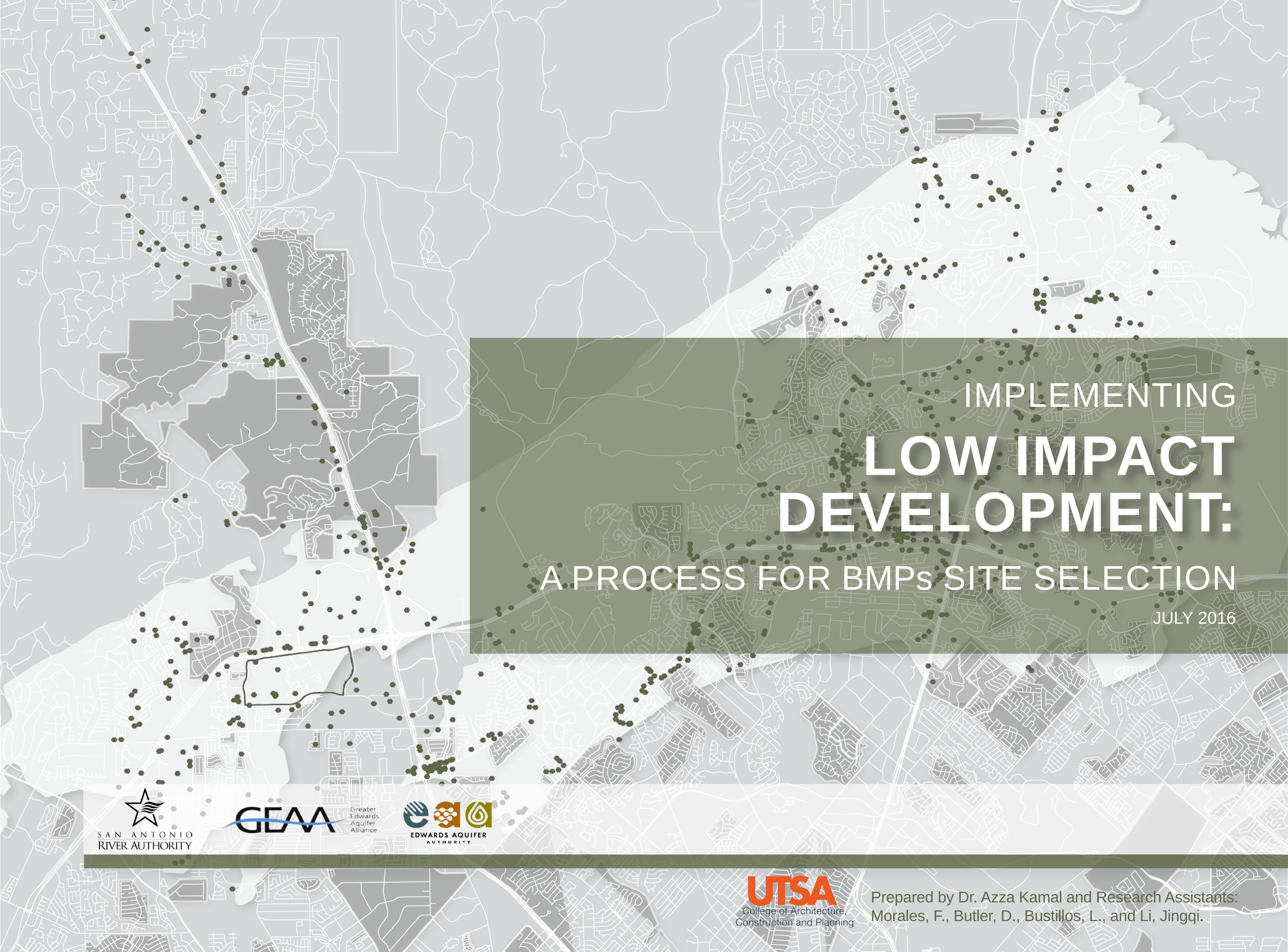

IMPLEMENTING

LOW IMPACT DEVELOPMENT:

A PROCESS FOR BMPs SITE SELECTION

JULY 2016

SAN ANTONIO RIVER AUTHORITY

GEAA Greater Edwards Aquifer Alliance

EDWARDS AQUIFER AUTHORITY

UTSA College of Architecture, Construction and Planning

Prepared by Dr. Azza Kamal and Research Assistants: Morales, F., Butler, D., Bustillos, L., and Li, Jingqi.

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Executive Summary

In Bexar County, Texas, there are approximately 3,029 engineered Best Management Practices (BMPs) for stormwater treatment in the Edwards Aquifer Region. These structures often encounter maintenance challenges and some are not functioning sufficiently to achieve the desired results of pollution prevention from non-point sources, making it difficult to enhance the quality of water treatment and the reduction of stormwater runoff (see section B.3, p. 84 and 93). This report proposes new techniques, known as Low Impact Development (LID), that emulate pre-development site conditions to replace these structures.

This report aims to develop an evidence-based process for selecting structured BMPs in the Edwards Aquifer Recharge Zone (EARZ). Selected site will be examined as a pilot project of unlined LID practices, which can be proposed to the Texas Commission on Environmental Quality (TCEQ) for further testing of performance and maintenance sustainability. Based on current research, unlined LID practices have not been thoroughly examined for efficiency or reliability, and therefore a pilot project will facilitate the opportunity for post-implementation measures of water quality and calculation of runoff volume after 1.5” storm event. The report establishes a systematic and reliable method for site selection for further development of LID practices on the EARZ considering the sensitivity of this region. A pilot project is defined as an existing BMP structure that has been redesigned by architecture students through a series of LID techniques in order to enhance the infiltration system whereby water quality and the recharge to the Aquifer will be improved.

The strategy for selection and redesigning BMPs encompasses a five-step geospatial analysis model using Geographic Information Systems (GIS). The model provides a technical and data-driven tool for the research partners as well as the state regulations regarding the future development on EARZ. The process emphasizes several attributes associated with two key themes identified in the model including: 1) site characteristics; and 2) pollutants loads: Nitrogen Oxide (NO), Nitrogen dioxide (NO2), Volatile Organic Compounds (VOC), Particulate Matter (PM), Total Suspended Solids (TSS), and Total Phosphorus (TP) from the adjacent built environment and infrastructure features.

Through collaboration with Greater Edwards Aquifer Alliance (GEAA), and with funding from San Antonio River Authority (SARA) and Edwards Aquifer Authority (EAA), this report offers a toolkit for implementing LID practices across various homeowner associations and businesses located on the EARZ through a strategy that incorporates stakeholders’ input to prioritize their needs.

In addition to the toolkit, this report includes two proposed pilot projects of LID practices in appendix A & B. Both projects are proposed by two teams of architecture students at the UTSA College of Architecture, Construction and Planning (CACP). Evidence from research and design of the two projects supports implementing LID techniques through a series of treatment trains in two sites on the UTSA main campus. The treatment train comprises lined practices and concludes with an unlined bioswale and bioretention basins that recharge stormwater to the EARZ. LID practices are proposed to replace two of the five existing UTSA campus BMPs. The report informs the future and broader research in order to improve the efficiency of LID in the City of San Antonio, and to help secure funding for examining further areas related to LID performance, maintenance, and unit cost.

Introduction

Purpose of this study

This report focuses on: 1) establishing an evidence-based method for selecting existing Best Management Practice (BMP) structures; 2) estimating the appropriate locations for on-site water treatment through a series of Low Impact Development (LID) practices; 3) proposing redevelopment of the entire sites through several designs of LID practices; and 4) addressing the challenges and possibilities of incorporating unlined LID practices over Edwards Aquifer Recharge Zone (EARZ). Criteria for LID projects were identified by integrating feedback of our funding partners (SARA, EAA, and GEAA) with evidence- based metrics. Sites are selected from a large inventory of hundreds of existing engineered BMP structures that are spatially distributed over the EARZ throughout the City of San Antonio (CoSA) and Hill Country Region.

A successful site selection process is largely based on establishing clear and precise goals that are tailored to specific community or project stakeholders. The overarching goals of this report were developed using input from our partners. These goals include as their utmost benefit promoting LID across CoSA and Bexar County, Texas, and at the same time enhancing water quality in the EARZ through unlined practices. Criteria for site characteristics and design strategies that support these goals were inferred from several discussions with our research partners. These criteria are thoroughly explained in section B-1 of the report. As a result, the geospatial model developed in this report incorporates multi-criteria attributes that promote users' awareness of LID practices in addition to enhance water quality and reduce stormwater runoff.

Study Area

The geospatial model delineates the study area through two consecutive scales including: 1) a broader regional scale; and 2) a neighborhood scale. The regional scale is the portion of the Edwards Aquifer Recharge Zone (EARZ) located in Bexar County, Texas. Within this portion, all structured BMP records were examined in order to select candidate sites for further analysis. The neighborhood scale is defined as the area, including all parcels and land uses, surrounding the selected candidate sites. In this report, candidate sites are presumed to be the BMPs located in the main campus of the University of Texas as San Antonio. The main campus is in a transition from a purely commuter campus to a traditional urban and residential campus, and therefore the proposed LID designs for the selected BMPs incorporate the 25-year growth projections adopted by UTSA. However, the projected allocation of lands, which could affect several of the attributes measured in this report, was only partially considered due to limited details of the campus master plan. Examples of these attributes include future points of pedestrian flow, future bus stops, and boundaries of future primary open spaces.

Following the neighborhood analysis, different metrics were used to examine five BMP structures located within UTSA campus boundaries. Developing these metrics is supported by extensive analyses of scholarly literature and is based on reliable measures that have previously been examined. Using a weighted average system, a ranking for some of these measures was also developed using stakeholders' input. In this report, stakeholders are identified as the research partners including officials at SARA, EAA, and GEAA. Incorporating stakeholders' input has been part of nationwide programs including the City of Austin's Green Infrastructure program, and its Green Infrastructure Working Group- GIWG (City of Austin, 2015).

Method

A thorough review of published work was conducted, and attributes associated with LID sites were deduced. These attributes were applied to BMP sites located within the geographic boundaries of the study area using geospatial model. Three preliminary attributes examined the capability of BMP sites to support LID practices using Site Capability Model (SCM). Advanced attributes were integrated in Site Suitability Model (SSM) that measured the suitability of BMP sites for implementing successful LID practices that would also shed more light on the project goals.

A mixed-method approach, encompassing secondary and primary data, was integrated with spatial analyses tools in a five-step geospatial model. The model expands from a macro (regional) scope to a micro (site specific) scope that encompasses selecting and redeveloping two BMP sites within UTSA main campus. The model includes: Step I, regional analysis, which was developed using three sets of secondary data attained from local, state, and national organizations; Step II, neighborhood analysis, which included secondary data analysis; Step III, constructing site capability model (SCM), which intertwined an analysis of secondary data and on-site primary data; Step IV, constructing Site Suitability Model (SSM), which combined several attributes developed using on-site primary data as well as secondary data; Step V, designing LID practices in UTSA, which included a site simulation and visual presentations using the analysis developed in previous steps.

Secondary data was attained from several agencies: TCEQ, EAA, and San Antonio Water System (SAWS) in addition to the US Census Bureau, and CoSA GIS portal. Primary data was gathered using on-site audit form for observing and documenting various attributes associated with site characteristics metrics.

Policy Recommendations

This section encompasses a discussion of the report’s major findings, and elucidates the inferences of public policy as well as future development of water treatment and conservation techniques in the study area. It also offers policy recommendations for future development on the EARZ, and highlights different means for promoting the implementation of LID practices. In addition, limited research on unlined LID techniques and other research caveats are also discussed.

Geospatial Analysis Model

A multi-criteria geospatial model for site selection provides a highly comprehensive and reliable tool that integrates data-driven metrics for site characteristics and pollutant loads in a digital and visual representation using GIS technology. Building a reliable model using standardized measures for site capability to support various LID requirements, and site suitability for successful implementation and performance helps planning and design professionals in matching existing sites with appropriate LID techniques. The model also helps policy makers and state regulators allocate more resources to the EARZ to enhance water quality, reduce stormwater runoff, and secure funding for further research on performance and maintenance of unlined LID practice. As a result, this model will improve public health and support a better return on investment (ROI) for the state agencies.

Thus, it is highly recommended for communities that wish to implement LID (i.e. Home Owner Associations and business owners) to seek technical assistance for adopting this model prior to selecting a site for LID implementation. This will guarantee the capability of a desired site to support a specific LID technique, and will enhance the suitability of site characteristics to meet the overall project goals as well as to achieve high performance and maintenance efficiency.

Pilot Project

Very limited studies have examined pollutants loading in stormwater infiltrated through unlined LID practices on the EARZ or similar karst aquifers. Recent research has only compared LID efficiency with undeveloped sites. Additionally, there is a lack of evidence in scientific publications with regard to the amounts of pollutants in stormwater infiltrated through LID practices that are designed with liner versus no-liner. This uncertainty about predicted performance of unlined LID on a recharge zone was also discussed in the recent work of Barrett (2015).

Therefore, implementing an unlined LID pilot project on the EARZ is highly recommended to establish data-supported evidence of unlined LID performance and maintenance. Examining a pilot project will provide scientists, engineers, designers, and facility personnel with collecting and monitoring data necessary to compare the performance and maintenance of lined and unlined practices. Examining such data will likely be centered on percent of pollutants removed, volume of stormwater runoff infiltrated into the aquifer, and feasibility and cost of maintenance.

LID Series

Implementing a pilot project on the EARZ should take into account that any project needs to encompass both types of LID structural specification including lined and unlined practices. The project proposed in this report encompasses a series of LID practices implemented as a treatment train. A model of this series is provided in the report appendices (A & B). When constructing the treatment train over the EARZ, it is advised that in the last typology of the series an unlined structure will be allowed. Yet, the remaining structures of LID in the treatment train need to be lined.

Stakeholders Input

For any LID project, establishing criteria for site characteristics and design strategies is largely subject to stakeholders' preferences. Project goals are crucial elements in flourishing design schemes as well as supporting sustainability, and efficient performance and maintenance. It is important for developers, business owners, and home owner associations to discuss and generate specific goals for a LID project prior to proceeding with site selection and implementation.

Based on reviewed studies and methods developed in this report, it is highly recommended to hold several meetings and focus groups with interested parties to solicit for their feedback and input in the design and objectives of any LID project. When adopting the site selection toolkit proposed in this report, policy makers need to incorporate stakeholders input in order to customize LID design strategy, and to tailor LID project to their views and interests.

Future Development

It is a requirement that future developments on the EARZ comply with Texas Administrative Code, Title 30 (Environmental Quality), Chapter 213 (Edwards Aquifer) rules and any associated guidance documents from the State of Texas as well as the following:

- San Antonio River Basin LID Technical Guidance Manual (2013).
- Edwards Recharge Zone District (ERZD) of the City of San Antonio (CoSA)'s Unified Land Development Code, including:
    1. UDCIII: 124, and UDCIV: 73.
    2. UDC Division 7: Special Procedures for Edwards Aquifer Overlay District (ERZD) for Edwards Aquifer Overlay permits.
    3. UDC Division 5: Natural Resource Protection (UDCV: 132) for the Edwards Aquifer, floodplains, and tree preservation.
    4. UDC Section 35-210 Low Impact Development and Natural Channel Design Protocol (LID/NCDP).
- All requirements established by the CoSA Watershed Protection and Management Department (WPMD).
- Applicable Bexar County Post-Construction Storm Water Control Measure Permits.

Part A
Part B
Part C

Caveat

1. There is a need to develop scientific measures of LID performance in the Hill Country region. Future developed measures need to examine the efficiency of water treatment based on lined vs. unlined techniques of rain gardens, vegetated and rock swales, bioretention areas, and other common practices.

2. There is a lack of comprehensive verified central listing of all constructed BMPs in the study area that have been monitored by EAA, and assessed for compliance by SAWS. The regional scope of analysis in the site selection model developed in this report was therefore incomplete due to missing a verification of 3,029 BMP permits available on the TCEQ central registry list.

3. The assumption that 15% of the BMPs in Bexar County are uncompliant needs to be confirmed. This is due to unavailability of lack of one centralized list of all constructed BMPs in Bexar County over the EARZ.

4. Further research is needed to inspect the efficiency of unlined LID practices through measuring percent of pollutant removal, and capacity and pace of stormwater infiltration.

5. Due to the built environment impacts on water quality treated through existing BMPs, further research also needs to examine the aspects of the built environment that enhance TSS and TP loading in construction sites adjacent to existing BMPs. The UTSA campus, and its adjacent sites and roads, are heavily subject to such hazards resulting from ongoing, and anticipated, construction activities.

6. Total nitrate and heavy metals did not have a significant impact on site selection model developed in this report (details are in appendix C). In future studies, metriccs for the attributes discussed in appendix C need to be developed and tested, where applicable.

7. There is insufficient data on LID cost per unit in the Hill Country Region. Limitations of applying results of other studies are due to variations in region, environment, and construction and labor cost. Constructing several experiential mockups will allow an exploration of different materials and construction specification that will help create standard estimates for the cost per unit.

8. Data sets acquired from different sources and agencies (i.e. SAWS inspection records, TCEQ BMP records, population, and VOC-emitting facilities) did not have the same timing, durations, or sample size.

9. Additional pollutants including microbial, nitrate (NO3), and ozone (O3) could be monitored through further research that may encompass

Organization of the Report

This report is organized around three parts that are comprised of twelve chapters in addition to the executive summary and this introduction. It addresses the related theories and regulations pertaining to the implementation of Low Impact Development (LID) in the Edwards Aquifer Recharge Zone (EARZ), and develops a multi-criteria geospatial model and two LID design proposals. Data used for the report was the most recent records available in April, 2016 at the UTSA campus as well as other local and national agencies. The following are the parts and chapters of the report:

Part A

This discusses the geographic boundaries where the EARZ is located according to various regulating agencies. It also includes a summary of geological formations comprising the nature of the aquifer. This part is divided into six topics discussed through the following chapters:

- Chapter one summarizes the region's location and ecology including EPA region six, TCEQ region 13.
- Chapter two focusses on defining the boundaries and challenges of the EARZ Region.
- Chapters three and four discuss the formation and sensitivity of the aquifer including its unique karst limestone as well as the special plans created to protect it.
- Chapter five summarizes the definitions, benefits, and considerations for LID in the Hill Country region.
- Chapter six reviews a number of regulations for stormwater management in Texas.

Part B

This part furnishes an introduction to site selection, and discusses the purpose and strategy of selection process through three chapters. Chapter one summarizes the objectives of site selection; Chapter two includes a detailed analysis of the specifications and benefits of ten Low Impact Development (LID) practices; Chapter three encompasses a step-by-step development of a geospatial analysis model including all theories and facts deduced from published work that support the development of the site characteristics and pollutant loads metrics.

