS REDUCTION (%)
Retention / Irrigation	100
Cartridge Filter System	95
Permeable Paving with underdrain	95
Wet Basins	93
Constructed Wetlands	93
Sand Filters	89
Bioretention	89
Vegetated Filter Strips	85
Extended Detention Basin	75
Grassy Swales	70

Table 7: BMP efficiency at removing Total Suspended Solids. (Source: Barrett, 2005).

Formula 1:

Required TSS load removal (L) = 27.2 (constant) * 1.12 (total impervious) * county rainfall in inches

The required 80% TSS reduction for the site is calculated at 1,005 lbs, based on a total impervious surface of 1.12 acres and an average county rainfall of 33 inches per year. With the TSS load removal calculated, the designer determines whether the LID techniques being considered are sufficient to capture the volume necessary for the time needed to achieve the TSS removal. NOTE: All calculations performed are shown in a table in the appendix.

Initial Steps for Designing a LID Treatment System

LID works best by separating stormwater volumes wherever possible, so that smaller amounts of water can be captured and dispersed around the site. In this example, we are using two 3,500 gallon cisterns to collect the runoff from the two primary roofs from the 1.5 inch storm, approximately 6,500 gallons. The 1.5 inch rainfall volume represents the threshold of 95% of rainfall events, meaning that 5% of storms are greater than 1.5 inch of rain in 24 hours. The cisterns will effectively remove most of the roof area from contributing runoff except in the case of more extreme rainfall events.

CONTRIBUTING ELEMENT	AREA		IMPERVIOUS SURFACE	
Sidewalks and building surround	7,250	sf	0.17	imp acre
Parking area (45 cars)	34,500	sf	0.79	imp acre
Roof	6,850	sf	0.16	imp acre
Total impervious surface (site + roof)	48,600	sf	1.12	imp acre
Subtract roof volume using cisterns	-6,850	sf		
Total site impervious surface	**41,750**	**sf**	**0.96**	**imp acre**
Site impervious factor	**24%**			

Table 8: Impervious surfaces contributing to site runoff, case study.

As part of calculating volumes for LID, the cisterns must be able to fully discharge into the landscape at an interval not exceeding 120 hours. If we recalculate the required TSS reduction, assuming the cisterns can handle the bulk of roof runoff, the required TSS load is 862 lbs. The remaining runoff is generated from the paved walkways, driveway and parking lot. This water must be treated, since paved surfaces have contaminants from car traffic. The designer has decided to use a bioswale with overflow into a shallow meadow basin, to treat the remaining runoff. To see if these LID techniques will work, it is necessary to run additional calculations that determine the runoff coefficient, total sediment removed, and the capture volume needed for the LID system.

Water Quality Calculations

Formula 2:

TSS removed = BMP efficiency * (Impervious area) * 34.6 (constant) + pervious area * 0.54 (constant) * annual county rainfall

Using a BMP efficiency of 93% for the combined LID, an impervious area of 0.96 acre, a pervious area of 3.04 acres and county rainfall of 33 inches, we can see that the bioretention system will need to remove a total sediment load of 862 lbs. Had we not used the cisterns, the number would be 1,237 lbs. This difference of 370 lbs. will allow us to downsize the rest of the LID system, as shown below.

Next, we calculate the fraction of annual rainfall treated by the LID system. This is a simple ratio, dividing the required load reduction (from Formula 1) by the TSS removed (from Formula 2). The fraction of annual runoff to be treated is 80% (81.2% without cisterns).

At this point, we need to consult a table developed for central Texas to determine the water quality volume needed for the LID system. This table uses the value for fraction of annual rainfall treated, calculated above, to supply the associated depth of rainfall that can be treated.

The runoff treatment fraction of 80% indicates a rainfall depth of 1.08 inches. The table, sourced from the Technical Guidance Manual (Table 3-5, 3-35) is reproduced in the appendix following this case study. Note the table would yield a value of 1.12 inches without the cisterns.

We can now use a graph (Figure 39) to give the runoff coefficient for this particular site. If the site were 100% impervious, the runoff coefficient would equal 1, which is 100% runoff. The relationship is not exactly linear, as can be seen from the graph below (reproduced from Technical Guidance Manual, 3-36). In this example, an impervious cover of 24% yields a runoff coefficient of 0.23 (without cisterns an impervious cover of 28% yields coefficient = 0.25).

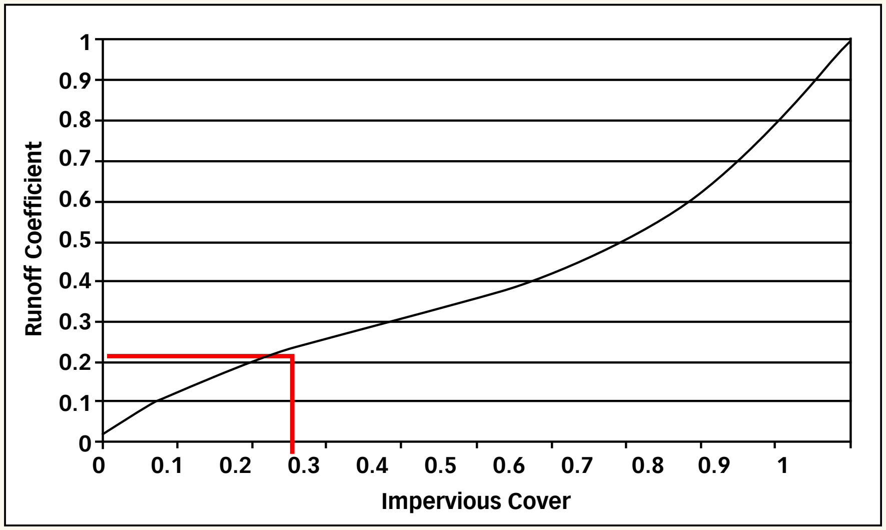


Figure 39. Runoff coefficient relationship to impervious cover. (Source: Barrett 2005).

Formula 3:

Water quality volume = Rainfall depth * Runoff coefficient * Area

The water quality volume needed from our LID system is usually expressed in cubic feet, so the necessary conversions from rainfall (inches) and contributing impervious area (acres) must be converted to cubic feet. The resultant water quality volume needed for our system is 865 cubic feet. This is usually rounded up by 20% to give a safety factor, so the figure we will use is 1,040 cubic feet. Compare this volume to that needed without the cisterns, 1,118 cubic feet, increased to 1,341 cubic feet and we see that the cisterns potentially make a real difference in the size of the LID features needed.