Part C

This part compares management and operation requirements for various LID practices. It also sheds light on the benefits of implementing LID through rating systems and incentive programs. This part includes two chapters. Chapter one discusses the complexity, schedule, cost, personnel, and sustainability of management and operation plans. Chapter two focuses on the local and national credit systems and incentive programs available for LID projects. Five programs were analyzed including: STARS, LEED for Neighborhood Development (ND), Envision, CoSA Incentive Program, and SARA Rebate Program.

Appendices

- Appendix A: Student Research Design Proposal
- Appendix B: Central Quad Design Proposal
- Appendix C: SCM & SSM data & measures

Bioretention Swale located in Phil Hardberger Park, San Antonio, Texas.

A

THE REGION & EDWARDS AQUIFER

A.1 Region: Location & Ecology

Watershed protection in the City of San Antonio, and Bexar County, Texas is governed by multiple organizations. The scope of this section is to review the responsibilities of these entities, which include the Texas Commission on Environmental Quality (TCEQ), the Edwards Aquifer Authority (EAA), and the San Antonio Water System (SAWS) which share the responsibility of protecting the Edwards Aquifer. TCEQ and SAWS require treatment to remove pollutants for intensive development of land that funnels rainfall into the Edwards Aquifer. The city and the county are falling under different regions according to the geographic and administrative governance of each organization as well as the areas of intervention for watershed protection.

Organizations Involved in Aquifer Protection

- TCEQ
- EAA
- SAWS
- USEPA
- ESB

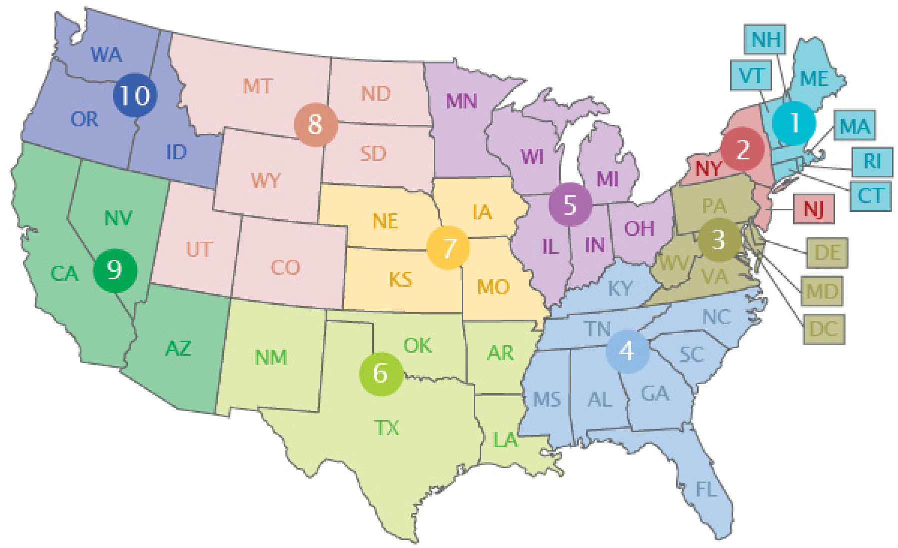

Figure A.1.1: U.S. Environmental Protection Agency's Administered Regions
Source: Water Environment Federation (2015)

EPA Region 6

On the federal level, Texas is located in Region 6 of the US Environmental Protection Agency (USEPA) geographic governing entities. The region, which encompasses four other states (Arkansas, Louisiana, New Mexico, Oklahoma) and 66 tribes, is served by the Environmental Services Branch Laboratory (ESB)[1] that provides high quality and methodologically-driven support for organic, inorganic, and biological analyses. The lab also monitors and conducts technical audits and provides technical expertise and assistance to the laboratories of Region 6.

TCEQ Region 13

According to the 1989 legislature, Texas Commission on Environmental Quality (TCEQ) is designated as the lead agency of the Texas Groundwater Protection Committee (TGPC). The regulatory protection of groundwater is primarily the responsibility of the TCEQ. Bexar County is among 15 counties located in Region 13[2], which is part of the regions that TCEQ embodies for regulating groundwater in Central Texas.

In May 1993, the 73rd Legislature established the Edwards Aquifer Authority (EAA), an agency responsible for the regulations to preserve and protect the unique groundwater resource of Edwards Aquifer. Starting 1996 a 17-member board of directors representing Atascosa, Bexar, Caldwell, Comal, Guadalupe, Hays, Medina, and Uvalde counties along with teams of geologists, hydro-geologists,

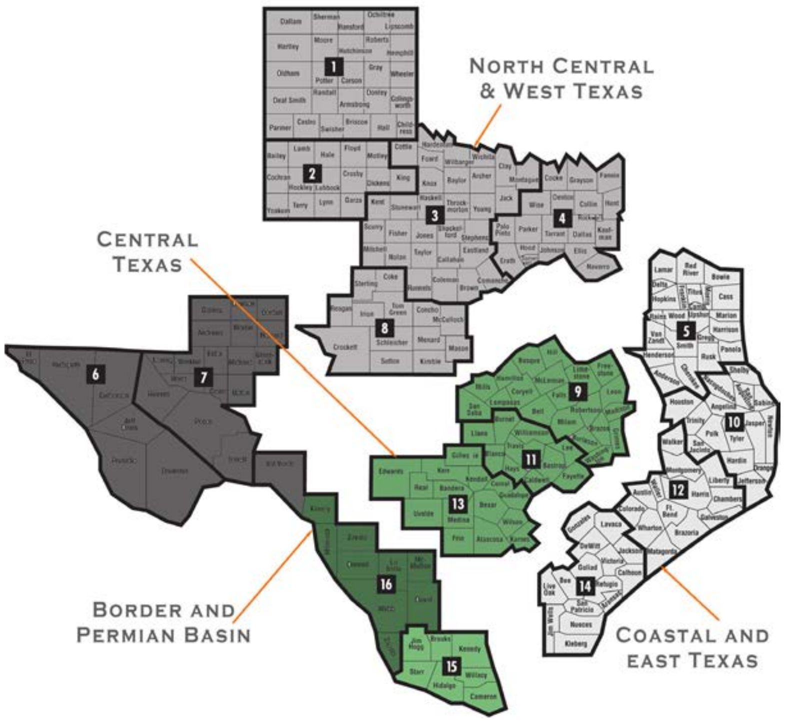

Figure A.1.2: Regions governed by Texas Commission on Environmental Quality (TCEQ).
Source: Based on TCEQ (2015)

environmental scientists, environmental technicians, educators, and administrative staff collaborate to manage, enhance, and protect the aquifer. Approximately two million South Texans rely on the aquifer as their primary source of water.

A Groundwater Conservation Plan (GCP)[3] is one of the areas administered by EAA, which aims to mandate a year-round reduction in water use to manage groundwater during extreme weather variability. GCP is managed through municipal, industrial, and irrigation permits to document their efforts on a triennial basis. Successful GCPs require implementation of Best Management Practices (BMPs) in order to achieve measurable water savings.

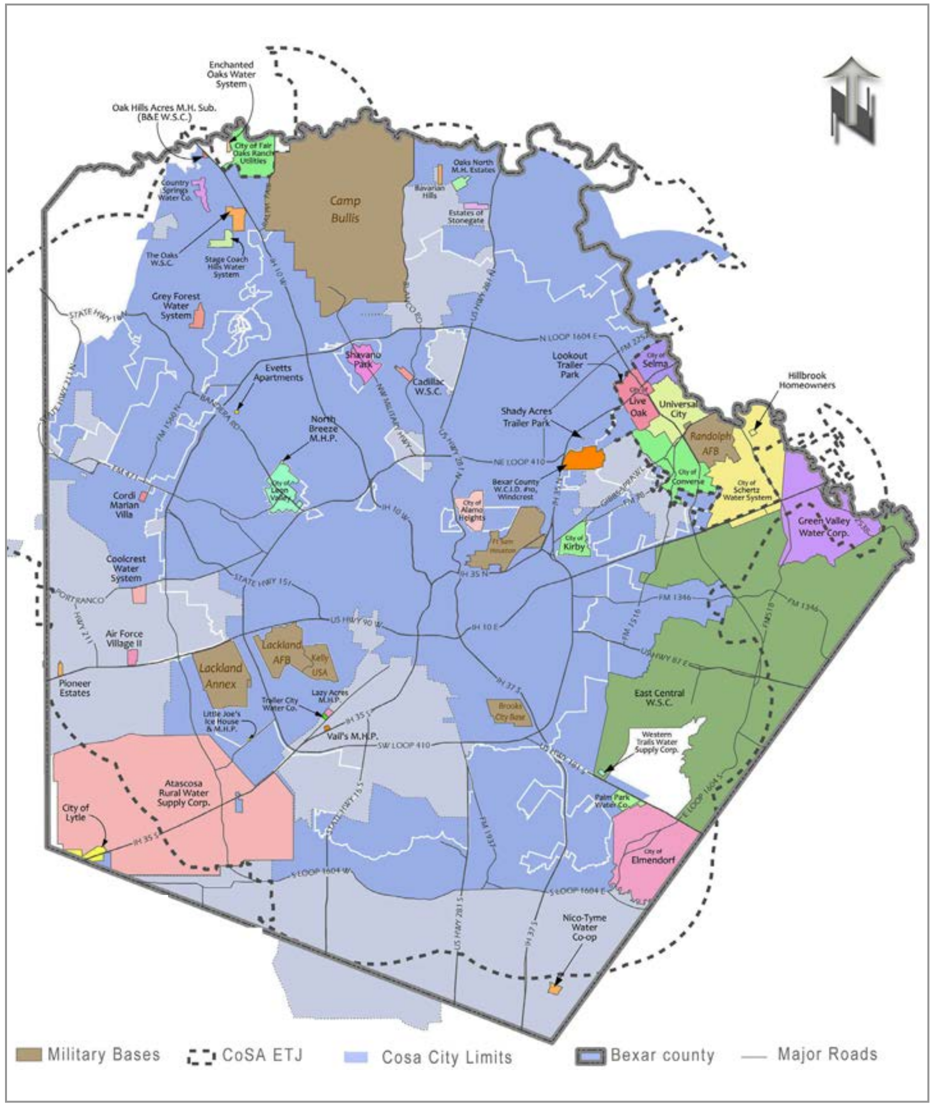

Figure: A.1.3: Water Service and Inspection Area of San Antonio and Bexar county, Texas.
Source: SAWS (2015)

Of the 15 counties, eight counties are regulated by the EAA. The EAA has regulatory jurisdiction in all of Bexar, Medina and Uvalde counties and portions of Atascosa, Caldwell, Comal, Guadalupe, and Hays counties. The EAA authorizes a total of 572,000 acre feet of groundwater withdrawals each year, which are used for municipal, industrial, and irrigation purposes. This total withdrawal amount was determined by calculating historical use combined with a goal to protect springflows and endangered species at Comal and San Marcos springs.

SAWS Region

San Antonio Water System (SAWS) was created in May 1992 through the consolidation of its three agencies (City Water Board, City Wastewater Department, and Alamo Water Conservation and Reuse District). As a public utility owned by the City of San Antonio, SAWS serves more than 1.6 million people in a smaller region that comprises Bexar County and parts of Comal, Medina and Atascosa counties. This population includes more than 460,000 water customers and 411,000 wastewater customers. The service areas are established by SAWS permits from state regulatory authorities. For water supply, these areas include most of Bexar County, and several suburban municipalities and adjacent parts of the county[4] in addition to serving SAWS own retail customers.

The Environmental Protection Agency (EPA) with assistance from the Texas Commission on Environmental Quality administers the Safe Drinking Water Act[5] to make sure tap water is safe to drink by restricting the presence of contaminants in public water systems. According to the act, SAWS, as a public utility entity, is required by law to report annually on the type and quantity of substances that exist in the drinking water. The act encompasses detailed guidelines concerning water quality requirements, as well as methods and frequency of testing.

Notes

1 U. S. Environmental Protection Agency- EPA, (2016). EPA Region 6 (South Central). Accessed on 1/12/2016: http://www.epa.gov/aboutepa/epa-region-6-south-central

2 Texas Commission on Environmental Quality-TCEQ (2016). Water Quality Program Successes, Accessed on 1/5/2016: http://www.tceq.state.tx.us/waterquality/watersuccess/waterqualitysuccess

3 Edwards Aquifer Authority (2016). Groundwater Conservation Plan (GCP). Accessed on 1/3/2016:http://www.edwardsaquifer.org/groundwater-permit-holders/groundwater-conservation-plan

4 San Antonio Water System- SAWS (2016). Service Areas. Accessed on 1/12/2016: http://www.saws.org/who_we_are/service/index.cfm

5 San Antonio Water System- SAWS (2016). Water Quality Concerns. Accessed on 1/12/2016: http://www.saws.org/Your_Water/WaterQuality/water_quality_concerns/

A.2 Edwards Aquifer Region

Location and Zones

The Edwards Aquifer is intensely faulted and fractured carbonate limestone (karst) that lies within the Balcones fault zone. The dynamics and size of this geologic anomaly make it one of the most wondrous aquifers in the nation, through its storage capacity, flow characteristics, water producing capabilities and efficient recharging ability. The entire aquifer and its catchment area in the San Antonio region is about 8,000 square miles[1] and includes all or part of 13 counties in south-central Texas shown in Figure A.2.1.

The aquifer comprises two primary zones, the recharge and the artesian, in addition to the Edwards Plateau (see Figure A.2.1), which is contributing to the recharge and artesian areas of the aquifer underlining the six counties south and east of the Balcones fault escarpment. The aquifer underlies approximately 3,600 square miles, and is about 180 miles long from west to east and varies from 5 to 30 miles wide. As a prominent reservoir, the aquifer receives most of its water from the drainage basins located on the Edwards Plateau (see Figure A.2.2). The catchment area, about 4,400 square miles[1], contains the drainage basins of the streams that recharge the Edwards aquifer.

In the San Antonio region, the Edwards limestone layer attains a thickness of approximately 450 to 500 feet. There is a total of 92 water wells supplying drinking water to SAWS customers pumping a daily average of 136.50 million gallons per day. From 1934 through 1994 the average recharge to the Edwards aquifer was 676,600 acre-feet.

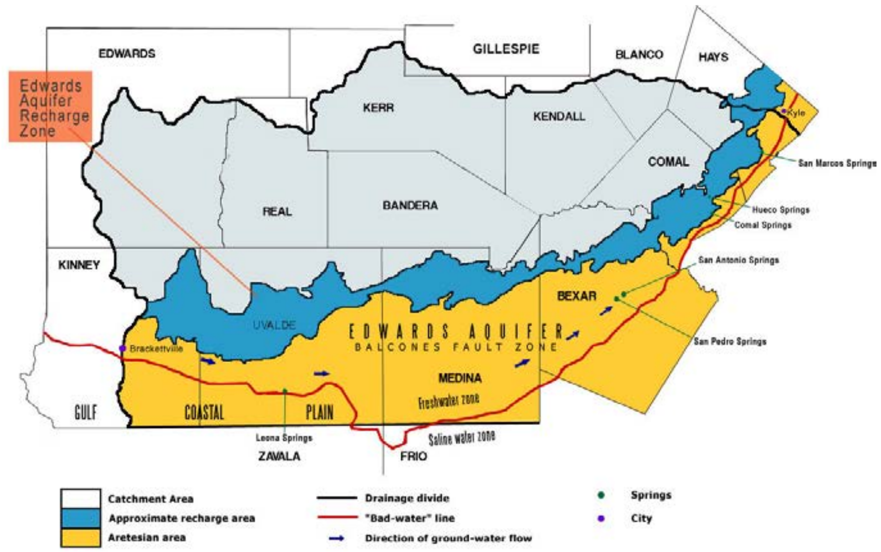

Figure A.2.1: Different zones of the Edwards Aquifer Region.
Source: Base on SAWS (2015)

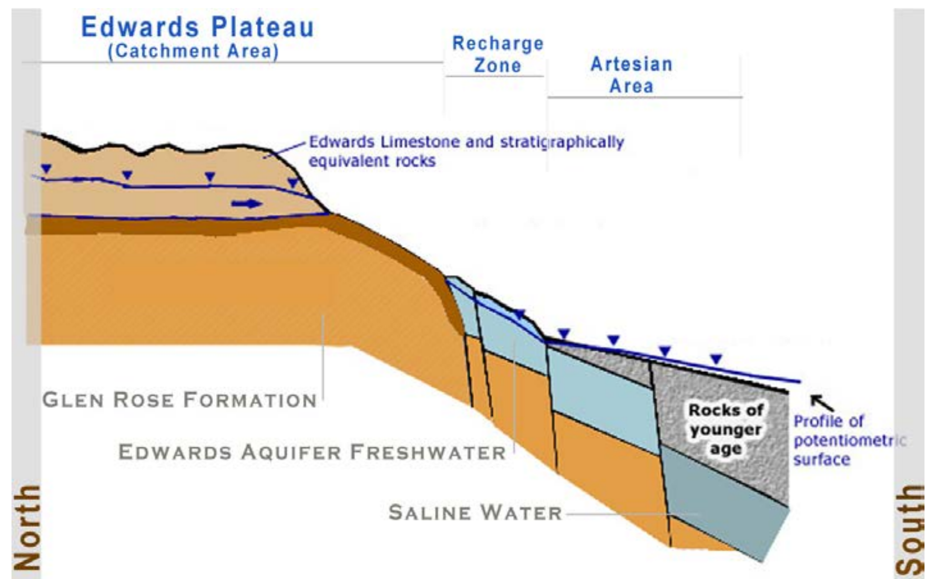

Figure A.2.2: North-South Cross Section of the Edwards Aquifer
Source: Based on SAWS (2015)

Best Management Practices
(BMPs)

According to the USEPA, there are two types of BMPs: structural or non-structural[2]. The structural is made of reinforced hardened materials such as concrete, which is associated with lack of aesthetics and integration of quality open spaces for the general public. Non-structural is mostly encompassing various plants, usually low-maintenance regional species, and soils, which is known as Low Impact Development (LID), and in other cases, it takes the form of a set of practices such as reduced fertilizer application. According to Texas state law, all permanent BMPs are required to 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.

The Central Registry records of the Texas Commission on Environmental Quality (TCEQ) database show that in the Edwards Aquifer Recharge Zone (EARZ), there are 3,029 water treatment engineered BMP structures[3]. Due to the lack of evidence through the current listing and procedures to verify whether these BMPs have been constructed, there is a need to scrutinize all the records. Adding to this, a 2010 report conducted by the Greater Edwards Aquifer Alliance (GEAA)[4] raised the following concerns regarding the inspection, maintenance, and awareness of the long-term performance necessity of the Bexar County BMPs:

Figure A.2.3: Structural BMP (sand filter) near the South Boundary of the UTSA main campus
Source: With Permission from the UTSA Office of Facilities (2015)

- Absence of a single centralized entity to be fully responsible for the County BMPs maintenance. Currently, the inspection records are maintained between several departments in SAWS and TCEQ (further analysis and recommendations are available in sections: Policy Recommendations, and B.3 of this report).