Designing a LID System

The LID features shown on Figure 40 are a parking lot bioswale (7,150 square feet) and two stormwater planters within the paved building plaza (450 square feet each). A 16,500 square foot overflow meadow is shown for overflow capture. Water drains into the parking lot bioswale by means of curb cuts or stormwater inlets sited at low

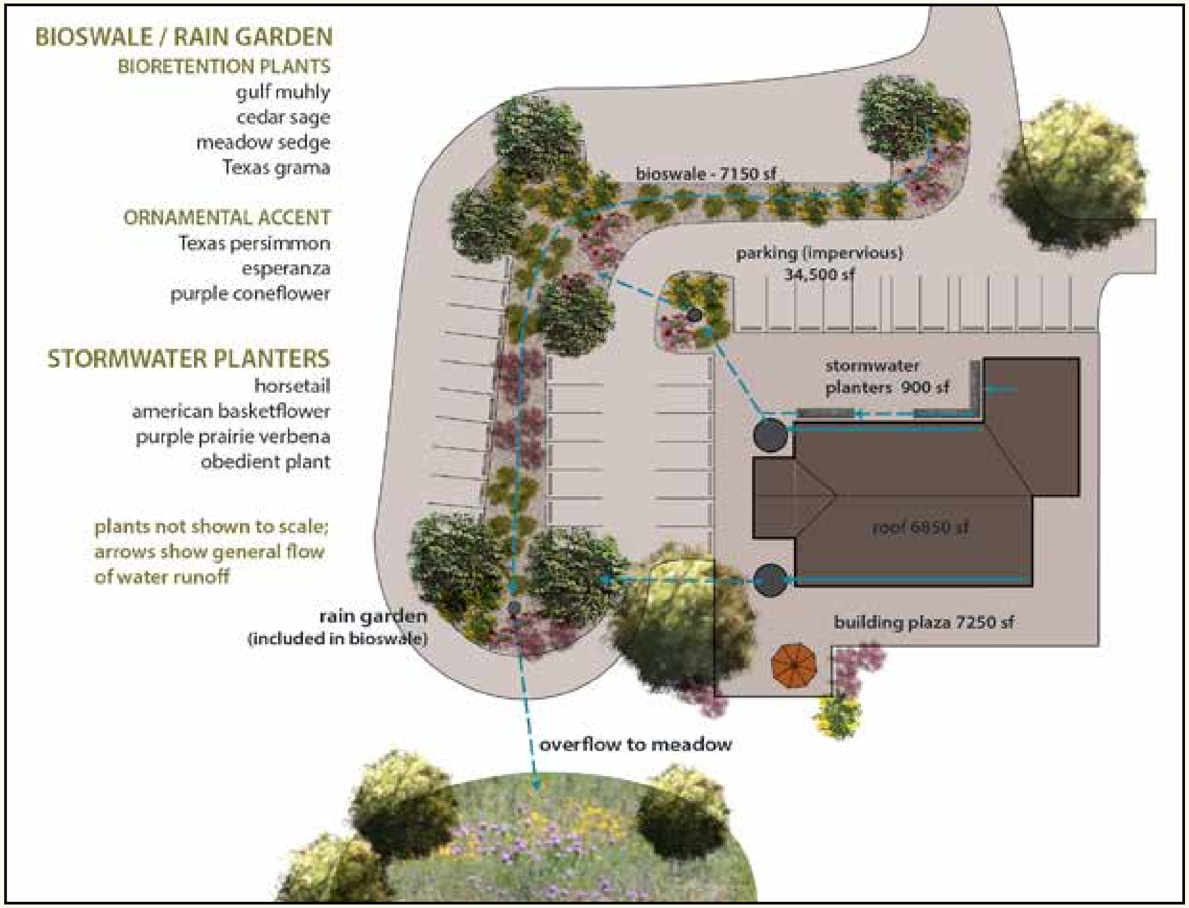


Figure 40. Plan showing landscaped LID areas with plant list. Plant spacing will vary; common spacing for grasses is approximately 18" on center (plants not shown to scale).

points within the parking area. A rain garden at the downstream end of the bioswale will infiltrate water, with overflow directed to a shallow meadow basin. In the final design, the bulk of the roof runoff is directed to the cisterns for slow release either into the landscape irrigation system (not shown in figures) or as a water supply for the building greywater system. A portion of roof runoff can be directed into the stormwater planters within the paved plaza area. Piped flows (shown as dashed arrows) and surface flow (shown as solid arrows) are directed into the main bioswale. The average width of the swale shown is approximately 14 feet, so a center depth of 8" is calculated to capture all of the water quality volume (1,040 cubic feet) needed. The bioswale should be designed with a shallow gradient and contain an overflow inlet so that overflow can empty into the detention basin after larger storm events. Figure 41 illustrates how a bioswale can be planted as a landscaped feature, as was done at the Patrick Heath Public Library in Boerne.

Figure 41. Parking lot bioswale at Patrick Heath Library, City of Boerne. (Photo courtesy of Paul Barwick).


Photo by William Sibley

Appendices

Appendix A: Sources and Links

LID Guidelines and Technical Information

US EPA National Menu of Stormwater Management Best Practices:
http://www.epa.gov/npdes/stormwater/menuofbmps

US EPA Green Infrastructure Design and Implementation Resources:
http://water.epa.gov/infrastructure/greeninfrastructure/gi_design.cfm

Harvested Rainwater: Sustainable Sources:
http://rainwater.sustainablesources.com/

Pervious Pavement by National Ready Mixed Concrete Association (NRMCA):
http://www.perviouspavement.org/

Rain Garden Fact Sheet for Central Texas:
www.austintexas.gov/department/grow-green

Rain Gardens: A How-to Manual for Homeowners:
http://dnr.wi.gov/waterways/shoreland/documents/rgmanual.pdf

Rainwater Harvesting:
https://agrilifebookstore.org

Stormwater Management: Rain Gardens:
https://agrilifebookstore.org

Organizations/Agencies and Links

Austin Watershed Protection Regulations:
http://austintexas.gov/department/watershed-protection/codes-and-regulations

Barton Springs/Edwards Aquifer Conservation District:
http://www.bseacd.org/about-us/history/

Edwards Aquifer Authority (EAA):
http://edwardsaquifer.org/

Harvested Rainwater: Sustainable Sources:
http://rainwater.sustainablesources.com/

Lady Bird Johnson Wildflower Center:
http://www.wildflower.org

Low Impact Design Center:
http://www.lowimpactdevelopment.org/greenstreets

National Butterfly Center, Mission, TX:
http://www.nationalbutterflycenter.org

Native Plant Society of Texas, Fredericksburg, TX:
http://www.npsot.org

Natural Resources Conservation Service: USDA NRCS:
http://www.nrcs.usda.gov/

San Antonio Water System (SAWS):
http://www.saws.org/

San Antonio River Authority (SARA):
http://www.sara-tx.org/lid_services/index.php