- There is no separate or joint-protocol between these entities to geographically and quantitatively register existing BMPs, and therefore a systematic comprehensive tracking record of BMP location, design type, construction or maintenance is not part of SAWS or TCEQ records.

- Lack of awareness of the sensitivity of the BMP and its contribution to mitigate storm runoff pollution among owners and the general public, and the critical role they play in protecting water quality in the Edwards Aquifer region.

- At least 10 to 15% of the structured BMPs are persistently non-compliant[4]. (Stormwater Pollution Prevention system, GEAA, 2010). However, with a detailed list of constructed BMPs, this percent may change.

In order to recommend implementing an effective system to maintain an up-to-date BMP geographic and quantifiable data set, it is important to review the existing data from the TCEQ central registry portal as well as the annual inspection records of SAWS. Through coordination with these two agencies as well as EAA, it could be possible to identify the problems in data verification, and hence offer a method that could employ scientific approach to incorporate one central list, and a tracking and monitoring system.

A structural BMP (sand filter) located in the south boundary of the UTSA main campus in San Antonio (2015)

Rainfall: Regions and Intensity

Low Impact Development or LID practices manage stormwater by minimizing impervious cover and by using natural or man-made systems to filter and recharge stormwater into the ground. Roads, parking lots, and other types of impervious cover are the most significant contributors to stormwater runoff. There is a direct relationship between the amount of impervious cover and the biological and physical condition of downstream receiving waters.

The intensity and quantity of rainfall are dependent upon the geographic region. Research has shown that the length of the most intense rainfall period contributing to the peak runoff rate is related to the time of concentration (Tc)[5] for the watershed, and this is why designing pervious coverage for surfaces in the most intense regions is crucial. In 1986, the Natural Resources Conservation Service (NRCS) developed a map synthesizing the main four regions of the 24-hour rainfall distributions in the United States. The regions are named I, IA, II, and III, and are based on data available on the National Weather Service (NWS) duration-frequency portal as well as local storm data. The distinctions of the four region is observed in the intensity and duration of rainfall as explained in the following box also shown in Figure A.2.4.

In the area of particular interest to this report, the Hill Country and Coastal Plains, the region is located in Type II Rainfall Zone, and therefore it experiences very intense rainfall events that produce flashy, high volume floods within a short period[6]. Design consideration to slow this flashy, high-intensity flow are crucial components of the structures mitigating stormwater runoff.

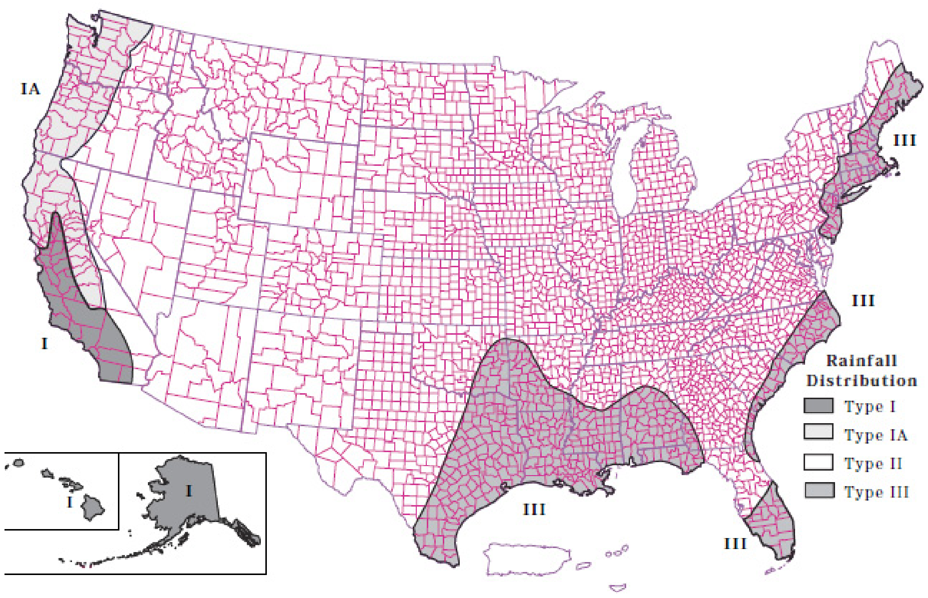

Figure A.2.4: Approximate geographic boundaries for NRCS (SCS) rainfall distributions.
Source: NRCS (1986, p. B2).

NRCS Rainfall Distribution Zones:

Types I & IA Represent the Pacific maritime climate with wet winters and dry summers.

Types IA Is the least intense

Types II Represents the rest of the country, and is the most intense short duration rainfall.

Types III Represents Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-hour rainfall amounts.

Notes

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6 Dorman, T., M. Frey, J. Wright, B. Wardynski, J. Smith, B. Tucker, J. Riverson, A. Teague, and K. Bishop. (2013). San Antonio River Basin Low Impact Development Technical Design Guidance Manual, v1. San Antonio, TX: San Antonio River Authority. pp. 37-39.

A.3 Edwards Aquifer: Formation

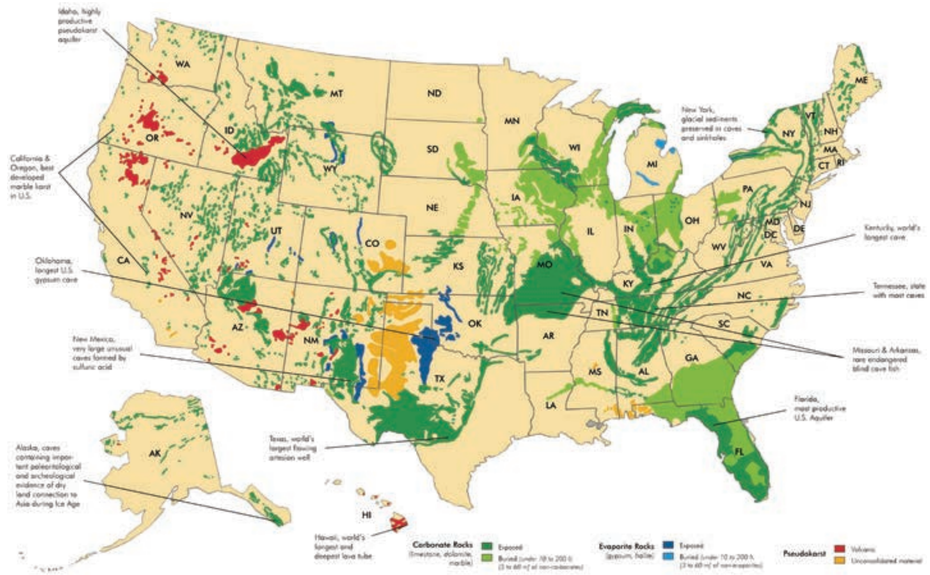

Figure A.3.1: U.S. Karst Map
Source: American Info Map (2016)

Karst Definition

Over the years, Edwards Aquifer has been composed of limestone known as karst. When groundwater from land surfaces enters karst aquifers like the Edwards, it moves at different rates. A study by the Greater Edwards Aquifer Alliance[1] indicates that this rate could range from less than one foot to several thousand feet per day, resulting in mixing some aquifer water that are hundreds of years old with other water that have been recharged by recent rainfall events. Several studies such as Johnson et al. (2010)[2], that discussed the entire recharge zone as well as parts of the contributing zone have raised concerns that the aquifer is vulnerable to contamination, even though identifiable karst features are not apparent[1].

It is therefore important for any attempt to deal with water management and conservation to first understand the nature of the Edwards Aquifer and its karst formation. Palmer (1991)[3], explained that karst is a landscape formed by the dissolution of soluble rocks including limestone, dolomite and gypsum. It is characterized by sinkholes, caves, and underground drainage systems.

Almost all surface karst features are formed through internal drainage, subsidence, and collapse triggered by the development of underlying caves. As it interacts with the carbon dioxide (CO2) in the atmosphere and soil, the rainwater becomes acidic, and then as it drains into fractures in the rock, it begins to dissolve away the rock creating a network of passages. As this process continues over hundreds of years, water flowing through the network continues to erode and enlarge the passages. This allows the plumbing system to transport increasingly larger amounts of water[4]. As a result, this dissolution process leads to the development of caves, sinkholes, springs, and sinking streams typical of a karst landscape[5].

It should be noted that, the term “karst” is usually used to describe regions where exposed soluble bedrock with an abundance of surface landforms exist. Examples of these surfaces include sinkholes, sinking streams, and springs that reflect the presence of subsurface voids or caves[6].

Karst Formation in the USA

Karst is an area collectively formed throughout an extended period on surfaces as a result of natural geologic substrates that are subject to solution and erosion. This geological process normally generates voids in the subsurface caused by several environmental and engineering problems. During the last few decades there has been a distinction between two types of karst formation. According to Palmer (1991)[3], karst features that reflect surficial (known as epigenic, solutional) processes are different from karst features that reflect deep-seated (known as hypogenic, solutional) processes. Both types, nevertheless, result in bedrock voids and therefore, the term “karst” has broadly been used as a recognition of karst features that exist deep in the subsurface in numerous environments, and has gained greater attention[7].

A geology-based approach is often adopted to map the karst distribution because the formation of the two types of karst is largely dependent on the presence of soluble rocks. Through compiling areas of soluble rocks from geologic maps, karst regions could be defined by effectively delineating areas that have a potential for karst development (for more details, see Ford and Williams, 2007)[7]. Figure A.3.1 also shows the US regions with different types of karst formation.

Central Texas Karst Aquifer

In central Texas, two million people get their drinking water from the Edwards Aquifer[9]. As the region becomes more urbanized, Edwards Aquifer becomes more important. Therefore understanding its structure and characteristics is vital for its protection. Karst development in the Aquifer has been associated with the geological nature of limestone in the region. Dissolution of the limestone has created a complex underground water flow network encompassing caves large enough for humans to access. According to Ferrill et al. (2004)[10], rainwater travels through this network until it reaches the water table of the aquifer. The karstified limestone acts as an aquifer storing drinkable water where later it can be extracted by humans.

Groundwater moves in different directions in the Edwards Aquifer. The general flow paths have been reported to be moving east in the western portion of the aquifer. It also moves northeast or south in the northern and eastern portion. A recent study by the Edwards Aquifer Authority (EAA) indicated that water also moves rapidly across any faults within the aquifer from the contiguous Contributing Zone directly upstream[1]. (see Figure A.2.2).

The Edwards Aquifer is one of the most productive groundwater reservoirs in the country, and one of the most biologically diverse karst aquifers in the world. Its significance is driven by the focus of its recharge zone, porosity of the rock layers, and transmission between aquifer formations and water quality conditions. A high diversity of species are found within the aquifer and associated springs and karst formations. Habitat management for these and other species is created through the Edwards Aquifer Recovery Implementation Program, which manages the recent Edwards Aquifer Habitat Conservation Plan[11].The species include: blind catfish, salamanders, aquatic crustaceans, and terrestrial cave invertebrates. 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).

Urbanization of the central Texas region causes a threat to this wildlife, and is considered one of the major challenges to managing this reservoir. With ongoing increase in density of people and structures, the region will face higher demand for water and increased pollution. Pollutants caused by different sources within the built environment are transmitted with the rainwater through the karstified limestone. During rain events, streams and surface runoff enters the aquifer via sinkholes and caves of the karst limestone. A natural filtration process produced by seeping through soil and bedrock, in non-urbanized areas, allows the water to bypass these layers before entering the aquifer. This direct recharge quickly replenishes the water supply. However, due to the excessive quantity of runoff that enters the engineered sewage system as a result of lacking appropriate infiltration medium as well as the vulnerability of small amount recharging the aquifer to contamination, there is an imminent need to examine feasible innovative approaches to increase management of water quantity and enhance its quality prior to entering the aquifer.

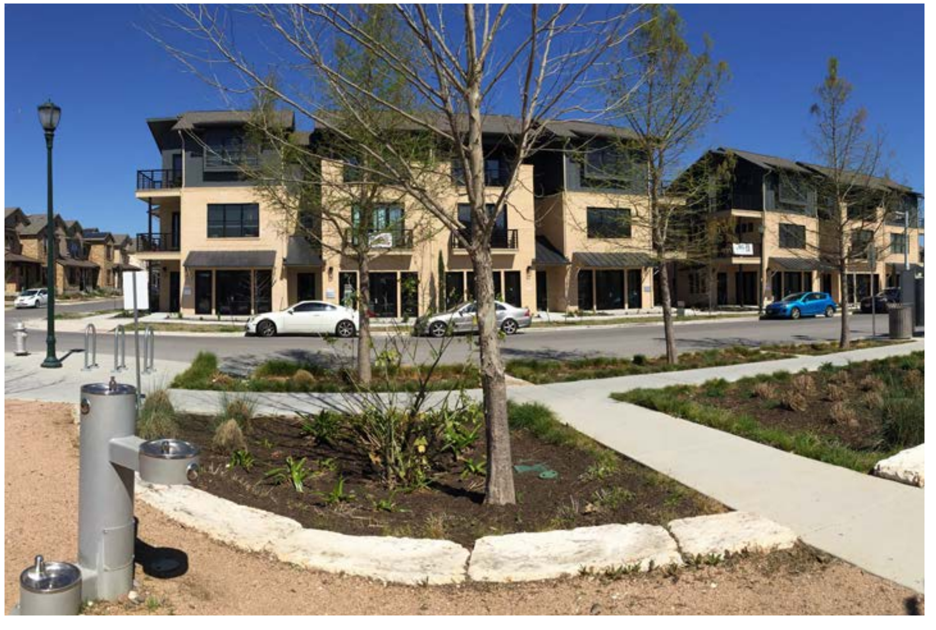

Figure A.3.2: Rain Garden at Mueller Community, Austin, Texas.

Notes

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A.4 Edwards Aquifer: Challenges

The existing regulations of Edwards Aquifer are limited and fall short of providing an effective and comprehensive system that controls water quality through a systematized process for reporting inspection and status of the water treatment structures. State, regional and local regulations concerning the aquifer largely deal with the allocation of water use. Inspection process to assure that Central Texas counties abide by water quality standards has lagged and is not sufficiently tied to the characteristics or water treatment performance of site preservation or overall impervious cover restrictions.

Water treatment structures, known as Best Management Practices (BMPs), are the accepted regional model for responding to water quality concerns. The majority of BMPs, however, are encountering maintenance problems and are implemented without a required pace or coordination with other agencies on the regular monitoring and reporting of compliance through a systematic and documented record that could be traced, updated, and analyzed.

Impervious cover restrictions are now recognized as an essential constituent of future plans to protect the health of the aquifer contributing and recharge zones. According to the 2014 report by the Greater Edwards Aquifer Alliance[1], a small percent of the communities and municipalities located over the aquifer set very limited and improperly designated restrictions on the percentages of individual properties rather than on total impervious cover in watersheds. The majority of the communities do not set restrictions on impervious cover. The report also called for the need for new regulations over the recharge zone, particularly since it is unlikely that communities can afford this level of protection everywhere, and therefore permanent regulations to preserve land through purchases, easements, and habitat conservation plans are crucial.

2015 Plan: Southern Edwards Plateau Habitat Conservation Plan (SEP-HCP)

In 2011, a consensus plan, known as the Southern Edwards Plateau Habitat Conservation Plan (SEP-HCP)[1] was created to serve as a roadmap for regional conservation of important land, water, and habitat sites. Under this plan, there are two endangered birds: 1) the Goldencheeked Warbler, and 2) the Black-capped Vireo, in addition to nine endangered karst invertebrates, primarily spiders and beetles[3]. Ongoing urbanization of the region causes a major threat to the existence of this habitat.

In order to preserve land and protect it against its habitat loss, a number of criteria were set for making decisions regarding land inclusion in the SEP-HCP plan. Also, an evaluation process is materialized through Geographic Information Systems (GIS) data to examine suitability of potential conservation lands so that protection funds could appropriately be allocated. A Conservation Advisory Board vets top candidate sites before landowner negotiations are begun. Criteria set for the GIS analysis include[1]:

- Geologic permeability for aquifer recharge
- Vegetation and biological habitat for karst invertebrates
- Parcel size and adjacency to other protected parcels.

Following the selection of candidate sites, the implementation process of the SEP-HCP will be in effect. Currently, the implementation is limited to the geographic extent of six Texas counties: Bexar, Bandera, Blanco, Comal, Kendall, and Medina. On December 18, 2015, the City of San Antonio approved the plan. The plan was officially announced by the U.S. Fish and Wildlife Service and is known as the Southern Edwards Plateau Habitat Conservation Plan (SEP HCP). Along with the plan, the City approved an incidental take permit covering commercial and residential development and infrastructure projects in the City of San Antonio and Bexar County, Texas. This approval will provide landowners and developers who have projects impacting nine federally protected threatened and endangered species and their habitat with streamlined process for complying with the Endangered Species Act (ESA).

Notes

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A.5 Low Impact Development (LID)

Definition

Surface and groundwater contamination is caused by two sources of pollution known as point and nonpoint. The United States Environmental Protection Agency (USEPA) defines point source as those from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack. Nonpoint sources of water contamination are the most significant, particularly as pollution from such sources increases with urbanization and urban sprawl[1]. This is because increasing impervious surfaces (e.g. roofs, roads, and parking lots) with the expansion of the amount of land covers enhances the likelihood of different types of chemical pollutants that accumulate on these surfaces to transmit to the ground water during rain events[2]. Therefore, different types of chronic and acute illness are the common symptoms to the people who drink this water. In order to reduce the negative impact of urbanization for nonpoint sources, a site design approach that emulates its natural characteristic through Green Infrastructure (GI) principles has successfully been integrated to emerging urbanized areas[3]. GI is used to describe the intertwined ecological landscape and site design practices for stormwater management.

Within the urban boundaries of a city, a GI approach applies Low Impact Development (LID) tools to eliminate or reduce pollutant loadings through filtering the pollutants and reducing the quantity of stormwater runoff in the areas adjacent to contamination sources. A LID tenet is to preserve and recreate natural landscape features, minimize effective imperviousness, and employ processes of infiltration, filtration, storage, evaporation and detention of stormwater runoff[4].

LID site design entails different techniques including rain gardens, vegetated swales, pervious pavements, and green roofs. Each type is subject to a set of landscaping and design guidelines to re-naturalize urban sites in order to manage rainfall runoff[5 & 6]. When properly designed, implemented, and managed, LID features capture stormater on-site, maintain it for longer periods to reduce peak storm flows and decrease overall runoff volumes, filter it through vegetation, and then penetrate it into the soil layers, where it can recharge groundwater reservoir. This approach is known as the Treatment Train (TT) technique that treats water through a sequence of BMPs and reduces the quantity of runoff. Also known as light imprint development, LID is a philosophy of stormwater management that seeks to mimic the natural hydrologic regime in urbanized watersheds.

As a radically different approach to conventional stormwater management, LID represents a significant advancement in the state of the art in stormwater management. It enhances the ability to protect surface and ground water quality, maintain the integrity of aquatic living resources and ecosystems, and preserve the physical integrity of receiving streams.

Several municipalities across the US have pioneered a breadth of new tools and practices in order to achieve good environmental designs that not only filter stormwater and reduce runoff, but also contribute to having a positive impact on the economy and quality of people lives[7]. LID can achieve stormwater control through the creation of a hydrologically functional landscape that functions as a comprehensive approach to land development or redevelopment[7].

LID designs are typically sized to manage runoff from frequent smaller storm events (typically in the range of one to two inches

Figure A.5.1: Vegetated Swale in the MIT Campus, Cambridge, Massachusetts.

over 24 hours). The size of LID feature is calculated based on the characterization of the drainage area, local hydrology, and other urban and ecological aspects. LID design is guided by several tools including applying either volume or flow-based criteria to determine the size, location, and type[8]. Example of designing a series of LID features are included in Appendix A and B of this report.

Benefits and Performance

LID values as a municipal, private, or public-private investment depend in part on their effects beyond water management. A cumulative modeling of these benefits is associated with the ability of communities, developers, investors, and owners to measure, quantify, and report these benefits. According to a 2010 report by the Center for Neighborhood Technology (CNT), scientific and quantitative measures focused on the benefits of only one practice (or feature), such as energy implications of green roofs, or a number of environmental or health impacts of a single practice, such as urban forestry's impact. The report also warns that these studies fell short in addressing a multifaceted measure for the cumulative assessment of multiple benefits[3]. For example, LID economic benefits have advanced considerably in recent years. However, estimating a holistic measure of its benefits is yet to be a developing field. According to the 2007 report by the United States Environmental Protection Agency on Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, the comparative construction costs of green infrastructure practices in residential construction could be estimated, yet the performance benefits were not included in this estimate[9].

Due to the apparent gaps in data availability and necessary tools of evaluation, decision-making regarding stormwater infrastructure investments has generally lacked a recognition of the monetary benefits that LID could offer the communities. With limited ability to quantify LID benefits, municipalities have often favored single-purpose grey infrastructure projects. However, any cost-benefit analysis comparing grey infrastructure with green infrastructure would be incomplete without factoring in the multiple benefits green infrastructure in general, and LID in particular, could render[3].

By implementing LID practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. When applied on a broad scale, LID could maintain and restore watershed's hydrologic and ecological functions. These principles, and the strategies described below, are considered the most beneficial when used together, often in a linked series of practices referred to as the treatment train approach[4] (also discussed in Chapter A.4 of this report).

A comprehensive report for Maryland, LID Integrated Design, that was published in 1999[7] as well as the San Antonio LID Guidance Manual[4] discussed the following as the primary benefits of LID:

- Minimizes stormwater impacts through multiple performance features including reducing imperviousness, conserving natural resources and ecosystems, maintaining natural drainage courses, and minimizing the need for pipes and grading.
- Mimics site pre-development hydrologic system for the urban and developing watersheds.
- Works with nature to manage on-site stormwater and treat stormwater as a resource for conservation and use.
- Provides runoff storage capability and measures that are dispersed across the sites' landscape features.
- Routes stormwater flow to maintain travel time and control the discharge through maintaining pre-development time of concentration.
- Creates an aesthetic and functional site drainage.
- Enhances feasibility by reducing construction, maintenance and inspection costs.
- Raises awareness among the general public and policy makers by implementing effective public education programs, participatory implementation, and by encouraging property owners to use pollution prevention measures and maintain the on-site stormwater management practices.

Furthermore, regional studies, such as Harris County Manual (2011)[10], summarize the primary benefit to water quality and quantity through itemizing the benefits for different LID practices (see Table A.5.1). However, the study was limited in quantifying the impact such practices have on the environment, economy, aesthetics, and visual quality.

In addition to the aforementioned benefits on the ecologic landscaping component of LID design characteristics, the feedback of the Green Infrastructure Working Group (GIWG)[11] and the Eagle Ford Shale BMP report[12] provided a further discussion of the LID impacts. The following box highlights further impacts on environment, economy, aesthetics, visual quality, and public health, and cost comparison for economic benefit of adopting LID rather than conventional approaches for water management in different case studies across the US (see also table A.5.2)[13]. Among 12 case studies discussed in Eagle Ford Shale BMP report, only one conventional water management design was estimated as 96 percent less cost than LID practices. The remaining 11 case studies have a reduction in cost of LID practice ranging from 15 to 80% when compared to the equivalent conventional site design.

Although most of these case studies provide a strong evidence of the economic benefits of adopting LID for site development, there are a number of challenges associated with multiple regions across the US that need to be addressed in design guidelines and stormwater runoff measures.

Table A.5.1: Runoff Management Functions

IMP	Effect or Function					
	Slow Runoff	Filtration	Retention	Detention	Evaporation	Water Quality
Disconnection	x	x				x
Soil Amendment		x				x
Vegetated Filter Strip	x	x			x	x
Vegetated Swale	x	x		x	x	x
Rainwater Harvesting			x	x		x
Bioretention	x	x		x	x	x
Permeable Pavement	x	x		x	x	x
Tree Box Filter	x			x		x
Storm Water Planter	x	x		x	x	x
Green Roof	x				x	x

Source: Based on Storey et al. (2011, p. 26

Table A.5.2: Cost comparison of conventional development vs LID

Project	Conventional Development cost (estimated)	Actual LID cost	Cost difference	% difference
2nd Avenue SEA st, Seattle, WA	$868,803	$651,548	$217,255	25%
Auburn Hills, WI	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall, WA	$27,600	$5,600	$22,000	80%
Bellingham Donovan Park, WA	$52,800	$12,800	$40,000	76%
Gap Greek AR	$4,620,360	$3,942,100	$678,500	15%
Garden Valley, WA	$324,400	$260,700	$63,700	20%
Kensington Estates, WA	$765,700	$1,502,900	$737,200	-96%
Laurel Springs, WI	$1,654,021	$1,149,552	$504,469	30%
Mill Creek (per lot), IL	$12,510	$9,100	$3,411	27%
Prairie Glen, WI	$1,001,848	$599,536	$405,312	40%
Somerset, MD	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus, IL	$3,162,160	$2,700,650	$461,510	15%

Source: Based on U.S. EPA (2009).
*Note that negative values denote increased cost for LID design over conventional developments costs.

LID impacts beyond water management benefits

- Air quality protection
- Natural hydrology maintenance
- Noise abatement
- Glare abatement
- Urban Heat Island mitigation
- Native vegetation protection
- Visual buffering
- Beautification
- Property value enhancement
- Unique identity
- Energy conservation
- Protection of health, safety, and general welfare

LID Considerations for Hill Country Region

As discussed in section A.2 of the report, the Hill Country and Coastal Plains experience very intense rainfall events that produce flashy, high volume floods. The San Antonio River Basin LID Design Manual[8] emphasizes the need to incorporate energy dissipation, flow transition and bypass features to handle extreme events without causing excessive damage. The manual also provides clear instructions for dealing with areas of steep slopes. In such sites, LID practices require more assessment and careful design. BMP options include terracing of bioretention features, using rock berms to spread flow, permeable pavement that collects and infiltrates water, and appropriate slope ratio in site planning in order to mitigate erosion and to slow the flow. Figure A.5.2 provides a schematic design of a series of level bioretention areas down a slope, which will calm flows and allow stormwater to pond temporarily behind internal control features before flowing to the next treatment area.

(b)(4)(B)(iii): No retention facilities or pervious pavement without an impermeable liner are allowed over the recharge zone to discourage the infiltration of pollutants. This requirement is misunderstood and/or misrepresented to preclude any use of pervious pavement and may be responsible for a "use impervious surfaces to channel stormwater runoff straight to rivers and streams" attitude that is in direct contradiction to this plan[12].

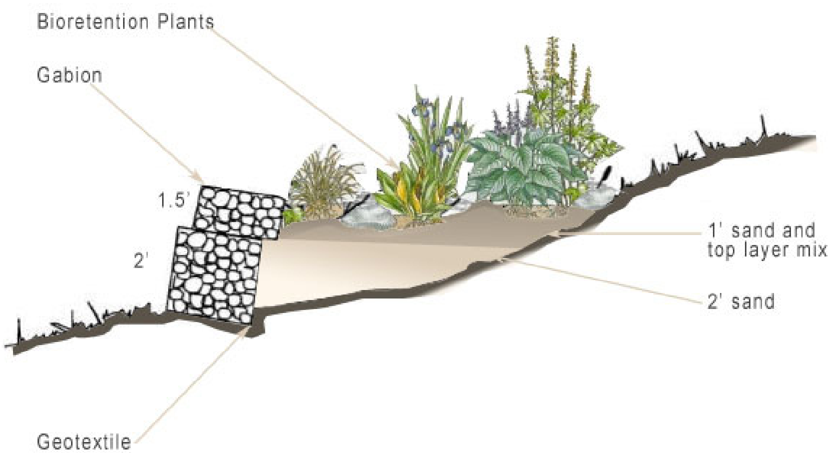

Figure A.5.2: Bioretention Terrace Suitable for Use on Slopes 10-20% as proposed by the San Antonio River Authority technical design manual.
Source: Based on Dorman, et al (2013)

Notes

1 U.S. Environmental Protection Agency- EPA (2015a), What is Nonpoint Source? Accessed on 12/12/2015 http://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-source

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11 City of Austin (2015). Green Infrastructure Working Group (GIWG), Watershed Protection Program, Accessed on 12/10/2015: http://www.austintexas.gov/page/green-infrastructure-working-group

12 San Antonio River Authority- SARA (2011). Best Practices Handbook to Assist Communities in the Eagle Ford Shale, 2nd Edition (Identification and Implementation of Best Practices). San Antonio, TX: San Antonio River Authority, pp. 605-607

13 U. S. Environmental Protection Agency- EPA, (2009). Managing Stormwater with Low Impact Development Practices: Addressing Barriers to LID. White Paper: EPA 901-F-09-003, Washington, D.C.: EPA.

A6 Texas Regional Regulations for Water Management

This code should include consideration for developments that have less than 20% impervious cover. Recent research by the Center for Watershed Protection (CWP) indicates that water quality is impacted when impervious cover reaches approximately 10% . Thus, BMPs should be required for all impervious cover to protect downstream water quality and meet the overriding goal of aquifer protection.

This code should include consideration for developments that have less than 20% impervious cover. Recent research by the Center for Watershed Protection (CWP) indicates that water quality is impacted when impervious cover reaches approximately 10%. Thus, BMPs should be required for all impervious cover to protect downstream water quality and meet the overriding goal of aquifer protection.

State Regulations

Texas Commission on Environmental Quality (TCEQ)

Texas Administrative Code[1] , Title 30, Part 1, Chapter 213, Subchapter A, Rule § 213.5 specifies required Edwards Aquifer Protection Plans, Notifications, and Exemptions. Regulations pertaining to permanent BMPs include the following:

- (b)(4)(D)(ii)(I) BMPs and measures must be designed, constructed, operated, and maintained to insure that 80% of the incremental increase in the annual mass loading of total suspended solids be removed.
- (b)(4)(D)(ii)(II) Owners of BMPs must insure that they are constructed and function as designed. A Texas licensed professional engineer must certify BMPs to assure that they were constructed as designed.
- (b)(4)(D)(ii)(III) Permanent BMPs are not required on low density single-family residential developments with 20% or less impervious cover.
- (b)(4)(D)(ii)(IV) The executive director may waive the requirement for other permanent BMPs for multi-family residential developments, schools, or small business sites where 20% or less impervious cover is used at the site. Otherwise, BMPs are required at these and all other non-single-family development sites.

City of Austin

Austin Land Development Code

The City of Austin's Land Development Code, § 25-8-211 "Water Quality Control Requirement," stipulates that all development within the Barton Springs Zone is required to incorporate water quality controls. The Barton Springs Zone includes all watersheds that contribute to the recharge of Barton Springs, including those portions of the Williamson, Slaughter, Onion, Bear and Little Bear Creek watersheds located in the Edwards Aquifer recharge or contributing zones. In watersheds outside the Barton Springs Zone, water quality controls are required for development:

- Located in the water quality transition zone;
- Of a golf course, play field, or similar recreational use, if fertilizer, herbicide, or pesticide is applied; or
- If the total of new and redeveloped impervious cover exceeds 8,000 square feet.

Within the Barton Springs Zone, § 25-8-511, also known as the Save our Springs Initiative, or (SOS), applies. SOS outlines stipulations regarding impervious cover in the Barton Springs Zone stating that impervious cover shall be limited to:

- 15% in the entire recharge zone
- 20% of the contributing zone within the Barton Creek Watershed
- 25% within the remainder of the contributing zone.

§ 25-8-213 "Water Quality Control Standards" stipulates that water quality controls must be designed in accordance with the Environmental Criteria Manual – a companion document to the Land Development Code available through the City of Austin that provides guidelines for the design of water quality controls. In addition, impervious liners are required wherever there is surface runoff to groundwater conductivity. However, if controls are arranged in series, then liners are not required for the second or later controls in the series following sedimentation, extended detention, or sedimentation/filtration. This section also stipulates that water quality controls must capture and treat:

- **The first one-half inch of runoff from within their contributing zones; and**
- **An additional one-tenth inch for each 10% increase in impervious cover over 20% of gross site area.**

Watershed Protection Ordinance (2013) Watershed Protection Department

On October 17, 2013, the Austin City Council passed a new Watershed Protection Ordinance, completing Phase 1 of the new ordinance. There is still work to be done on Phase 2, Green Stormwater Infrastructure.

The ordinance improves creek and floodplain protection; prevents unsustainable public expense on drainage systems; simplifies development regulations where possible; and minimizes the impact on the ability to develop land.

The City held a series of stakeholder meetings from August 2011 through July 2014 to obtain public input. A Green Infrastructure Working Group met in January 2015 as part of the City's land development code rewrite process, CodeNEXT, to discuss how the Imagine Austin goals of integrating nature into the city and creating complete communities can be achieved through revisions to the City's zoning and environment codes.

Green Infrastructure Working Group (GIWG)

This group examined how the code can encourage the broader vision of green infrastructure established by Imagine Austin: "an interconnected system of parks, waterways, open space, trails, green streets, tree canopy, agriculture, and stormwater management features that mimic natural hydrology." Ten Key Priorities by Green Infrastructure Working Group were identified in order of total votes:

1. Onsite infiltration/retention of stormwater
2. Integration of green elements into all contexts
3. Re-use/conservation of stormwater
4. Functional pervious areas
5. Redevelopment should be required to mitigate its share of downstream flooding
6. Adequate provisions for trees
7. Publicly-accessible open space
8. Special considerations for redevelopment for onsite infiltration/retention requirements
9. Adequacy of infrastructure capacity used to guide land-use planning and redevelopment
10. Green elements in both right-of-way and site setbacks

Houston Area

Houston Code of Ordinances

The City of Houston's Code of Ordinances, § 47-651, "Storm water quality permit application generally," stipulates that projects seeking a storm water quality permit shall submit a storm water quality management plan that complies with the Houston Department of Public Works and Engineering Design Manual for Wastewater Collection Systems, Water Lines, Storm Drainage and Street Paving. Chapters 9 and 13 of the manual include design standards for conventional and LID storm water controls respectively, and chapter 13 stipulates that employed control measures must handle the first half-inch of runoff. No limitations to percent impervious cover were found.

Harris County

Harris County, in conjunction with the Harris County Flood Control District, has published a LID design manual titled "Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management." Significant parameters from the guide include the following:

- Minimum detention rate with approved low impact techniques is 0.35 acre-feet per acre
- Harris County Flood Control District may monitor, test and/or inspect any LID facilities
- LID design must show that the post-project condition has an equal or lower peak flow than the pre-project condition peak flow
- Eligible LID practices include those that would result in:

  —Reduced impervious cover
  —Disconnected impervious cover
  —Increased time of concentration, including cumulatively over the entire development site
  —Increased losses in effective rainfall through storage, interception, etc.
  —Dispersed storage
  —A 1.25 safety factor for engineered soil void space
- LID-based projects of one acre or larger must have a Storm Water Quality (SWQ) Permit and a Storm Water Quality Management Plan (SWQMP)

San Antonio

San Antonio Unified Development Code

The City of San Antonio takes a regional approach to storm water management rather than site-by-site mitigation. § 35-504 of San Antonio's Unified Development Code stipulates that all developers must participate in the regional storm water management plan in one of three ways:

- Payment of a fee in lieu of on-site detention
- Construction of on-site or off-site measures to mitigate increases in runoff resulting from proposed development
- Construction or participation in the construction of an off-site regional stormwater facility to mitigate increased stormwater runoff anticipated from ultimate development of the watershed

§ 35-521, which covers specific protections for the Edwards Aquifer Recharge Zone, requires a Water Pollution Abatement Plan of new developments within the recharge zone and refers developers back to TCEQ requirements. It reads as follows:

- As a condition of all zonings/rezonings within the Edwards Aquifer Recharge Zone Overlay District (ERZD), a water pollution abatement plan approved by the TCEQ shall be required for all regulated development as established and defined by Texas Administrative Code, 31 TAC 213, prior to the issuance of a building permit and/or certificate of occupancy.

§ 35-210 Low Impact Development and Natural Channel Design Protocol (LID/NCDP): This section is to provide site design flexibility, development incentives, and strategies to implement Low Impact Development and Natural Channel Design Protocols. The section provides information on voluntary Use Pattern application and may be processed as part of a plat, tree affidavit, tree permit, building permit, Master Development Plan, or other development review applications. The terms and benefits of this application are below:

- This section reduces the need for variances that would otherwise be required for applicants that voluntarily desire to implement LID/NCDP approaches within their site. This section also implements existing city policies which call for the use of LID/NCDP techniques, including but not limited to SA2020, Master Plan, and Complete Streets policies.

- The provisions of this section shall apply to any voluntary application meeting the requirements of subsections (b) through (o) of this section and which is designated as a "Low Impact Development and Natural Channel Design Protocol (LID/NCDP) Plan" by the applicant.