SITES™: The Sustainable Sites Initiative:
http://www.sustainablesites.org

Texas Land and Water Sustainability Forum:
http://texaslid.org/

Texas Parks and Wildlife Department: Prohibited Exotic Species:
http://www.tpwd.state.tx.us/huntwild/wild/species/exotic/#plant

Texas Invasives.org: Invasive Plants Database:
http://www.texasinvasives.org/invasives_database/index.php

TCEQ offices:
http://www.tceq.texas.gov/about/directory/region/reglist.html

USDA Natural Resources Conservation Service:
http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home/

Local Sources and Suppliers

Nurseries

Alltex Nursery and Landscape, Kerrville TX, 830-895-5242
http://www.alltexlandscapes.com

Friendly Natives, Fredericksburg TX, 830 997-6288
http://www.friendlynatives.com

From Seeds to Home Nursery, San Angelo TX, 325-651-4523

Hill Country Natives, Leander TX, 512-914-7519
http://www.hillcountrynatives.net

Miller Nursery and Tree Company, Stephenville TX, 254-968-2211
http://www.millernurseryandtree.com

Native Ornamentals, Mertzon TX, 325-835-2021

Snider Nursery, Gorman TX, 254-734-2027
http://www.snidernurserylandscaping.com

Stuart Nursery, Inc., Weatherford TX, 817-596-0003
http://www.stuartnurseryinc.com

Wichita Valley Landscape, Wichita Falls TX, 940-696-3082
http://www.wvlandscape.com

Womack Nursery Company, DeLeon TX, 254 893-6497
http://www.womacknursery.com

Seed Sources

Douglas King Seed Company, 1-888-DKSEEDS.
http://www.dkseeds.com

Native American Seed,
email to: info@seedsource.com

Texas Organic Products (City of Austin-approved biofiltration media mix)
http://www.texasdisposal.com/texas-organic-composting-texas-organic-products

Turner Seed Co. Breckenridge TX, 800-722-8616
http://www.turnerseed.com

Wildseed Farms, Fredericksburg TX, 830-990-8080
http://www.wildseedfarms.com

Appendix B: Definitions

Aquifer: Rocks or sediments, such as cavernous limestone and unconsolidated sand that store, conduct, and yield water in significant quantities for human use.

Best Management Practices (BMPs): Procedures for managing stormwater runoff to prevent or reduce the discharge of pollutants. BMPs can include structural and non-structural techniques as well as maintenance procedures, local ordinances, and other management practices.

Bioinfiltration: A practice to treat stormwater runoff by utilizing plants and root systems to slow the downward movement of water through soils, providing treatment and groundwater replenishment. Since plants also uptake water during evapotranspiration, bioinfiltration may reduce the overall volume of recharge water.

Bioretention: A practice to manage and treat stormwater runoff, designed to mimic natural water treatment with plants, soils and shallow basins. Water quality treatment takes place as water is retained in a landscaped basin in contact with plants and soils. The pooled, treated water gradually infiltrates through soil layers into groundwater or an underdrain.

Detention Basin: Land depression engineered to temporarily detain a volume of water for a specified period of time before releasing water into storm water systems. Compare to retention basin.

Edwards Aquifer Contributing Zone: The area or watershed where runoff from precipitation flows downslope to the Recharge Zone of the Edwards Aquifer.

Edwards Aquifer Recharge Zone: The area where the geologic units constituting the Edwards Aquifer crop out, where caves, sinkholes, faults, fractures, and other permeable features allow recharge of surface waters into the Edwards Aquifer.

Infiltration: Gravity-driven movement of water through soils, providing treatment and groundwater replenishment. Infiltration is the most commonly utilized natural water treatment method where soils provide acceptable rates of filtration.

Karst: A terrain characterized by landforms and subsurface features, such as sinkholes and caves, which are produced by solution of bedrock. Karst areas commonly have few surface streams; most water moves through cavities underground.

Karst Feature: Generally, a geologic feature formed directly or indirectly by solution, including caves; often used to describe features that are not large enough to be considered caves, but have some probable relation to subsurface drainage or groundwater movement. These features typically include but are not limited to sinkholes, enlarged fractures, noncavernous springs and seeps, soil pipes, and epikarstic solution cavities.

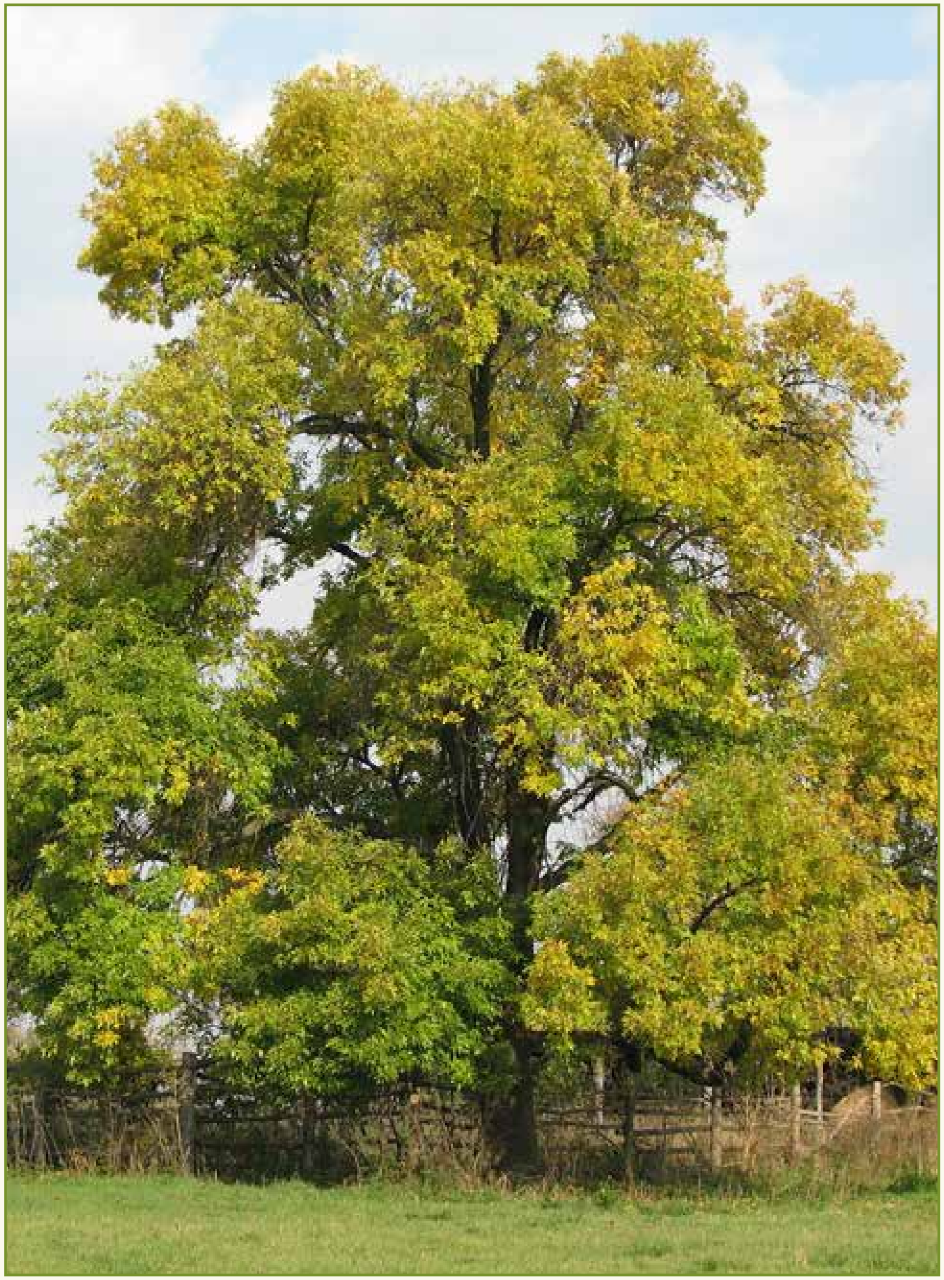
Low Impact Development (LID): A philosophy of stormwater management that seeks to mimic the natural hydrologic regime in urbanized watersheds by retaining water onsite for treatment and eventual recharge. LID typically relies on small, dispersed landscape features such as grassy swales, bioswales, rain gardens, infiltration basins and other means of treating potential runoff through plant and soil functions.

Non-Structural Best Management Practices: Methods of reducing stormwater pollution by utilizing the natural landscape as a filter. Includes techniques such as tree protection, landscape conservation, riparian buffer preservation, minimal soil compaction, and impervious cover reduction and downspout disconnection.

Recharge: Natural or artificially induced flow of surface water to an aquifer.

Retention basin: Land depression calculated to retain, or hold, a specified volume of water for the purpose of reducing peak stormwater discharge as part of an engineered stormwater treatment system. Compare to detention basin.

Structural Best Management Practices: Methods of reducing stormwater pollution through means of constructed landscape features such as infiltration basins, rain gardens, vegetated swales, pervious pavement, green roofs, sand filters, and constructed wetlands.


Black Walnut Tree - *Juglans nigra*

Appendix C: Plant Selection Guide

This native plant guide was created to assist in plant selection based on the key parameters that affect the suitability of a plant to a particular site including site moisture, sun exposure, and soil type. The native species included in this guide are naturally adapted to local conditions, but a plant is not necessarily suitable for all sites simply because it is native to the area. When plants are matched to the specific site conditions that they are most adapted to, they stand a better chance of surviving and thriving to their greatest abilities over time.

Existing native plant species of a site can provide a great foundation for plant selection, and an inventory of native plant species present is highly recommended. As natives, these plants are adapted to survive the extremes in weather, as well as natural disasters and pests that occur in the region. Protection of individual native plants or native plant communities during site development can provide significant ecological benefits for a site and should be considered. Salvaging and relocating native plants that would otherwise be destroyed by development is another option that can add benefit to a site. Regardless of the approaches taken, using appropriate native plants in the landscape is a smart choice for any site.

Although native plants can survive the often fluctuating climatic conditions experienced in the Edwards Aquifer region, they require care in order to become successfully established. In particular, they will likely require supplemental water unless sufficient rainfall occurs for some period immediately following installation, as all plants typically do. The appropriate period of time will depend on the species chosen, the type of plant material used (e.g. live root, seed, container stock), and the particular season at the time of planting. Once established, native plants are better able to withstand local conditions including drought, high temperatures, and periodic freezes. If placed in an appropriate site, they require little care over the long term, provide habitat for native animals, aid in the conservation of our local species biodiversity, and provide beauty to the landscape.

Native Canopy Trees

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand	
Carya illinoinensis	Pecan			X		X			X	X	X	X	75-100
Celtis laevigata - DR	Hackberry, Sugarberry				X		X		X	X	X	X	60-80
Fraxinus texensis	Texas ash				X	X			X		X		30-45
Juglans nigra	Black walnut			X		X	X			X	X	X	72-100
Morus rubra	Red mulberry			X	X	X	X	X		X	X	X	50-75
Platanus occidentalis - DR	American sycamore			X		X	X	X		X	X	X	75-100
Populus deltoides - DR	Cottonwood		X	X	X	X	X	X		X	X	X	75-100
Quercus macrocarpa	Bur oak		X	X	X	X	X	X	X	X	X	X	50-70
Quercus muhlenbergii	Chinquapin oak			X	X	X	X			X	X	X	45-100
Quercus virginiana	Live oak		X	X	X	X	X		X	X	X	X	50-70
Quercus texana	Texas red oak		X	X			X			X			50-75
Taxodium distichum - DR	Bald cypress	X	X	X		X	X			X	X	X	50-75
Ulmus americana	American elm			X		X	X			X	X	X	75-100
Ulmus crassifolia	Cedar elm			X			X		X	X	X	X	50-70

DR= deer resistant *S = shallow water W = wet/saturated soil M = moderate/moist soil; D = dry soil


Pecan


Hackberry, Sugarberry


Texas ash


Black walnut


Red mulberry


American sycamore


Cottonwood


Bur oak


Chinquapin oak


Live oak


Texas red oak


Bald cypress


American elm


Cedar elm

Native Small Trees and Large Shrubs

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand	(Feet)
Acacia farnesiana	Huisache				X	X			X	X	X	X	15-25
Acacia rigidula	Black brush acacia				X	X	X		X	X	X	X	5-15
Acer grandidentatum - DR	Bigtooth maple			X	X	X	X			X	X	X	15-25
Aesculus pavia - DR	Red buckeye				X		X		X	X	X	X	8-15
Cercis canadensis var. texensis	Texas redbud				X	X	X			X	X	X	10-20
Diospyros texana - DR	Texas persimmon				X	X				X	X	X	10-15
Ehretia anacua - DR	Anacua				X	X	X			X	X	X	20-45
Parkinsonia aculeata	Retama, Palo verde			X	X	X			X	X	X	X	12-20
Prosopis glandulosa - DR	Honey mesquite				X	X			X	X	X	X	25-30
Prunus mexicana	Mexican plum			X	X	X	X			X	X	X	15-20
Salix nigra	Black willow		X	X		X	X	X		X	X	X	15-60
Ungnadia speciosa - DR	Mexican buckeye				X		X		X	X	X	X	8-30

DR= deer resistant *S = shallow water W = wet/saturated soil M = moderate/moist soil; D = dry soil