Notes

1 Texas Secretary of State. (2016). Texas Administrative Code. Office of the Secretary of State: http://texreg.sos.state.tx.us/public/readtac$ext.ViewTAC?tac_view=3&ti=30&pt=1

2 San Antonio River Authority. (2016). Best Practices Handbook to Assist Communities in the Eagle Ford Shale: Identification and Implementation of Best Practices. San Antonio,TX: San Antonio River Authority. https://www.sara-tx.org/wp-content/uploads/2015/04/Eagle-Ford-Shale_Best_Practices_Handbook.pdf

3 City of Austin. (2016). Environmental Criteria Manual. Austin, TX: City of Austin. Retrieved from https://www2.municode.com/library/tx/austin/codes/environmental_criteria_manual

4 City of Austin. (2016). Land Development Code. Austin, TX: City of Austin. Retrieved May 16, 2016, from https://www2.municode.com/library/tx/austin/codes/land_development_code

5 City of Austin. (2016). Watershed Protection Ordinance. Retrieved May 16, 2016, from City of Austin: http://www.austintexas.gov/department/watershed-protection-ordinance

6 City of Austin. (2016). Green Infrastructure Working Group. Retrieved May 16, 2016, from City of Austin: http://www.austintexas.gov/page/green-infrastructure-working-group

7 City of Austin. (2015). Green Infrastructure Working Group Summary. Austin, TX: City of Austin. Retrieved May 20, 2016, from https://austintexas.gov/page/green-infrastructure-working-group

8 City of Houston. (2016). Code of Ordinances. Retrieved May 16, 2016, from City of Houston: https://www2.municode.com/library/tx/houston/codes/code_of_ordinances

9 Harris County Flood Control District. (2011). Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management. Technical Report. Houston, TX: Harris County Flood Control District. https://www.hcfcd.org/media/1543/2011-final_lid_gidc.pdf

10 San Antonio River Authority. (2016). Best Practices Handbook to Assist Communities in the Eagle Ford Shale: Identification and Implementation of Best Practices. San Antonio,TX: San Antonio River Authority. https://www.sara-tx.org/wp-content/uploads/2015/04/Eagle-Ford-Shale_Best_Practices_Handbook.pdf

11 City of San Antonio- CoSA (2016). UDC Amendments: Sec. 35-210 Low Impact Development and Natural Channel Design Protocol (LID/NCDP). San Antonio,TX: City of San Antonio http://docsonline.sanantonio.gov/FileUploads/dsd/11-23-15UDCAmendments.pdf

A.7 Technical Regulation for Unlined Practices

Introduction: Regulatory Issues

Central to the deployment of low impact development (LID) practices within the Edwards Aquifer Recharge Zone (EARZ) is the question of whether or not these facilities should allow infiltration. Infiltration is generally desirable within aquifer recharge zones, as this is the means by which aquifer stores are replenished. However, urban stormwater runoff is typically laced with various pollutants and suspended solids that would degrade overall water quality within an aquifer if allowed to enter. LID practices can reduce pollutant and suspended solid levels in stormwater runoff, but possibly not to pre-development levels. Accordingly, Texas Commission on Environmental Quality (TCEQ) as well as several municipal regulations prohibit unlined LID facilities within aquifer recharge zones.

Key regulations at play in The Southern Edwards Aquifer Recharge Zone, located in and near San Antonio, include those outlined in the City of San Antonio Unified Development Code (UDC) and in the Texas Administrative Code (TAC). UDC section 35-504 requires that proper measures be taken in new development through retention, detention and distribution of stormwater to minimize negative impact on water quantity and quality. The same section goes on to encourage innovative stormwater management practices, including those that enhance the recharge of groundwater. However, later, in UDC section 35-521, adherence to TCEQ Title 30 of the TAC is required by reference. TCEQ Title 30 is elaborated upon by a technical guidance document published by TCEQ titled Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices. This guide includes requirements for liners under stormwater control measures (SCMs) in the Edwards Aquifer recharge zone. (Richter & Peacock, 2015)

Regulations protecting the Barton Springs Recharge Zone (BSRZ) near Austin include the Land Development Code (LDC), Save our Springs (SOS) ordinance, and guidance provided by Environmental Criteria Manual (ECM) Section 1.6.9. While the LDC contains a strict liner requirement in areas where surface runoff to groundwater conductivity is possible, it relaxes this requirement where stormwater control measures function in series – allowing the second and later measures to be unlined after sedimentation, extended detention or sedimentation/filtration have occurred. Conversely, the SOS ordinance does not expressly stipulate the use of liners, but sets forth such high standards for runoff quality control that liners are made necessary de facto. As such, liner requirements are given in various sections of the ECM. (Richter & Peacock, 2015)

Though state regulations require the lining of SCMs over the Edwards Aquifer Recharge Zone, it is interesting to note that the Austin Land Development Code makes provision for unlined SCMs that are part of a larger series of SCMs operating in tandem, acknowledging that this approach might adequately reduce pollutant levels in stormwater runoff so as to make it suitable for aquifer recharge.

In an effort to determine if sufficient data exists to warrant amending TCEQ and other regulations to allow unlined LID facilities in aquifer recharge zones, two studies were reviewed that examined the effectiveness of LID practices in pollutant removal – one in the Barton Springs Recharge Zone near Austin (Figure A.7.1) and the other in Marion County, Florida, a karst region in the central part of the state (Figure A.7.2).

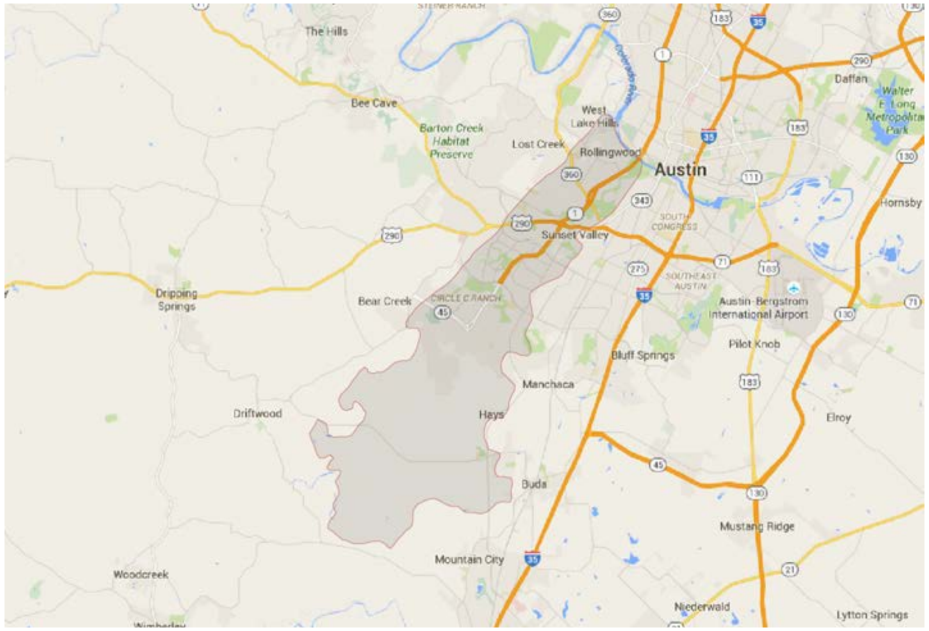


Figure A.7.1: Barton Springs Recharge Zone, Texas (highlighted in gray)

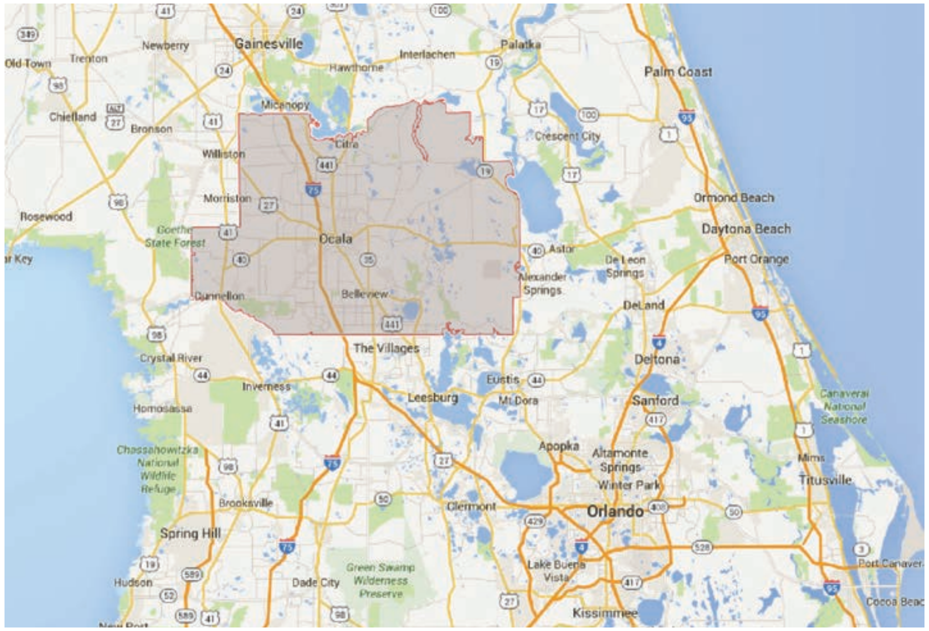


Figure A.7.2: Marion County Florida (highlighted in gray)

Background of Studies

The first study, Richter & Peacock, 2015[1], compared samples of runoff from undeveloped areas and effluent from LID facilities, both from in and around the City of Austin (COA). The undeveloped area runoff quality was used as a baseline for evaluating the quality of water treated by the LID facilities with the understanding that these facilities must demonstrate the ability to reduce runoff pollutents to pre-development levels if infiltration from these facilities is to be allowed.

The study also included a review of current literature on the subject of pollutant removal from stormwater runoff through LID and sought data from such measures employed over karst settings. The overall conclusion of the literature review was that not enough data currently exists on the effectiveness of pollutant removal through LID over karst regions. Where data was available, pre-development pollutant levels were not used as a baseline of study. Therefore, while infiltrating LID facilities have been shown to reduce pollutant levels, it has not been determined that they do so to pre-development levels.

The Florida study, Wanielista, et al., 2011[2], examined two unlined bioretention facilities with differing soil media compositions, both over karst areas, and evaluated specifically the facilities' effectiveness in preventing transport of nitrogen and phosphorus to groundwater through infiltration.

Study Methodologies

In the Austin study, water samples were taken from streams under baseflow conditions, stormwater runoff from undeveloped locations and from several SCM effluents.

The SCM effluents sampled included permeable friction course (PFC), sand filter, bio-filtration and retention-irrigation effluents.

The effluent quality from each SCM sampled was equivalent to the quality of effluent that would have been infiltrated after treatment if unlined facilities were allowed. Parameters studied included chemical oxygen demand (COD), total suspended solids (TSS), zinc, E.coli, total organic carbon (TOC), nitrate, total nitrogen, dissolved phosphorus and total phosphorus.

Two sets of stream baseflow data were collected in the study. The first set, "Undeveloped Runoff USGS" comprised samples collected from creeks in minimally developed areas in collaboration with the United States Geological Survey (USGS). These samples represented stormwater that would infiltrate over the Barton Springs Zone through creek beds. The second data set, "Undeveloped Runoff COA" comprised surface runoff samples collected by the COA in upland undeveloped areas and represented runoff that would infiltrate through soils over the recharge zone or enter the aquifer through caves or sinkholes rather than through a creek bed.

All three data sets were then aggregated into a meta-analysis comparison of water quality parameters.

In the Florida study, two unlined dry detention basins were selected in a karst zone through a culling process involving a range of criteria including easy site access, the presence of active karst formations and well-defined watershed, water tables and good infiltration capacity.

Once the two sites were selected, monitor wells of varying depth were installed in and around both basins. Monitored parameters included: rainfall, basin stage, ground water level, subsurface temperature and volumetric moisture content. Data were collected over a three year period.

Conclusions & Recommendations

The Austin study found that no SCM reduced runoff pollutants to predevelopment levels and therefore could not advise any change to current liner regulations for SCMs over the Edwards Aquifer Recharge Zone at this time. However, in noting that the study assumed infiltrating runoff through SCMs would not increase pollutant concentrations compared to the surface discharge of effluent, it was recommended that this assumption be tested through direct measurement of basin infiltration concentrations with lysimeters or wells, to definitively determine whether or not infiltrating systems can meet regulatory requirements and provide adequate aquifer protection. The study specifically called for further monitoring of biofiltration facilities, as its data on that particular facility type was limited. It was also suggested that the nutrient removal capacity of subsurface soils in the Austin area should be further investigated.

The Florida study found that one of the studied detention basins did sucessfully remove nitrogen from runoff before it could enter the groundwater system. However the study was limited in that nitrogen was the only pollutant form investigated. It also did not use predevelopment water quality as a baseline of comparison.

In conclusion, it is highly recommended that an unlined bioretention facility should be deployed in the Edwards Aquifer Recharge Zone as a pilot project. Such a project should maximize the number of variables tested in order to determine the most effective configuration and internal composition for reducing runoff pollutants to acceptable levels. Means of achieving such multi-variable assessment might include deploying an entire treatment train of LID SCMs as it has been shown that a several step process of filtration more effectively removes pollutants. Another option would be to partition the system in order to test various engineered soil media compositions.

Notes

1 Richter, A., & Peacock, E. (2015). Evaluation of potential for water quality impacts from unlined stormwater basins in the Barton Springs Recharge Zone. City of Austin Department of Watershed Protection.

2 Wanielista, M., Chang, N.-B., Xuan, Z., Naujock, L., & Biscardi, P. (2011). Nitrogen Transport and Transformation Beneath Stormwater Retention Basins in Karst Areas and Effectiveness of Stormwater Best Management Practices for Reducing Nitrate Leaching to Ground Water, Marion County, Florida. University of Central Florida Stormwater Management Academy: Civil, Engineering and Construction Engineering Department.

Bioretention Swale located in Phil Hardberger Park, San Antonio, Texas.

SITE SELECTION

B.1 Introduction to Site Selection

Purpose

Location is a product of three factors: space, time, and attributes[1]. Depending on the purpose and the uses of the site, the scope of the selection process may require an analysis of different attributes associated with various spatial scales including parcels, community, region, or nation. In site selection process, there is a wide array of factors that collectively contribute to the appropriate location of a site to serve a specific purpose.

The purpose of this report focuses on site selection within college and university campuses, and therefore a review of relevant studies on selection strategies was conducted. Due to the complexity of the built environment within the campuses, which in many cases encompass the same functions as small cities, the expansion or renovation may involve the construction of administrative buildings, parking lots and garages, pedestrian circulation systems, and new facilities for recreational and intercollegiate athletics[2]. Campus sites could range from a few to hundred acres or hectares in area. While a variety of potential sites may be available for any given project, each site could be dramatically different in their suitability for the proposed uses[2]. Topography for example could be a development constraint due to the site's high susceptibility to erosion or the site's poor accessibility. On the other hand, constraints of relatively flat sites might include the area's susceptibility to flooding. Other constraints could include –among physical, biological, and social attributes- the potential of the site for promoting campus life while maintaining proximity to vital spaces and academic buildings in a way that could influence the design –and ultimately the function- of any new facility or spaces[2].

The proposed uses of a site are important determinants of the method of site selection. Design and development team needs to establish clear and specific site selection criteria that are appropriate for the uses[2]. In this report, we are more interested in selecting sites that will be aligned with the broader initiative of promoting Low Impact Development (LID) in the City of San Antonio (CoSA). The initiative is collaboratively acknowledged by CoSA, San Antonio River Authority (SARA), Edwards Aquifer Authority (EAA), and the Greater Edwards Aquifer Alliance (GEAA). Multi-layered factors associated with increasing user's awareness of different LID practices and benefits will be the criteria this report focuses on. Site will be selected from the current records of engineered BMP structures that are spatially distributed throughout the city and Bexar County, TX. An outline of site selection approach is shown in Figure B.1.1.

Selection Criteria

This report focuses on establishing an evidence-based method for selecting existing Best Management Practices (BMPs) sites that will be eligible for redevelopment through designing a series of Low Impact Development (LID) practices. Prior to establishing a method for site analysis model, or embarking on data collection, LID project criteria were identified using a similar approach to that developed by Austin's working group task committee[3]. Through coordination with the funding agencies, research partners, and the UTSA office of facilities, the following criteria were identified as the most important site characteristics and design strategies for LID projects:

Criteria for Site Selection and Design Strategy

- **Increase stormwater quality, and reduce runoff volume through infiltration**
- **Maximize exposure to raise users' awareness about LID benefits**
- **Re-naturalize the sites to emulate pre-development and enhance outdoor activities**
- **Design an efficient and sustainable maintenance and operation**
- **Assure an ease of maintenance**
- **Enhance sustainability of site design and use of native plants and xeriscaping practices**
- **Integrate wayfinding elements for the site and its vicinity**

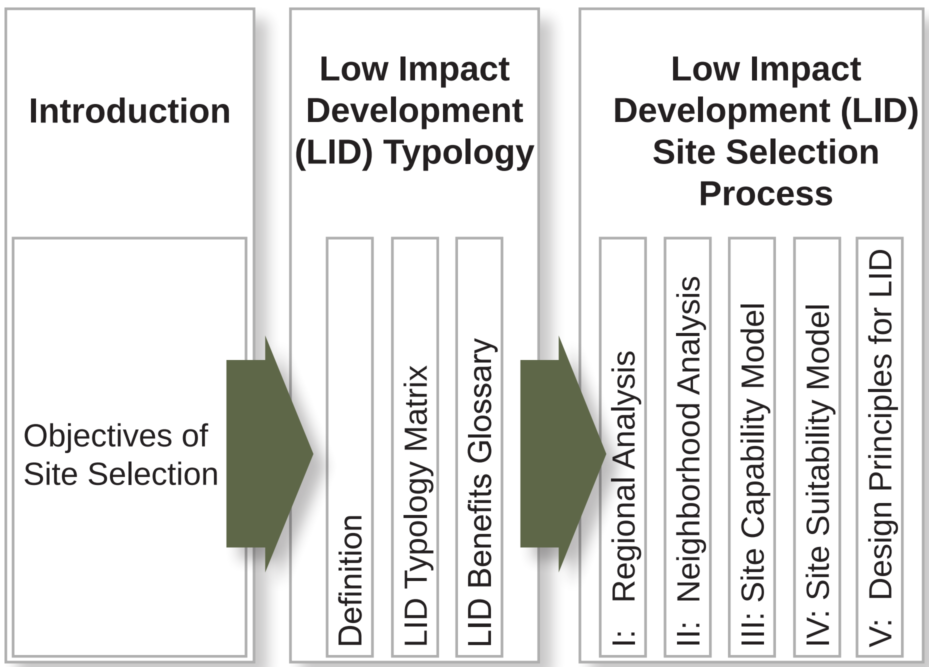


Figure B.1.1: Approach to Site Selection

A thorough review of literature was conducted to establish a background of theories and practices that support these criteria, and to highlight the attributes associated with adopting these criteria. In the following sections of this part, we will shed more lights on the two main themes resulted from this review of literature as well as the attributes, measures, and calculations of several features within the built environment. A detailed discussion of the analysis and the process is also discussed in section B-3 of this report.

Notes

1 Johnston, R. J. (1980). Multivariate Statistical Analysis in Geography: A printer on the General Linear Model. Essex, England: Longman Scientific and Technical.

2 LaGro, J. (2001). Site analysis: Linking Program and Concept in Land Planning and Design. New York, NY: Wiley.

3 City of Austin (2015). Green Infrastructure Working Group (GIWG) Summary. Accessed on 4/4/2016. https://austintexas.gov/sites/default/files/files/Watershed/GIWG-Stakeholder-Feedback-and-Recommendations.pdf

B.2 Low Impact Development Practices

Definitions of LID Practices

Bioretention Area
A vegetated depression to provide stormwater detention, filtration and infiltration through engineered soil media and the biological processes of plants and microorganisms.

Bioretention Swale
A shallow open channel designed to remove pollutants by filtering stormwater through vegetation and reduce runoff volume through infiltration.

Rock Infiltration Swale
A shallow rock-lined channel designed to improve stormwater quality and reduce runoff volume through filtration and infiltration.

Vegetated Swale
A shallow plant-lined channel designed to remove pollutants by filtering stormwater through vegetation and reduce runoff volume through infiltration.

Sand Filter
A surface or subsurface chamber that improves stormwater quality by filtering it vertically through a sand media.

Permeable Pavement
Hardscape that improves stormwater quality and can promote infiltration by allowing percolation of stormwater through subsurface aggregate.

Green Roof
Drought tolerant plants grown in a thin layer of media underlain by a liner and drainage components installed on a flat or gently sloped roof to reduce runoff volume.

Flow-Through Planter
A planter box that captures, temporarily stores and filters stormwater runoff.

Rainwater Harvesting
The use of water storage vessels that can collect and store rooftop runoff from a downspout for later use.

Vegetated Filter Strip
A band of dense vegetation situated between a pollution source and a downstream receiving water body or conveyance mechanism.

Figure B.2.1: Vegetated Swale in the MIT Campus, Cambridge, Massachusetts.

LID Practices Matrix

The following pages include ten LID practices.

- Bioretention Area
- Bioretention Swale
- Rock Infiltration Swale
- Vegetated Swale
- Sand Filters
- Permeable Pavement
- Green Roof
- Flow- Through Planter
- Rainwater Harvesting
- Vegetated Filter Strip

LID Typology	Bioretention Area	Bioretention Swale	Rock Infiltration Swale	Vegetated Swale
Descriptions & Applications				
Features & Benefits	Bioretention systems generally include a depressed ponding area, an engineered soil mix and an underdrain or underground detention or water harvesting system.[2] Vegetation in bioretention areas helps attenuate stormwater flows and break down pollutants through bacterial processes, fungi and other organisms in the planter soil. Vegetation also reduces erosion and traps sediments.[3]	Bioretention swales differ from vegetated swales in that they are designed to provide additional stormwater quality treatment through retention. The additional retention is achieved by way of an engineered soil media, check dams, berms and/or a low linear slope. They can be used as an alternative to culverts or storm sewers and can also provide landscape enhancement where desired.[6]	Rock infiltration swales are similar to bioretention swales except that they employ a rock surface instead of a vegetative surface. They offer versatility, in that they can be configured to suite various spatial conditions more effectively than other systems.[1]	As part of the shallow channel and vegetation, vegetated swales often incorporate check dams that act as flow spreaders in the stream, inducing sheet flow. Check dams can also facilitate stormwater detention as a means of encouraging sedimentation and reducing runoff velocity. They can also provide pretreatment when used in tandem with other structural treatment controls.[2]
Limitations & Disadvantages	Not suitable for steep slopes. TCEQ Edwards Rules require liners and underdrains for bioretention ponds over the recharge zone. May not be the sole treatment mechanism on sites with significant impervious area due to the need to treat water through multiple LID practices. Not suitable where water table is within 6 feet of the surface or in a geologically unstable area. Cost of bioretention systems can be somewhat higher than other LID types due to the cost of liners, underdrain systems and other control structures.[6]	Bioretention swales require greater widths than culverts, hardened swales or grassy swales. They do not effectively drain very flat areas and pose an erosion risk at steeper sites.[6]	Rock infiltration swales do not facilitate stormwater conveyance as their primary function. They are more suitable for facilitating infiltration and filtration.[1]	Vegetated swales are not recommended in areas with very flat or steep topography, as such conditions can cause standing water or erosion. Additionally, they do not facilitate infiltration as their primary function and are more suitable for facilitating conveyance and filtration.[7]

LID Typology	Bioretention Area	Bioretention Swale	Rock Infiltration Swale	Vegetated Swale
Treatment Efficiency				
Runoff Volume (Infiltration)	High (if unlined), Low (if lined)[1]	High (if unlined), Low (if lined)[1]	High (if unlined), Low (if lined)[1]	Low[1]
Detention Storage	Medium[4]	Medium[4]	No data	Medium[4]
Pollutant & Other Solids Removal				
Adsorption[10]	Medium[4]	Medium[4]		Medium[4]
Microbial Degredation	Medium/High[4]	Medium/High[4]		Low/Medium[4]
Filtration	Medium[4]	Medium[4]		Medium[4]
Plant Uptake	Medium/High[4]	Medium/High[4]		Medium[4]
Evapotranspiration	Low/Medium[4]	Low/Medium[4]		Low/Medium[4]
Trash/Debris	Medium	Medium	High[1]	High[1]
Sediment	High[1]	High[1]	High[1]	High[1]
Nutrients	Medium[1]	Medium[1]	Medium[1]	Low[1]
Pathogens	High[1]	High[1]	High[1]	Low[1]
Metals	High[1 & 6]	High[1]	High[1]	Medium[1]
Oil & Grease	High[1]	High[1]	High[1]	Medium[1]
Organics	High[1]	High[1]	High[1]	Medium[1]
Site Requirements (if applicable)				
Underground Utilities	A utilities inventory should be completed to ensure that site development will not interfere with or affect utilities[1]			
Catchment Area	Less than 5 acres, fully stabilized[1]		Less than 2 acres, fully stabilized[1]	Less than 2 acres[1]

LID Typology	Bioretention Area	Bioretention Swale	Rock Infiltration Swale	Vegetated Swale
Site Requirements, continued (if applicable)				
Sizing & Spatial Requirements	Size and depth will depend on infiltration rate of existing soils[3] as well as the size of the catchment area and the volume of runoff the system must handle.[6] A sizing factor of 6% assumes a site infiltration rate less than 2 in/hr., where the depression size would be 6% of the area of the drainage area. Size may be reduced if infiltration rate is greater than 2 in/hr using the ASTM D3395-09 method, or if amended soil depth is increased.[3] Bioretention areas may assume whatever shape best suits site design requirements provided that a minimum width of 30" maintained to ensure sufficient treatment time (length to be calculated based on incoming flow).[3]	As with bioretention areas, bioretention swale sizing is generally a function of the design storm runoff volume produced within the desired catchment area,[7] the infiltration rates of existing and/or engineered soil media and available space. Bioretention swales are typically 2 to 8 feet wide, having a maximum ponding depth of 18 inches.[7]	Should be sized to handle a 10-year, 24 hour rain event.[11] If infiltration is desired, infiltration rates of existing and/or engineered soil media will impact sizing requirements.	Swale footprint typically equals 10% to 20% of upsteam drainage area.[1] Swale length should be 100 feet minimum.[3] If infiltration is desired, infiltration rates of existing and/or engineered soil media will impact sizing requirements.
Head Requirements	Minimum 2.5 to 3.5 ft of elevation difference between inlet and outlet to receiving storm drain network (only if needed for the flow volume).[1] Flow entrance can be facilitated through a variety of mechanisms including over level spreaders, through curb cuts, trench drains or through roof leaders with direct surface connection.[5]	Minimum 2.5 to 3.5 ft of elevation difference between inlet and outlet to receiving storm drain network (only if needed for the flow volume).[1]	Minimum 2.5 to 3.5 ft of elevation difference between inlet and outlet to receiving storm drain network (only if needed for the flow volume).[1]	Length and slope of channel should be such that flowing stormwater resides for at least 10 minutes before exiting.[10]

LID Typology	Bioretention Area	Bioretention Swale	Rock Infiltration Swale	Vegetated Swale
Site Requirements, continued (if applicable)				
Slopes	For bioretention areas and bioretention and rock swales: Slopes draining into bioretention: 15% or less. Side slopes: 3:1 or flatter (horizontal : vertical). Internal longitudinal slope: 2% or less.[1] Bioretention areas in flat landscaped open areas should not slope more than 0.5% in any direction.[3] Average slope from inlet to outlet: 4% or less (for bioretention swales).[1] For vegetated swales: Overall slope: 1%-6% (1%-2% optimum). Slopes greater than 2.5% should incorporate grade control. Slopes flatter than 0.5% may result in ponding.[1] Side slopes: 4:1 or flatter (horizontal : vertical). Freeboard area side slope: 2.5:1 or flatter (horizontal : vertical). Swale bottom width: 2 ft. min. Treatment area width: 6 ft. min. Treatment area depth: 6 in. max. Freeboard area depth: 1 ft. min.[3]			
Setbacks	From structures and foundations: 10 ft. From septic fields and water supply wells: 100 ft. From steep slopes: 50ft[1]. Bioretention areas should not be placed immediately upslope of building structures including all retaining walls and foundations.[3]			
Structural Requirements	Positive overflow outlets must be provided for excess runoff when subsurface and surface storage capacities are exceeded. Common devices employed include domed risers, inlet structures, weirs and similar devices.[5] The life of a bioretention system can be extended by incorporating a forebay, vegetated swale or sedimentation basin for pre-treating runoff in order to prevent the bioretention media from becoming prematurely clogged with sediment.[6]	Check dams should be incorporated at intervals along length of swale to ensure 6-18 inches of ponding depth. Positive overflow outlets must be provided for excess runoff when maximum desired ponding depth is exceeded. Common devices employed include domed risers, inlet structures, weirs and similar devices.[1]	Check dams may be necessary at intervals along length of swale to facilitate sedimentation,[10] and, if desired, infiltration.	A 4 foot energy dissipater, which is either a porous tube or gabion mattress structure, should be employed to slow and spread water flow across treatment area.[3] Treatment area should be lined with high density jute or coconut matting over 12 inches of native topsoil. 2.5 to 3 inches of 3/4 to 2 inch river rock should be placed over matting.[3]

LID Typology	Bioretention Area	Bioretention Swale	Rock Infiltration Swale	Vegetated Swale
Site Requirements, continued (if applicable)				
Engineered Soil Media	Soil media depth for bioretention areas should be 1.5 - 4 feet; the deeper the better, for pollutant removal, hydrologic benefits and deeper rooting depths. Media composition should be 65% sand, 20% sandy loam and 15% compost from vegetation-based feedstock. Animal wastes or by-products should not be employed.[1] Media permeability should be 5 in/hr for the flow-based SUSMP method or 1-6 in/hr for alternate designs. Drainage layer beneath soil media should be comprised of 2 -4 inches washed sand over 2 inches choking stone over 18 inches of ASTM No. 57 stone. Soil media should be covered by 3 inches dimensional chipped hardwood or triple shredded, aged hardwood.[1]		Soil media depth should be 2 -4 feet. Media composition should be 65% sand, 20% sandy loam and 15% compost from vegetation-based feedstock. Animal wastes or by-products should be avoided.[1] Media permeability should be 5 in/hr for the flow-based SUSMP method or 1-6 in/hr for alternate designs. Drainage layer beneath soil media should be 2 -4 inches washed sand over 2 inches choking stone over 18 inches of ASTM No. 57 stone. Swale surface should be cobble.[1]	Not applicable
Engineered Soil Media for Biofiltration	For bioswales, biofiltration planters and rain gardens where more rapid drainage is desired: 85-88% washed course sand 8-12% fines passing a #270 sieve 2-5% organic matter[7]			Not applicable
Engineered Soil Media for Bioretention	For bioretention facilities where retention is desired in support of surface vegetation: 50% clean sand 25% crushed local stone with fines 25% locally excavated soil[6]			Not applicable
Water Table & Bedrock	Minimum 10 ft separation between bottom of cut (subgrade) and seasonal high water table, bedrock, or other restrictive features[1]			
Native Soil Suitability & Drainage	Suitable in any soil type. Underdrain recommended if subsoil infiltration is less than 0.5 in/hr. Liner might be needed if expansive clays or calcereous minerals are present in subsoils.[1]			

<table>
<tr><th>LID Typology</th><th>Bioretention Area</th><th>Bioretention Swale</th><th>Rock Infiltration Swale</th><th>Vegetated Swale</th></tr>
<tr><th colspan="5">Site Requirements, continued (if applicable)</th></tr>
<tr><td>Vegetation</td><td colspan="2">The potential for inundation should be considered when selecting plant species. Herbaceous rushes, sedges, perennials, ferns and shrubs that are appropriate for wet-to-moist soil conditions are ideal. In bioretention basins with sloped sides, there will be a moisture gradient from moist at the bottom to relatively dry at the top. The exact nature of the gradient will depend upon the designed maximum water depth, total basin/swale depth and the steepness of the side slopes. Planting zones that accord with the moisture gradient should be created and plants appropriate to each moisture level should be used. Vegetation should be planted densely and evenly to ensure proper function of the bioretention basin/swale.
Specifically for basins, quantities per 100 square feet should be as follows:
115 herbaceous plants, 1' on center spacing, 1/2 gallon container size; or 100 herbaceous plants, 1' on center, and 4 shrubs, 1 gallon container size 2' on center.
Trees are acceptable in bioretention basins/swales and should be selected by their adaptability to moist conditions and their anticipated size at maturity. In basins with sloped sides, trees should be located on the side slopes rather than at the bottom.[3]</td><td>Not applicable</td><td>The same principles of inundation and moisture gradient that apply to bioretention areas and swales also apply to vegetated swales. Additionally, plant spacing for vegetated swales should be as follows:
1.Treatment area = 6 plugs per square foot (min. 1-inch diameter by 6-inch tall)
2A.Total number of shrubs per acre = area in square feet x 0.05
2B.Total number of trees per acre (only tracts wider than 30 feet) = area in square feet x 0.01
3.Groundcover = plant and seed to achieve 100% coverage[3]</td></tr>
<tr><td>Areas of Concern</td><td>Infiltration not allowed at sites with known soil contamination. An appropriate impermeable liner must be used at these locations.[1] Plants selected for bioretention systems should be drought and inundation tolerant. Systems should be designed such that surface ponding does not exceed 24 hours.[2]</td><td>Infiltration not allowed at sites with known soil contamination. An appropriate impermeable liner must be used at these locations.[1]</td><td>Infiltration not allowed at sites with known soil contamination. An appropriate impermeable liner must be used at these locations.[1]</td><td>Swales should not be used to receive stormwater runoff from contaminated sites unless adequate pretreatment is provided upstream.[1]</td></tr>
</table>

LID Typology	Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Descriptions & Applications				
Features & Benefits	Sand filters can be surface or subsurface systems. Surface installations are similar in form to bioretention areas, though without vegetation and consisting of different soil media. Subsurface systems are typically housed in subdivided concrete chambers where one chamber is reserved for sedimentation and the other for the sand media itself. Weir slots allow passage of water from the sedimentation chamber to the filtration chamber. Sand filters can be compact and therefor useful where space is limited. They can offer deep ponding depths, which helps in saving space. Sand filters can also reduce peak runoff rates for frequent storms.[1]	Permeable pavement systems typically include underlying engineered media consisting of clean sands and gravels that facilitate infiltration of stormwater into site soils or an underdrain system.[2] They generally fall under two categories: (1) pervious concrete and asphalt, and (2) permeable pavers. Pervious concrete and asphalt are poured in place and resemble conventional asphalt, though compositionally, fines are removed to create more void space for water infiltration. Permeable pavers are solid, independent units made of pre-cast concrete, brick, stone or cobbles positioned to allow water flow between them.[3]	Through appropriate selection of materials, vegetated covers can provide significant rainfall retention and detention functions.[5] Vegetative roofs can provide benefits in addition to runoff volume reduction such as noise reduction inside the building, increased roof longevity, habitat provision, improved aesthetic value and evaporative cooling, which lowers building energy use for HVAC systems and helps minimize urban heat island effect.[5]	Flow-through planters are generally comprised of a concrete box filled with soil media, vegetation and an internal underdrain system.[2] Flow-through planters are highly adaptable to urban settings and retrofit applications due to their compactness. They also do not require setbacks from building foundations if properly waterproofed.[7]
Limitations & Disadvantages	Sand filters lack the pollutant removal capabilities provided by the biological activity and fine clays in bioretention systems.[1]	Permeable pavements can be prone to clogging if not properly maintained, reducing their effectiveness. They are typically not suitable for high or heavy traffic areas.[7]	Structural limitations of existing buildings can preclude use of green roofs in retrofit applications. Green roofs also tend to be more costly than other systems.[7]	Flow-through planters can typically only serve small areas and they do not facilitate infiltration and groundwater recharge.[7]
Treatment Efficiency				
Runoff Volume (Infiltration)	Low[1] Medium[4]	High (lined)/ Low (unlined)[1]	Low[4]	Low[1]
Detention Storage	Low/Medium[4]	Low/Medium[4]	Medium/High[4]	No data

LID Typology		Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Treatment Efficiency, continued					
Pollutant & Other Solids Removal	Adsorption[10]	Medium/High[4]	Medium/High[4]	Medium[4]	No data
	Microbial Degredation	Medium[4]	Low/Medium[4]	Medium[4]	
	Filtration	High[4]	Medium/High[4]	Medium/High[4]	
	Plant Uptake	Low[4]	Low[4]	Medium[4]	
	Evapotranspiration	Low[4]	Low[4]	Low/Medium[4]	
	Trash/Debris	No data	No data	Medium[1]	
	Sediment	Low/Medium[4]	Low/Medium[4]	Low/Medium[4]	High[1]
	Nutrients	Low[1]	Low[1]	Low[1]	Medium[1]
	Pathogens	Medium[1]	Medium[1]	Low[1]	High[1]
	Metals	Low[1]	High[1]	High[1]	High[1]
	Oil & Grease	Medium[1]	Medium[1]	No data	High[1]
	Organics	Medium[1]	Low[1]		High[1]
Site Requirements (if applicable)					
Underground Utilities		A utilities inventory should be completed to ensure that site development will not interfere with or affect utilities[1]			
Catchment Area		Catchment areas for sand filters can be similar to those of bioretention facilities and can also include parking lots and roadsides.	Permeable pavement replaces impervious area at a 1:1 ratio. To deter clogging over time, porous pavement should capture only direct rainfall.[3]	Varies widely from a few square feet to several acres.[1] Vegetative roofs may not receive runoff from other impervious areas such as an adjacent conventional roof.[3]	Less than 0.35 acres and fully stabilized.[1] Planter surface area should be at least 6% of the area of impervious surface it serves.[3]
Sizing & Spatial Requirements		Sizing for sand filters should be based upon the desired level of water quality treatment and expected runoff volume from desired catchment area.[1]	Typically designed to treat stormwater that falls on pavement surface area and run on from other impervious surfaces. Permeable pavement should not be used in high-traffic areas.[1]	Determined by area of roof to be served and associated structural loads.	Planters may be of any shape desired, however a minimum planter width of 30 inches is required to ensure sufficient time for water treatment and to avoid short-circuiting the system. A minimum of 18 inches of treatment depth must be provided in the growing medium.[3]