Huisache


Black brush acacia


Bigtooth maple


Red buckeye


Texas redbud


Texas persimmon


Anacua


Retama, Palo verde


Honey mesquite


Mexican plum


Black willow


Mexican buckeye

Native Subshrubs and Vines

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand	(Feet)
Baccharis neglecta - DR	False willow				X		X				X	X	6-12
Berberis trifoliolata - DR	Agarita			X	X	X	X		X	X	X		3-6
Campsis radicans	Trumpet creeper			X	X	X			X	X	X	X	25-35
Cephalanthus occidentalis - DR	Buttonbush		X	X			X	X		X	X	X	6-12
Clematis drummondii	Old man's beard			X	X		X			X	X	X	3-6
Cocculus carolinus - DR	Carolina snailseed			X			X			X	X	X	3-15
Lantana urticoides - DR	Texas lantana				X	X	X		X	X	X	X	2-6
Leucophyllum frutescens - DR	Cenizo, Texas sage				X	X	X		X	X	X	X	2-8
Ludwigia octovalvis	Narrow-leaf water primrose	X	X	X		X	X			X	X		3-6
Malvaviscus arboreus var. drummondii - DR	Turk's cap			X	X		X	X		X	X	X	3-6
Merremia dissecta - DR	Alamo vine			X	X	X	X		X	X	X	X	6-12
Parthenocissus quinquefolia - DR	Virginia creeper			X		X	X	X	X	X	X	X	12-36
Passiflora foetida - DR	Downy passionflower				X	X	X				X	X	3-6
Sambucus nigra ssp. Canadensis	Common elderberry		X				X		X	X	X	X	6-12
Vitis mustangensis	Mustang grape				X		X			X	X	X	25-35

DR= deer resistant *S = shallow water W = wet/saturated soil M = moderate/moist soil; D = dry soil


False willow


Agarita


Trumpet creeper


Buttonbush


Old man's beard


Carolina snailseed


Texas lantana


Cenizo, Texas sage


Narrow-leaf water primrose


Turk's cap


Alamo vine


Virginia creeper


Downy passionflower


Common elderberry


Mustang grape

Native Forbs and Wildflowers

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)	Duration
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand		
Amblyolepis setigera	Huisache daisy			X	X	X	X		X		X	X	0-1	A
Argemone albiflora	White pricklypoppy			X	X	X	X		X	X	X	X	2-4	A
Asclepias tuberosa - DR	Butterflyweed			X	X	X	X			X	X	X	1-2	P
Bacopa monnieri - DR	Water hyssop	X	X	X		X	X			X	X	X	0.5-1	P
Calyptocarpus vialis	Straggler daisy			X	X	X	X	X	X	X	X	X	0.5-1	P
Callirhoe involucrata	Winecup			X	X	X	X		X	X	X	X	1	P
Chamaecrista fasciculata	Partridge pea			X	X	X	X			X	X	X	1-3	A
Castilleja coccinea	Indian or scarlet paintbrush			X		X				X	X	X	0.5-1.5	A / B
Centaurea Americana	American basket-flower		X	X		X				X	X	X	2-5	A
Commelina erecta	Widow's tears				X		X				X	X	0.5-1.5	P
Cooperia pedunculata - DR	Hill Country rain lily			X		X			X	X	X	X	0-1	P
Coreopsis basalis	Golden wave			X	X	X	X					X	0.5-1.5	A
Coreopsis lanceolata	Lanceleaf coreopsis, Tickseed			X	X	X	X	X		X	X	X	1-2.5	P
Coreopsis tinctoria - DR	Plains coreopsis			X	X	X	X			X	X	X	1-2	A
Dalea candida	White prairie clover			X	X	X			X	X	X	X	1-2	P
Dalea purpurea - DR	Purple prairie clover			X	X	X			X	X	X	X	1-3	P
Desmanthus illinoensis	Illinois bundleflower			X		X	X		X	X	X	X	1-3	P
Dracopis amplexicaulis	Clasping leaf coneflower			X		X	X			X	X	X	1-2	A
Echinacea purpurea	Purple coneflower			X	X	X	X			X	X	X	2-5	P
Engelmannia peristenia	Engelmann's or Cutleaf daisy			X	X		X	X	X	X	X	X	1-3	p
Gaillardia pulchella - DR	Indian blanket, Firewheel			X	X	X	X			X	X	X	1-2	A
Gaura Lindheimeri - DR	White guara			X	X	X	X		X	X	X	X	2-5	P
Gaura suffulta	Bee blossom			X		X					X	X	0-3	A
Glandularia bipinnatifido - DR	Purple prairie verbena		X	X			X		X	X	X	X	0-1	P
Helianthus annus	Annual sunflower			X	X	X	X		X	X	X	X	2-8	A
Helianthus maximiliani - DR	Maximilian sunflower			X		X	X			X	X	X	4-6	P
Hydrocotyle umbellata	Manyflower marsh pennywort		X	X		X	X	X		X	X	X	0-1	P
Ipomopsis rubra	Standing cypress				X	X	X				X	X	2-4	P
Justica americana	American water-willow	X	X	X		X	X	X		X	X	X	1-3	P

DR= deer resistant   *S = shallow water   W = wet/saturated soil   M = moderate/moist soil   D = dry soil   A = annual   P = Perennial   B = Biennial

Native Forbs and Wildflowers

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height	Duration
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand	(Feet)	
Liatris mucronata	Gayfeather				X	X	X		X	X	X	X	1-3	P
Lupinus texensis - DR	Texas bluebonnet			X	X	X			X	X	X	X	0.5-1.5	A
Monarda citriodora - DR	Horsemint			X	X	X	X			X	X	X	1-3	A
Oenothera jamesii - DR	River primrose		X			X			X	X	X	X	3-6	B
Oenothera speciosa - DR	Pink evening primrose			X	X	X	X		X	X	X	X	1-2	P
Oxalis drummondii - DR	Drummond's woodsorrel			X	X	X	X					X	0-1	P
Oxalis stricta - DR	Yellow wood-sorrel				X	X			X	X	X	X	0-1	P
Penstemon cobaea	Foxglove			X	X	X	X		X	X	X	X	1-1.5	P
Penstemon trifloris	Hill Country penstemon			X	X	X	X		X	X	X	X	1-1.5	P
Phacelia congesta - DR	Blue curls			X	X	X	X	X		X	X	X	1-3	A / B
Phlox drummondii	Drummond phlox			X		X	X					X	0.5-1.5	A
Phyla nodiflora - DR	Frogfruit		X	X	X	X	X	X		X	X	X	0.5	P
Physostegia intermedia - DR	Obedient plant		X	X		X	X	X		X	X	X	3-6	P
Pontederia cordata	Pickerelweed	X	X			X	X			X	X	X	1-3	P
Ratibida columnifera - DR	Mexican hat			X	X	X	X		X	X	X	X	1-3	P
Rivina humilis - DR	Pigeonberry			X			X		X	X	X	X	1-3	P
Rudbeckia hirta- DR	Black-Eyed Susan			X	X	X	X			X	X	X	1-3	A
Ruellia nudiflora	Wild petunia			X	X	X	X	X				X	1-3	P
Sagittaria latifolia	Broadleaf arrowhead	X				X	X		X	X	X		1-3	P
Salvia azurea	Pitcher sage			X	X	X	X		X	X	X	X	2-6	P
Salvia coccinea - DR	Scarlet sage			X		X	X		X	X	X	X	0.5-2	P
Salvia farinacea- DR	Mealy blue sage				X	X	X		X	X	X	X	1-3	P
Senna lindheimeriana - DR	Lindheimers senna				X	X	X		X	X	X	X	3-6	P
Simsia calva	Bush sunflower				X	X			X				1-3	P
Thelesperma filifolium - DR	Greenthread				X	X						X	1-3	A
Verbena bipinnatifida - DR	Prairie verbena			X	X	X	X		X	X	X	X	0.5-1	P
Verbena halei - DR	Texas vervain				X	X				X	X	X	1-3	P
Verbesina encelioides -DR	Cowpen daisy				X	X			X	X	X	X	1-3	A
Wedelia texana- DR	Zexmenia			X	X	X	X		X	X	X	X	1-3	P