LID Typology	Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Site Requirements, continued (if applicable)				
System Types & Structural Requirements	Surface sand filters are installed in shallow depressions on the surface. Stormwater flowing into surface sand filters must be pretreated by vegetated swales, filter strips or forebays.[1] Subsurface sand filters are contained within deeper pits or concrete chambers. They must include a sedimentation chamber for pretreatment and are ideal for roadsides and parking lot edges.[1]	Pavement depth varies per application, however subsurface design should remain generally consistent. Pervious pavements are underlain by a storage reservoir situated on uncompacted subgrade to facilitate infiltration. Storage reservoirs consist of a stone bed of uniformly graded and clean-washed coarse aggregate sized from 1.5 to 2.5 in. in diameter, with a void space of at least 40% or other premanufactured structural storage units.[5] Bedding course: 1" or greater choker course meeting AASHTO No. 57. Aggregate Base: washed 3/4" to 2" uniformly graded aggregate. Course depth depth will vary per design. Geotextile Fabric: (if applicable) non-woven geotextile fabric should be placed between the subgrade and the aggregate base for proper separation.[3]	Single-medium assemblies are typically employed on pitched-roof applications and for thin and lightweight installations. This system type usually incorporates drought-tolerant plants and utilizes coarse engineered media with high permeability.[5] Duel-media systems utilize two types of nonsoil media. A finer-grained medium+E75 with some organic content is placed over a basic layer of coarse lightweight mineral aggregate. This combination improves drought tolerance by replicating a natural alpine growing environment where sandy topsoil overlies gravelly subsoil.[5] Structure should be evaluated or designed by structural engineer to ensure that it can support a vegetated roof.[1] Typical dead loads for wet extensive vegetated roof systems range from 8 to 36 pounds per square foot lb/ft2. Live load is a function of rainfall retention. E.g., 2 in. of rain equals 10.4 lb/ft2 of live load.[5]	While planter shapes and sizes can vary based upon site needs, system components remain generally the same. Care should be taken to ensure protection of adjacent building structures and foundations from planter leakage through proper waterproofing.[1]

LID Typology	Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Site Requirements, continued (if applicable)				
Slopes	For above ground systems: Side slopes: 3:1 or flatter (horizontal : vertical) Slopes draining into above ground sand filters should include pretreatment mechanisms. For below ground systems employed along roadways or parking lots, slopes of adjacent paved areas should be factored into design.	Pervious pavement should not be used on slopes greater than 20H : 1V.[3]	Can be installed on sloped or flat roof surfaces.[1] Roof slope requirements are 1/4" per foot as a minimum and up to a 4:12 pitch or greater with proper slope control.[3] Vegetated systems planned for roofs with a slope of 2 : 12 or greater must include supplemental measures to prevent sliding.[5]	Internal longitudinal slopes should not exceed 0.5%[3]
Setbacks	From structures and foundations: 10 ft From septic fields and water supply wells: 100 ft From steep slopes: 50 ft[1] Impermeable liners are recommended between base rock and adjacent foudations and conventional asphalt or concrete.[1]		Not applicable	10 foot minimum setback from building structures required for planters without an impermeable layer. Typically, no setback from building structures is required where planters are lined with waterproofed concrete or a 60 mil. PVC liner to prevent infiltration.[3]
Drainage Requirements	Where existing soils have low permeability and infiltration rates are less than 0.5 inches per hour, an under-drain system connected to an approved outlet structure should be provided.[3] An impermeable liner should be incorporated where infiltration is not desired.		Green roofs should incorporate a drainage layer consisting of a minimum of 2 inches of clean inorganic aggregate such as No. 8 stone if not using a prefabricated green roof system. Minimum detention capacity of overall system should be 0.8 inches minimum.[1] Design of roof drainage system should anticipate the need to handle significant rainfall events so as to avoid inundation.[5]	An overflow drain should be provided to ensure no more than 6 inches of water can pond in planter prior to overflow. A perforated pipe system should be provided to drain excess water and prevent long-term ponding.[3]

LID Typology	Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Site Requirements, continued (if applicable)				
Engineered Soil Media	No engineered soil media. The used media should be 1.5 - 4 feet in depth and should be composed of washed concrete sand free of fines, stones and debris, followed by 2 -4 inches of choking stone over 18 inches of ASTM No. 57 stone.[1]	Subsurface components of permeable pavement generally include a bedding course and a reservoir layer. The bedding course is situated immediately below the surface pavement layer and should be 2 inches of ASTM No. 8 stone. The reservoir layer is situated below the bedding course and should be composed of washed ASTM No. 57 stone. Depth of reservoir layer will depend on needed water detention capacity.[1]	Engineered media should have a high mineral content, typically 85% to 97% nonorganic for extensive vegetated roof covers. 2 in. to 6 in. of non-engineered soil medium should also be incorporated. System assemblies that are 4 in. and deeper can include more than one type of engineered media. Vegetated roofs intended to provide water quality benefits should generally not be fertilized. Irrigation might be required in dry climates to ensure plant survival and proper function of system.[5]	Internal amended soil mix is composed of one part orgainic compost, one part gravelly sand and one part top soil.[3]
Water Table & Bedrock	Minimum 10 ft separation between bottom of cut (subgrade) and seasonal high water table, bedrock, or other restrictive features.[1]		Not applicable	Seasonal high water table should be located below bottom of planter.[1]
Native Soil Suitability	Examine site compaction and soil characteristics when infiltration is planned to existing soils, and determine site specific permeability. Well-drained soils are ideal. Underdrains should be included when infiltration rate is less than 0.5 in/hr.[1]	Site compactions and soil characteristics should be examined. Minimize compaction during construction; do not place the bed bottom on compacted fill. Determine site specific permeability. It is ideal to have well-drained soils.[1]	Not applicable	Soils within the drainage area must be stabilized. Local soils must provide adequate structural support if flow-through planters are fully contained.[1]

LID Typology	Sand Filters	Permeable Pavement	Green Roof	Flow-Through Planter
Site Requirements, continued (if applicable)				
Vegetation & Irrigation	Not applicable, except for any ornamental landscaping that might be incorporated.		All vegetative roof system types can be installed with or without irrigation systems. Irrigation systems are recommended though for arid climates.[5] Ideally, vegetation should include drought tolerant species that can survive without supplemental irrigation.[1]	Inundation will occur periodically, so planter should be planted with herbaceous species such as rushes, sedges, perennials, ferns and shrubs suitable for wet conditions. Most moisture-tolerant plants can withstand seasonal drought during summer months and do not need irrigation after establishment. Quantities per 100 square feet should be as follows: 115 herbaceous plants, 1' on center spacing, 1/2 gallon container size; or 100 herbaceous plants, 1' on center, and 4 shrubs, 1 gallon container size 2' on center.[3]
Areas of Concern	If lined, sand filters can be used at sites with known soil contamination. Impermeable membranes must be used to contain infiltration within areas of concern.[1] (unless Low Impct Development was effectively implemented, and water quality measures met the requirements).	Permeable pavement designed for infiltration should not be used over contaminated soils. Impermeable membranes can be used to contain flow within areas of concern.[1] Permeable pavement systems should incorporate an underdrain or a subsurface detention or retention system with the capacity to drain the surface within 24 hours. Permeable pavements are not permitted for driveway aprons or public streets.[2]	Care should be taken to ensure security of media and vegetation in areas of significant wind loads.[1]	Fully contained flow through planters may be used in places with known soil contamination.[1] Planters located near buildings and other structures should include a waterproofing layer. Planters should be designed to accommodate a maximum ponding depth of 24 inches and to drain ponded water within 24 hours.[2]

LID Typology	Rainwater Harvesting	Vegetated Filter Strip
Descriptions & Applications		
Features & Benefits	Rainwater harvesting systems can include cisterns, rain barrels and underground storage systems. Captured water is typically used for irrigation purposes.[2] Capture-reuse systems can provide water for potable use as well through various filtration and disinfection means. When providing potable use, capture-reuse systems reduce potable water use from other sources and also reduce stormwater discharge volumes.[5]	Vegetated filter strips are gently sloped open areas that help to slow and filter runoff. They work well as part of a treatment train, providing pretreatment before runoff enters another LID facility. They are effective in handling sheet flows from roadways and parking surfaces.[6] Filter strips are typically easy to install and require minimal earthwork.[7]
Limitations & Disadvantages	Rainwater harvesting systems reduce runoff volume only when storage components are not already full.[2] Standing water in the system that is not properly covered can promote mosquito breeding. Pumping may be required to circulate water within the system and for reuse depending upon site topography, and measures should be taken to protect the system from freezing during winter[10].Also, rainwater harvesting should not use potable water backup.	Filter strips can require a large footprint for adequate treatment and must typically be sited adjacent to impervious surfaces since they are best suited to handing sheet flow.[7] They may also require supplemental irrigation and are appropriate in gently sloping area only.[10]

LID Typology		Rainwater Harvesting	Vegetated Filter Strip
Treatment Efficiency			
Runoff Volume (Infiltration)		Varies based on cistern size and drawdown mechanisms.[1] None[4]	Medium[4]
Detention Storage		High[4]	Low/Medium[4]
Pollutant & Other Solids Removal	Adsorption[10]	Low[4]	Medium[4]
	Microbial Degredation	Low[4]	Low/Medium[4]
	Filtration	Low/Medium[4]	Medium[4]
	Plant Uptake	None[4]	Medium[4]
	Evapotranspiration	Low[4]	Low/Medium[4]
	Sediment	Medium[4]	Low[4]
	Trash/Debris	No data	No data
	Nutrients	No data	No data
	Pathogens	No data	No data
	Metals	No data	No data
	Oil & Grease	No data	No data
	Organics	No data	No data
Site Requirements (if applicable)			
Underground Utilities		A utilities inventory should be completed to ensure that site development will not interfere with or affect utilities.[1]	
Catchment Area		Rooftop area[1]	Would vary based upon size of impervious surface to be serviced and available adjacent space.
Sizing & Spatial Requirements		Rainwater catchment systems should be sized to handle multiple rainfall events either through adequate water storage capacity or by deploying stores at a sufficient rate as to ensure adequate storage capacity for successive rainfall events.[2 & 5]	Where infiltration rate is less than 2 in/hr, strip area should be at least 6% size of catchment area. Strip area can be decreased if infiltration rate of existing soil is greater than 2 in/hr or if amended soil depth is increased.[3]

LID Typology	Rainwater Harvesting	Vegetated Filter Strip
Site Requirements, continued (if applicable)		
Slopes & Flow Paths	Not applicable	Flow path to filter should not exceed 75 feet for impervious ground cover and 150 feet for pervious ground cover unless energy dissipators and/or flow spreaders are employed.[2] Minimum width of strip should be 5 feet measured parallel to direction of stormwater flow. Strips should be sloped at between 0.5% and 6%, and the slope of the impervious surface draining into the strip should be less than 6%.[3]
Setbacks	Cistern overflows should be kept away from building foundations at least 5 ft.[1]	Check with local building department to confirm site specific requirements.[3]
Structural Requirements	For cisterns less than 2000 pounds, a gravel foundation may be adequate. Cisterns greater than 2000 pounds should be situated on concrete foundations.[1]	Check dams might be necessary to maintain shallow slopes if exisitng slopes exceed 5%. Check dams are usually 3 to 5 inches high located every 10 feet where slopes exceed 5%. Level spreaders might be required to evenly disperse runoff across the filter strip. Level spreader tops must be horizontal and at a height adequate to direct sheet flow to the soil without causing scour. Grade boards may be of any material that will withstand weather and solar degredation.[3]

Figure B.2.3: Mueller Neighborhood, Austin, Texas.

LID Typology	Rainwater Harvesting	Vegetated Filter Strip
Site Requirements, continued (if applicable)		
Engineered Soil Media	Not applicable	Top 18 in. of existing soils should be tilled and amended with compost to enhance pollutant removal, reduce surface ponding time and slow runoff by enhancing vegetative cover.[2] Amended soil should be equal parts organic compost, gravelly sand and weed-free, decomposed, non-woody topsoil free of animal waste.[3]
Drainage Requirements	Overflow volume or outflow volume should not be directed to areas where infiltration is undesired.[1]	Not applicable
Water Table & Bedrock	Seasonal high water table should be located below the bottom of cisterns, especially underground cisterns, to prevent bouyancy forces from affecting the cistern.[1]	Not applicable
Native Soil Suitability	Cisterns should be securely mounted on stable soils. A geotechnical report should be done to assess the structural capacity of the soil if unknown.[1]	Care should be taken to ensure soil that is upturned or exposed during creation of the vegetative filter strip is able to support healthy vegetative growth conditions in order to avoid the necessity of excessive fertilization. Top soil retained from the site during the grading phase or other soil amendments can be applied over the area to alleviate the problem.[2]

Figure B.2.4: Phil Hardberger Park, San Antonio, Texas.

LID Typology	Rainwater Harvesting	Vegetated Filter Strip
Site Requirements, continued (if applicable)		
Vegetation	Not applicable, except for any ornamental landscaping that might be incorporated.	Filter strip vegetation can consist of herbs, shrubs, grasses, wildflowers, groundcovers and trees. All employed species should be suited to moist-to-dry soil conditions and self-sustaining. Native plants are preferred, however adapted, non-invasive ornamentals are acceptable for additional aesthetic and/or functional value. Filter stip must have 100% vegetation coverage to ensure proper stormwater treatment and proper hydrologic function. Where check dams are required, plants suited to moist planting conditions should be used on the upslope sides where periodic inundation and ponding might occur.[3]
Areas of Concern	Cisterns should be opaque to prevent algal growth. System should be designed in such a way as to prevent backwatering onto roofs during a 100 year rain event. Signage should be incorporated to warn against consumption of non-potable water.[1]	Difficulty can be encountered in maintaining sheet flow, which can lead to erosion. Filter strips should not be employed on steep sites and are not suitable for treating high velocity flows.[9]

Notes

1 San Diego County Department of Public Works. (2014). Low Impact Development Handbook: Stormwater Management Strategies.

2 Storey, A. L., Blount, J., & Talbott, M. D. (2011). Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management.

3 Clean Water Services. (2009). Low Impact Development Approaches Handbook. Retrieved from: http://nacto.org/docs/usdg/lid_handbook_clean_water_services.pdf

4 Jia, H., Yao, H., Tang, Y., Yu, S. L., Zhen, J. X., & Lu, Y. (2013). Development of a multi-criteria index ranking system for urban runoff best management practices (BMPs) selection. Environmental Monitoring and Assessment, 7915-7933.

5 Cahill, T. H. (2012). Low Impact Development and Sustainable Stormwater Management. Hoboken: John Wiley & Sons, Inc.

6 Greater Edwards Aquifer Alliance. (2014). Watershed Stewardship for the Edwards Aquifer Region: A Low Impact Development Manual.

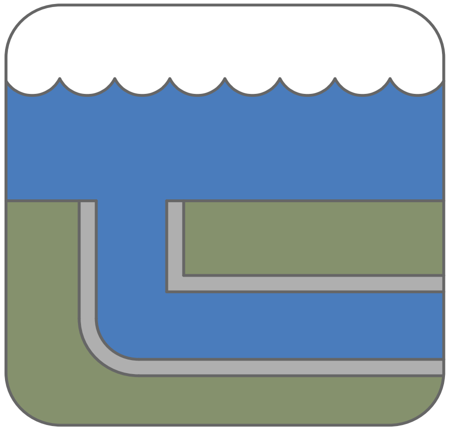
7 Dorman, T., M. Frey, J. Wright, B. Wardynski, J. Smith, B. Tucker, J. Riverson, A. Teague, and K. Bishop. (2013). San Antonio River Basin Low Impact Development Technical Design Guidance Manual, v1. San Antonio, TX: San Antonio River Authority, p.44.

8 Center for Research in Water Resources & Lady Bird Johnson Wildflower Center - University of Texas at Austin. (2011). San Antonio LID Guidance Manual.

9 Prince George's County Department of Environmental Resources, Programs and Planning Division. (1999). Low-Impact Development Design Strategies. Prince George's County, Md.

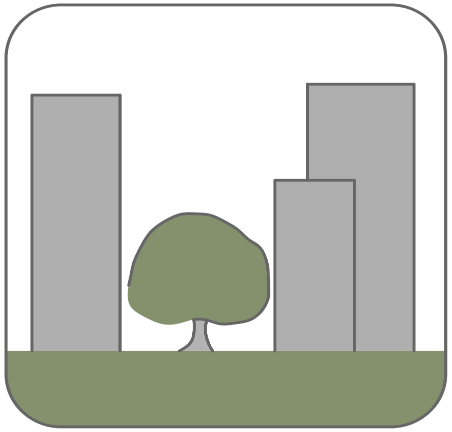
10 Adsorption is a surface phenomenon with common mechanism for organic and inorganic pollutants removal. When a solution containing absorbable solute comes into contact with a solid with a highly porous surface structure, liquid–solid intermolecular forces of attraction cause some of the solute molecules from the solution to be concentrated or deposited at the solid surface. Adsorption is ab efficient technique for the removal of highly toxic organic compounds from water.

LID Benefits Glossary

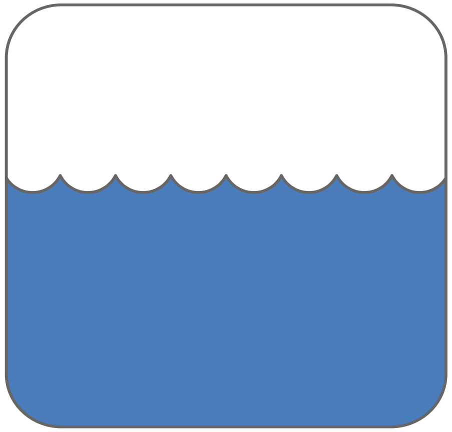


Reduces loads on stormwater infrastructure as well as the need for expansion of those infrastructures when new development occurs.