DR= deer resistant   *S = shallow water   W = wet/saturated soil   M = moderate/moist soil   D = dry soil   A = annual   P = Perennial   B = Biennial


Huisache daisy


White pricklypoppy


Butterflyweed


Water hyssop


Straggler daisy


Winecup


Partridge pea


Indian paintbrush, Scarlet paintbrush


American basket-flower


Widow's tears


Hill Country rain lily


Golden wave


Lanceleaf coreopsis, Tickseed


Plains coreopsis


White prairie clover


Purple prairie clover


Illinois bundleflower


Clasping leaf coneflower


Purple coneflower


Engelmann's daisy, Cutleaf daisy


Indian blanket, Firewheel


White guara


Bee blossom


Purple prairie verbena


Annual sunflower


Maximilian sunflower


Manyflower marsh pennywort


Standing cypress


American water-willow


Gayfeather


Texas bluebonnet


Horsemint


River primrose


Pink evening primrose


Drummond's woodsorrel


Yellow wood-sorrel


Foxglove


Hill Country penstemon


Butterflyweed


Blue curls


Drummond phlox


Frogfruit


Obedient plant


Pickerelweed


Mexican hat


Pigeonberry


Black-Eyed Susan


Wild petunia


Broadleaf arrowhead


Pitcher sage


Scarlet sage


Mealy blue sage


Lindheimers senna


Brush sunflower


Greenthread


Prairie verbena


Texas vervain


Cowpen daisy


Zexmenia

Native Grasses, Sedges and Rushes

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)	Duration
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand		
Andropogon gerardii - DR	Big bluestem			X		X	X		X	X	X	X	4-8	P
Andropogon glomeratus - DR	Bushy bluestem		X	X		X				X	X	X	2-5	P
Aristida purpurea - DR	Purple threeawn				X	X				X	X	X	1-1.5	A
Bothriochloa barbinodis	Cane bluestem			X	X	X			X	X	X	X	1-3	P
Bouteloua curtipendula - DR	Sideoats grama			X	X	X	X			X	X	X	1-3	P
Bouteloua dactyloides	Buffalograss				X	X			X	X	X		0-1	P
Bouteloua hirsuta	Hairy grama				X		X		X	X	X	X	0.5-1.5	P
Bouteloua rigidiseta - DR	Texas grama				X	X				X	X	X	0.5-1	P
Carex planostachys	Cedar sedge				X		X		X	X	X		0-1	P
Chasmanthium latifolium-DR	Inland sea oats			X			X	X		X	X		1-4	P
Chloris cucullata	Hooded windmillgrass			X			X				X	X	0.5-2	P
Eleocharis quadrangulata	Squarestem spikerush	X	X			X				X	X		1.5-4	P
Eleocharis tenuis	Slender spikerush		X	X		X				X	X	X	1-3	P
Equisetum hyemale - DR	Horsetail, scouring rush		X	X		X	X	X		X	X		1-3	P
Elymus canadensis - DR	Canada wildrye			X	X	X	X		X	X	X	X	2-4	P
Eragrostis trichodes	Sand lovegrass			X	X		X				X	X	3	P
Eriochloa sericea - DR	Texas cupgrass			X	X	X	X		X	X	X	X	1-2	P
Leptochloa dubia	Green sprangletop			X	X	X	X		X	X	X	X	2-3	P
Muhlenbergia capillaris	Gulf muhly			X	X	X	X		X	X	X	X	1-3	P
Muhlenbergia lindheimeri	Big muhly - DR			X	X	X	X		X	X	X	X	2-5	P
Panicum obtusum	Vine mesquite			X	X		X				X	X	2	P
Panicum virgatum - DR	Switchgrass		X	X	X	X	X		X	X	X	X	3-6	P
Setaria leucopila	Plains bristlegrass				X	X				X		X	3-6	P
Schoenoplectus tabernaemontani	Softstem bulrush		X			X				X	X		3-6	P
Schizachyrium scoparium - DR	Little bluestem			X	X	X	X		X	X	X	X	1.5-2	P
Sorghastrum nutans - DR	Indiangrass			X	X	X	X		X	X	X	X	3-6	P
Tridens flavus	Purpletop			X		X	X		X	X	X	X	2-6	P
Tripsacum dactyloides	Eastern gamagrass		X	X			X			X	X	X	3-6	P

DR= deer resistant *S = shallow water W = wet/saturated soil M = moderate/moist soil D = dry soil A = annual P = Perennial B = Biennial


Big bluestem


Bushy bluestem


Purple threeawn


Cane bluestem


Sideoats grama


Buffalograss


Hairy grama


Texas grama


Cedar sedge


Inland sea oats


Hooded windmillgrass


Squarestem spikerush


Slender spikerush


Horsetail, Scouring rush


Canada wildrye


Sand lovegrass


Texas cupgrass


Green sprangletop


Gulf muhly


Big muhly


Vine mesquite


Switchgrass


Plains bristlegrass


Softstem bulrush


Little bluestem


Indiangrass


Purpletop


Eastern gamagrass

Appendix D: Municipal Regulations — Comparison of Cities

Includes plans for the preservation of significant trees, restrictions on building on steep slopes, in floodplains and near critical environmental features; cut and fill limitations; access and egress restrictions; parking requirements; landscape area requirements; building height limitations; and impervious cover limitations.

City Regulations	San Antonio and ETJ	New Braunfels	San Marcos and ETJ on Recharge Zone	Sunset Valley
Impervious Cover Limits	Single Family = 30% Multi-Family = 50% Commercial = 65% Commercial at major transportation nodes = 85% ETJ only, all types = 15%	Considering monthly stormwater utility fee assessed based on impervious cover on all developed property.	Less than 3 acres = 40% 3 – 5 acres = 30% More than 5 acres = 20% Waterway buffer zones = 10%	Single Family 18% Commercial 18%. Monthly Stormwater Utility Fee assessed based on impervious cover on all developed property.
Tree and Vegetation Preservation Ordinance	Preserve 35% of the existing trees and add 2 new trees	Unlawful to remove any protected tree. Install 4-foot high fencing around root protection zone during construction. Up to $2,000 fine.	City only: Tree preservation and protection incentives to retain existing trees	"Trees are hereby declared to be of great value." Ordinances same as Austin.
Habitat Compliance for Endangered Species*	Follows Recovery Plan for Bexar County Karst Invertebrates by the U.S. Fish and Wildlife Service, and Management Guidelines for the Golden-cheeked Warbler by Texas Parks and Wildlife Department.	Edwards Aquifer Habitat Conservation Plan: to protect the endangered species of the Comal and San Marcos rivers and springs.	8 species endangered or threatened living in the San Marcos region of the Edwards Aquifer: Texas blind salamander, Fountain darter, Comal Springs riffle beetle, Comal Springs dyropid beetle, Peck's cave amphipod, San Marcos gambusia, Texas wild-rice and San Marcos Salamander.	The Balcones Canyonlands Conservation Plan allows endangered species habitat to be taken while setting aside land to mitigate for that habitat.
Drainage Control	Stormwater detention facilities required.	Stormwater utility fee. Regional stormwater detention facilities.	Rate of runoff must be less than or equal to that prior to construction.	Stormwater Utility Fee.
Watershed Protection	Edwards Aquifer Protection Initiative: A voter-approved 1/8 cent sales tax used to purchase properties located over the Edwards Aquifer recharge and contributing zones.	Mitigation of aquifer features required. Control alteration of natural floodplains and stream channels. Control filling, grading, dredging, and other development that may increase flood damage.	Erosion and sedimentation controls uses the Austin Drainage Criteria and Environmental Criteria. Water Quality Zones along waterways. Sensitive Feature Protection Zones up to 200 feet around. Offers incentives for Transfer of Development Rights from land in the recharge zone to land outside; and Parkland Dedication Credit.	Watershed Protection Ordinances.

City Regulations	Austin
Impervious Cover Limits	Duplex and single family: Less than 10,000 ft^2 = 2,500 ft^2 limit (25% or more) 10,000 ft^2 – 15,000 ft^2 = 3,500 ft^2 (35% - 23%) 15,000 ft^2 – 1 acre = 5,000 ft^2 (33% - 12%) 1–3 acres = 7,000 ft^2 (16% - 5%) More than 3 acres = 10,000 ft^2 maximum (8% or less) Note: 1. Limit calculation Includes adjacent roadway ft^2 if limit is over 5,000 ft^2 2. 1 acre = 43,560 ft^2
Tree and Vegetation Preservation Ordinance	Permanent revegetation required after development. Clearing of vegetation is prohibited unless approved. Roadway clearing width may not exceed twice the roadway surface width. A minimum of 50% of critical root zone must be preserved with natural ground cover. Not more than 25% of foliage should be removed from trees.
Habitat Compliance for Endangered Species*	Site plan shall include a map of: 1. Suitable habitat for any endangered birds, 2. Occupied territories of endangered birds, 3. Karst features which may harbor endangered cave invertebrates, 4. Locations of any endangered plant populations. The Balcones Canyonlands Conservation Plan allows an incidental "take" of eight locally occurring endangered species under the Endangered Species Act. "Take" is the removal of occupied endangered species habitat or species displacement due to development, in exchange for the creation of suitable endangered species habitat, called the Balcones Canyonlands Preserve.
Drainage Control	Stormwater detention facilities required. Water quality controls required for impervious run-off. Temporary erosion and sedimentation controls required until permanent revegetation established. Control at a 'treatment level' of a filtration system under the Environmental Criteria Manual. Additional control requirements in place for the Barton Springs Zone.
Watershed Protection	Environmental assessment required if over a karst aquifer, in water zones, or on a 15% or more gradient. Critical Water Quality Zones (100+ feet wide) along waterways and lakes. Water Quality Transition Zones adjacent to critical water quality zones (also 100+ feet wide). Hydrogeological report demonstrate the drainage protects recharge of aquifer; Vegetation report to survey trees, vegetation, and detail erosion control; Wastewater report justify sewer lines within water zone, construction techniques, effects on waterways and aquifer. Minimize contaminants, maintain overland sheet flow, natural drainage. Enforcement - A person commits an offense if allows sediment from a construction site to enter a waterway by failing to maintain erosion controls or failing to follow the approved sequence of construction. Cost Recovery Program - incentives for redeveloping in an urban watershed requiring water quality control. City of Austin bans driveway sealants containing PAH.

*(If in karst 1 or 2, or in TPWD potential habitat for the Golden-cheeked Warbler, AND if no Regional Habitat Conservation Plan nor endangered species survey submitted to US Fish and Wildlife)

Coal tar sealants contain a number of known and potential carcinogens, including benzene, naphthalene, and significant concentrations of polycyclic aromatic hydrocarbons (PAHs): EAA ban. On November 13, 2012, the EAA Board of Directors approved Final Rules including a prohibition on the use of coal tar-based pavement sealant products after December 31, 2012, in Comal and Hays counties within areas on the Edwards Aquifer Recharge Zone.

Appendix E: Water Quality Calculations for Case Study

	Steps in Sizing Stormwater Treatment Systems	Formulas (from Technical Guidance Manual 3-33, Barrett 2005)
1.	**Calculate required TSS (Total Suspended Solid) removal based on increase in impervious cover.**	Required TSS removal (L) = 27.2 * An * P 27.2 is a constant. An = net acreage increase impervious. P = rainfall
	Enter net increase in impervious area (An). Example is 1.12 acres proposed impervious surface for a 4 acre site.	Required TSS load removal (L) = 27.2 * **1.12** * P
	Enter average annual rainfall (P) for county. Example Comal County = 33 inches per year.	L = 27.2 *1.12 * **33**
	TSS load to be removed	Required TSS Removal (L) = 1005.3 lbs
	Choose LID System based on site design criteria and TSS Removal >80%	BMP efficiency of bioretention swale + dry meadow basin = 93%
	Calculate sediment load removed by BMP	TSS removed (L_R) = BMP efficiency * (Ai * 34.6 + Ap * 0.54) * P
	Enter BMP efficiency – bioswale + dry detention basin = 0.93	L_R = **0.93** * (Ai * 34.6+ Ap * 0.54) * P
	Enter contributing drainage area size, for impervious (Ai) and pervious (Ap) acreage. Using cisterns has effectively reduced impervious cover from 1.11 acres (site + roof) to 0.96 acres (site only)	L_R = 0.93 * (**0.96** * 34.6 + **3.04** * 0.54) * P
	Enter average annual rainfall for county. Example Comal County = 33 inches.	L_R = 0.93 * (0.96 * 34.6 + 3.04 * 0.54) * **33**
	Total Sediment Load to be removed by BMP	TSS to be removed by LID system (L_R) = 861.7 lbs (using cisterns)
	Calculate fraction of annual runoff for treatment	F = Required TSS removal (L) / sum of load removed by BMP (L_R)
	Enter values calculated above for LID system	F = **861.7** / **1070**
	Fraction of annual runoff treated by BMP	0.80 OR 80%
	Calculate capture volume of BMP using rainfall depth	See Table 3-5 of the *Technical Design Manual*
	Fraction of annual rainfall treated by BMP for central Texas, where 100% of rainfall occurs in storms of 4.0 inches or less.	Since F = 0.93, corresponding rainfall depth = 1.08 inches (80% of annual runoff occurs in storms of 1.08 inches or less)
	Caluclate water quality volume needed	WQV = Rainfall depth * Runoff coefficient * Ai
	Enter values for rainfall depth and area of impervious cover	WQV = **1.08** * Runoff coefficient *0.96
	Calculate runoff coefficient using graph (Appendix A) or formula.	Runoff coefficient = 1.72(IC)3 – 1.97 (IC)2 + 1.23(IC) + 0.2
	Enter site fraction of impervious cover = 0.96 acres / 4 acres = 0.24 or 24%	See graph Figure 3-12 of the *Technical Design Manual*
	Runoff coefficient value for site with 24% impervious cover (IC)	Runoff coefficient = 0.23
	Convert values for rainfall depth to feet and area to square feet	WQV = (1.08/12) * **0.23** * (0.96*43560)
	Water Quality Volume needed	WQV = 865.6 cubic ft.
	Oversize system by 20%	WQV = 865.6 * 1.2 = **1038.7** cubic ft.

Appendix F: Case Study — Brush Management for Water Recharge

By Bryan Hummel, MS Biology

This case study utilizes brush and shredded juniper mulch placed along slope contours in a series of thick mulch terraces to slow rainwater runoff along a steep slope. Keeping soil and water on the landscape longer has multiple benefits in hilly areas such as the Edwards-Trinity region. These benefits include unlocking the growth potential for plants, increasing landscape productivity, increasing infiltration and potentially increasing spring flow, increasing the quality and duration of stream flow, decreasing erosion, decreasing floodwater volumes, and improving the health of the entire riparian zone downstream, which in turn increases groundwater recharge along the length of the stream course (especially if these activities are done in the contributing zone upstream from the recharge zones).

The photograph shown is of a steep caliche hillside characteristic of the Edwards-Trinity region and illustrates the contour brush/mulch terracing method.

Several techniques can be utilized:

- Placing brush piles along the contours;
- Placing brush piles along the contours and shredding the brush in place;
- Placing thick layers of shredded mulch along the contours;
- Placing berms of soil and rock along the contours;
- Placing brushpiles and large logs from any dead trees along the contour lines then covering this brush/logs up with soil to create contour berms. ***It is of utmost importance that the base of the piles be kept level with the contours so that water collects evenly along the terraces.*** If terraces are allowed to tilt downhill, they will serve as conduits for water flow which may cause berm blowouts and erosion.

With survey equipment or 3D laser levels and marking paint, contour lines can be quickly mapped on almost any landscape. Placing the cut brush in contour strips before shredding was utilized successfully in this example to create a series of thick water harvesting mulch terraces with minimal soil disturbance. It is important not to disturb trees and other vegetation just downhill of these contour lines because the native vegetation will act as "earth anchors" to stabilize the terraces and provide wildlife cover. Nearby vegetation will help keep brush and mulch in place until plant roots and soil microbes stick all the mulch partials together like biological glue. "Earth anchors" are especially important in riparian areas and high velocity drainages. Without something to hold back the forces of flowing water, brush berms will be pushed downstream until it has a "blowout" and breaks apart. The thickness of the mulch berm varies and can be as small as small as six inches tall and one foot wide. Using larger equipment and having the berms double as access roads, the berms in this project had dimensions about 15 inches tall and 15 feet wide.

These contour mulch berms significantly slow the movement of runoff, and allow greater time and surface area for the water to infiltrate into our soil and eventually into the aquifer system. During rain events these berms hold back long shallow ponds. Even during an 11 inch rain event, there were only two small areas where water overtopped these mulch berms (mainly because the mulch was not laid out on perfect contour). Considerably less runoff was observed downstream from this treatment, which means significantly more water was infiltrated into the groundwater system. Less immediate runoff should result in less downstream flooding, less erosive scouring, significantly more infiltration and a healthier riparian system downstream. By keeping and spreading out additional moisture along the hillsides, vegetation both above and below these mulch strips is thriving, spreading, and re-seeding; often several times larger and more productive than the same species a few feet uphill from the berm.

"I can tell you that the big bluestem is over my head along many of these berms, the wildflowers are thriving just along the berms while suffering elsewhere and the new growth of oaks and remaining juniper is roughly 300% longer in the mulch berm treatments than in the control sites....as of September 2013."

Bryan Hummel, MS, Hummel Ventures LLC

The gravity irrigated strips of vegetation act as biological filters, capturing enormous quantities of soil, sediment, and seeds. A positive feedback loop is established where more infiltration of runoff grows more grasses, more grasses capture and hold onto more soil, more soil holds onto more moisture, which in turn grows better grasses that hold the berm in place longer and increases infiltration. Eventually a thick line of trees, shrubs, wildflowers and grasses forms along the contours, restarting the process of ecological succession in a regenerative, self-sustaining, pattern that only improves with age. As noted above, it is absolutely critical that the initial brush strips are placed on exact contour (or as closely as you can get with the available tools).

If you do not have the equipment to shred the contour brush strips, just leaving the trimmed brush in contour strips provides enormous benefit by slowing runoff and filtering leaves, seeds and organic matter from the runoff. Seeds deposited in this brushy berm are protected from deer/livestock and mostly grow without herbivory. Nearby plants get additional soil, organic matter, and water infiltration after every precipitation event. In northern climates the brush acts as snow fences which also keep water on the property longer.

A good source for soil management using contouring is this agricultural page created by the USDA Natural Resources Conservation Service: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/technical/?cid=nrcs142p2_008508

The Woodlands, located just outside of Houston, incorporates hundreds of rain gardens to capture and infiltrate storm water. Created in 1974 by George P. Mitchell, this master planned town continues to be recognized as a model for America's most livable communities and an inspiration for the Low Impact Development movement.

Photos by Annalisa Peace

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