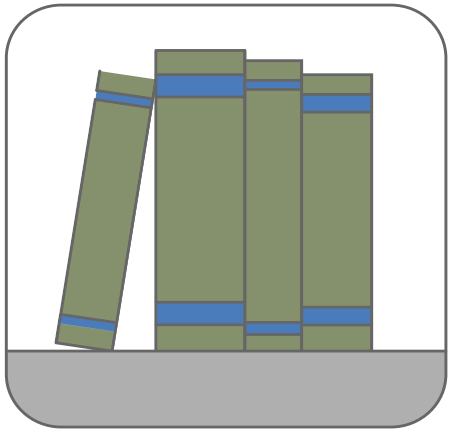
Creates opportunities for outdoor recreation, promoting active lifestyles and community health.



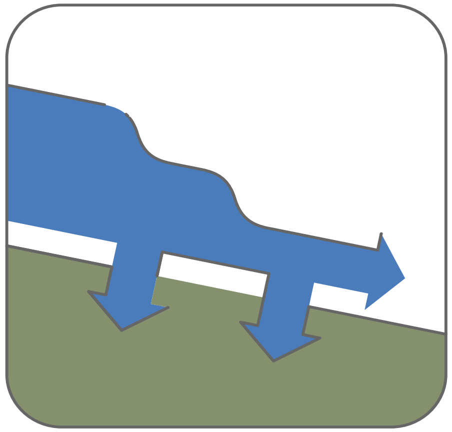
Reduces urban heat island effect by introducing vegetation into the urban environment.



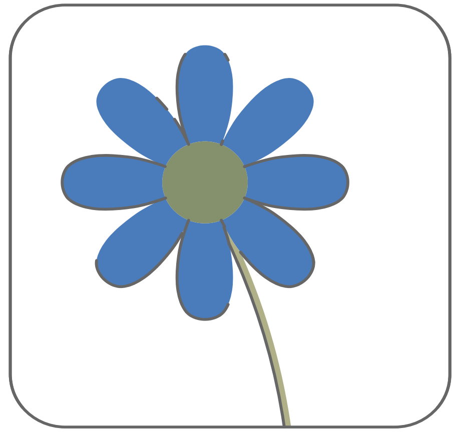
Reduces flood danger by collecting and conveying stormwater runoff out of the area or storing it for later use or infiltration.



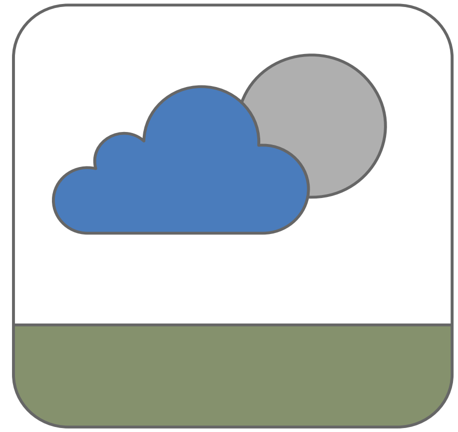
Promotes community involvement, education and awareness of ecological and hydrological systems in their environment.



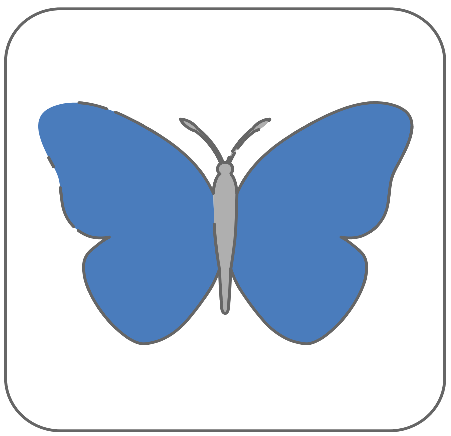
Reduces quantity of stormwater runoff by promoting infiltration.



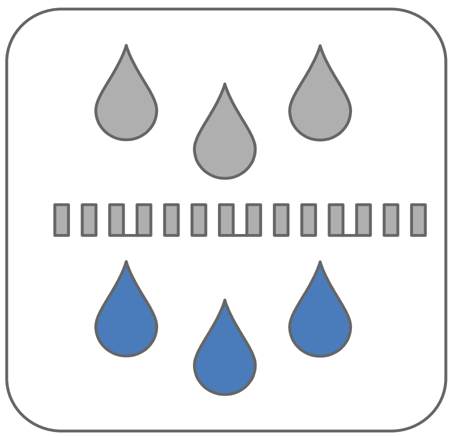
Improves aesthetic quality and softens the urban environment by introducing natural flora and fauna.



Enhances overall local environment through improved water quality, aesthetics, habitat and/or community awareness.



Introduces natural habitat into urban settings to the benefit of local species.

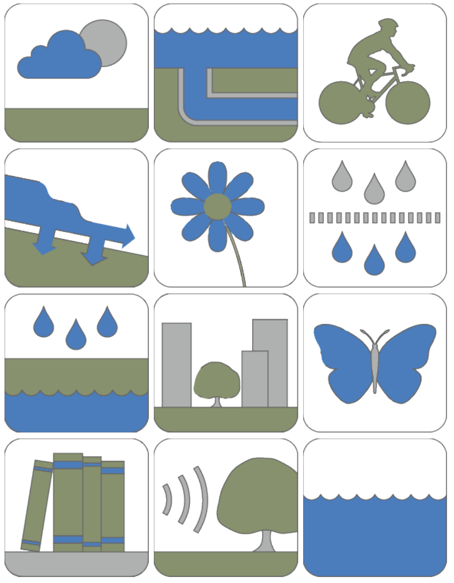


Improves stormwater runoff quality through filtration, microbial degradation, adsorption and evapotranspiration.

Mitigates urban noise pollution with vegetative buffers.

Encourages and facilitates local groundwater and aquifer recharge through infiltration.

Bioretention Area



Description

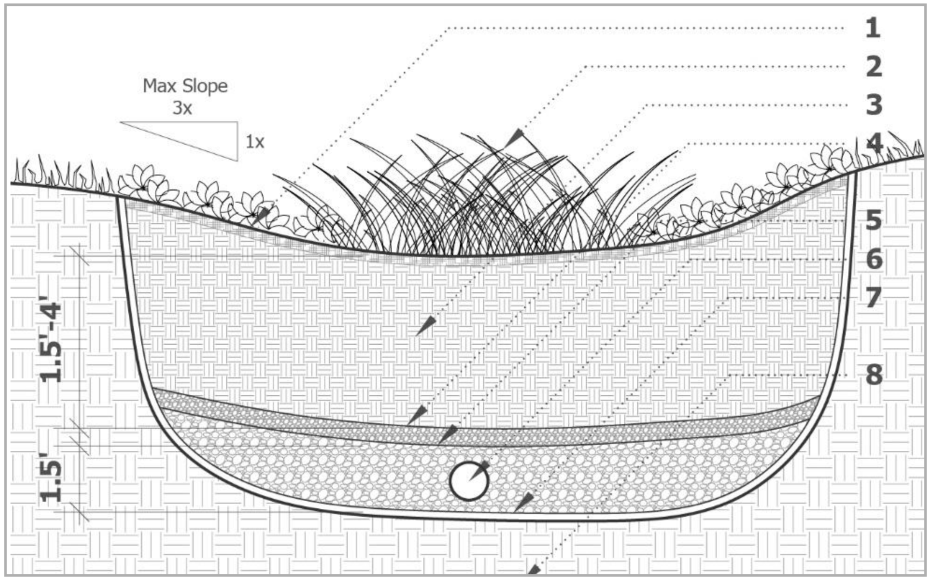
A bioretention area is a vegetated depression designed to provide stormwater detention, filtration and infiltration through engineered soil media and the biological processes of plants and microorganisms. Types of bioretention systems include rain gardens as well as tree box filters, curb extensions and planter box filters, which are suitable for dense urban settings.

Applications

- Sites requiring detention and slow release of stormwater.
- Areas needing noise reduction, heat island mitigation, pollution reduction or added landscape interest.
- As part of a series of LID practices on larger sites.

Components

1. 3 inch mulch layer
2. Vegetation
3. Engineered soil media
4. 2-4 inches of washed sand over 2 inches of washed choking stone
5. Drainage layer (larger stone)
6. Underdrain system (for lined systems only)
7. Impervious liner (where applicable)
8. Undisturbed soil



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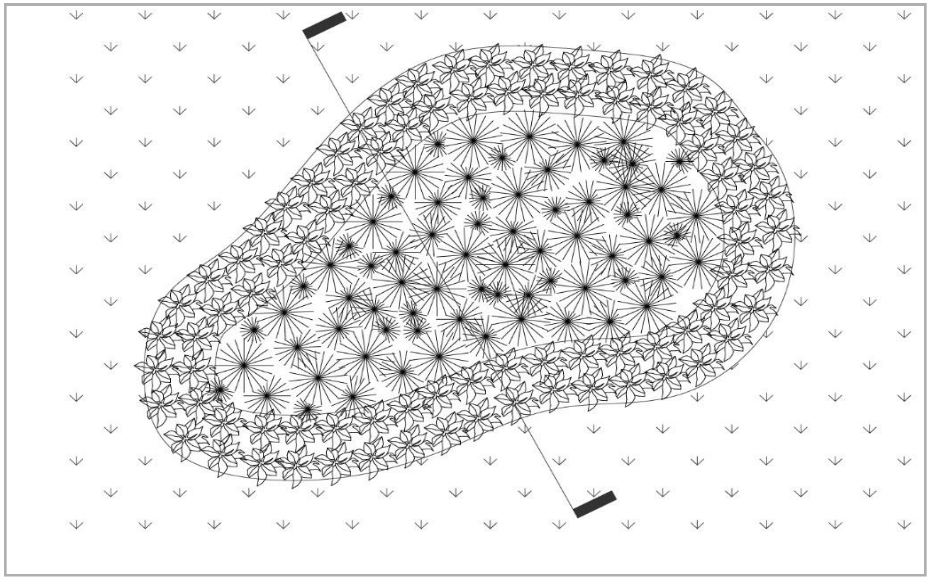


Plan

Site Design Requirements

Drainage Area
< 5 acres
Sizing
6% of drainage area
Available Space
30” minimum width
Head Requirements
> = 2.5 to 3.5 ft. elevation difference between inlet and outlet (optional)
Slopes
- < = 15% for slopes draining into bioretention area
- < = 3:1, horizontal : vertical for side slopes
- <= 2% for internal longitudinal slopes
- < = 0.5% slope in all directions from bioretention areas in flat landscaped open areas

Setbacks
- 10 ft. from structures & foundations
- 100 ft. from septic fields & water wells
- 50 ft. from steep slopes

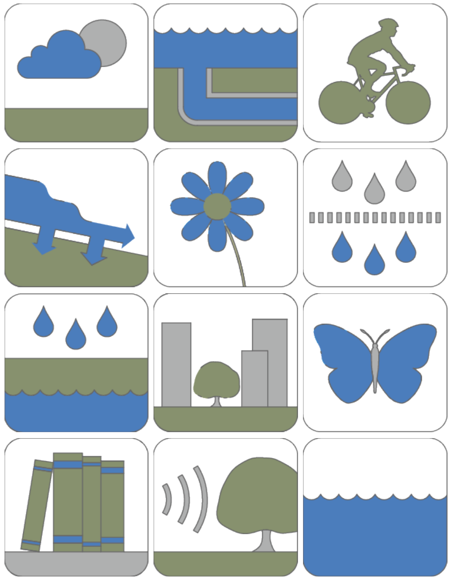
Operation & Maintenance

- All system components should be inspected quarterly and within 24 hours of major storm events.
- Invasive or dead vegetation should be removed or replaced as needed.
- Litter and debris removal should occur biweekly or with routine property maintenance.
- Temporary watering may be necessary daily or weekly during the system establishment period and in dry summer months.
- Mowing and pruning should occur annually or as needed.
- Fill material replacement should occur every 5 years.
- Fertilization should occur one time initially.

Figure B.2.5: Biorentention Area in LBJ Wild Flower Center, Austin, Texas.

Treatment Efficiency		
Runoff Volume (unlined)		High
Runoff Volume (lined)		Low
Detention Storage		Med
Pollutant Removal	Adsorption	Med/ High
	Microbial Degradation	Med
	Filtration	Med
	Plant Uptake	Med/ High
	Evapotranspiration	Low/ Med
	Sediment	Med/ High
	Nutrients	Med
	Pathogens	High
	Metals	High
	Oil & Grease	High
	Organics	High

Bioretention Swale



Description

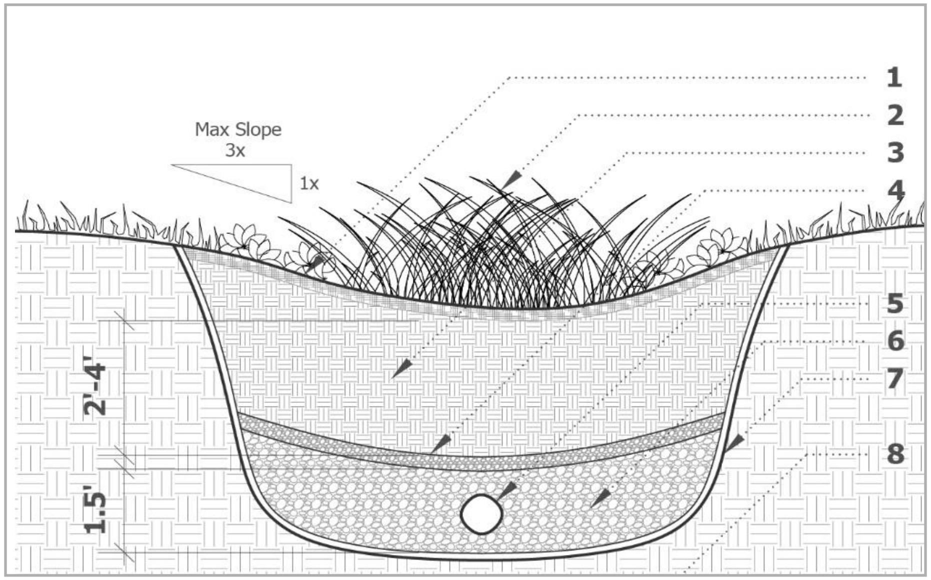
A bioretention swale is a shallow open channel designed to remove pollutants by filtering stormwater through vegetation and reduce runoff volume through infiltration. Like bioretention areas, bioretention swales include an engineered soil media component.

Applications

- Sites where infiltration and filtration but not necessarily efficient conveyance of stormwater are desirable.
- Areas needing noise reduction, heat island mitigation, pollution reduction or added landscape interest.
- As part of a series of LID practices on larger sites.

Components

1. 3 inch mulch layer
2. Vegetation
3. Engineered soil media
4. 2-4 inches of washed sand over 2 inches of choking stone
5. Underdrain system (for lined systems only)
6. Drainage layer (larger stone)
7. Impervious liner (where applicable)
8. Undisturbed soil



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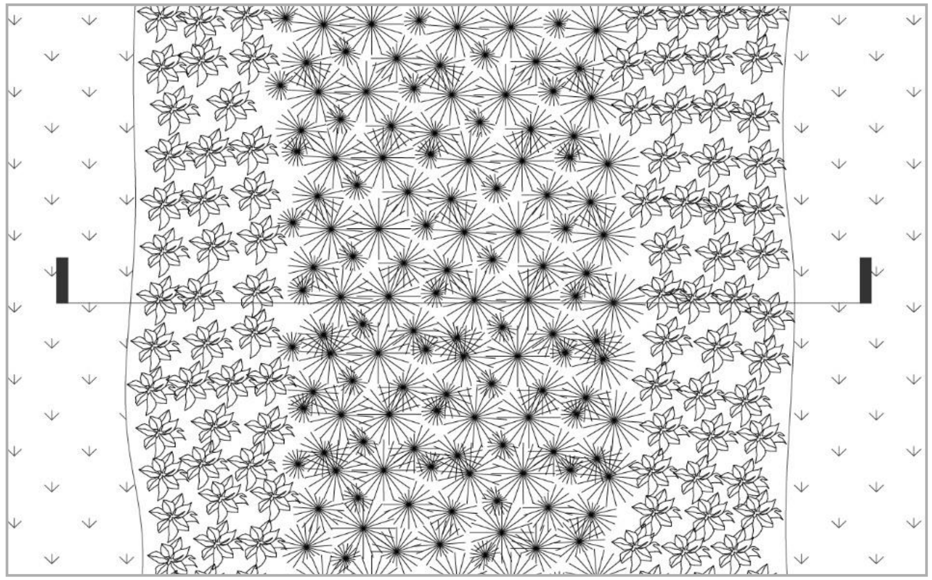


Plan

Site Design Requirements

Drainage Area
< 5 acres

Head Requirements
> = 2.5 to 3.5 ft. elevation difference between inlet and outlet

Slopes
- < = 15% for slopes draining into bioretention area
- < = 3:1, horizontal : vertical for side slopes
- < = 2% for internal longitudinal slopes
- < = 4% slope from inlet to outlet

Setbacks
- 10 ft. from structures & foundations
- 100 ft. from septic fields & water wells
- 50 ft. from steep slopes

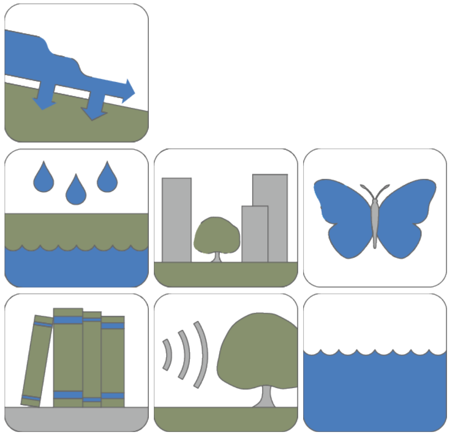
Operation & Maintenance

- All system components should be inspected quarterly and within 24 hours of major storm events.
- Dead vegetation should be replaced annually.
- Litter and debris removal should occur biweekly or with routine property maintenance.
- Temporary watering may be necessary once every 2 to 3 days for the first 1 to 2 months.
- Mowing and pruning should occur annually or as needed.
- Fertilization should occur one time initially.

Figure B.2.6: Bioretention Swale located in Phil Hardberger Park, San Antonio, Texas.
Source: with permission of San Antonio River Authority SARA (2016)

Treatment Efficiency		
Runoff Volume (unlined)		High
Runoff Volume (lined)		Low
Detention Storage		Med
Pollutant Removal	Adsorption	Med/ High
	Microbial Degradation	Med
	Filtration	Med
	Plant Uptake	Med/ High
	Evapotranspiration	Low/ Med
	Sediment	Med/ High
	Nutrients	Med
	Pathogens	High
	Metals	High
	Oil & Grease	High
	Organics	High

Rock Infiltration Swale



Description

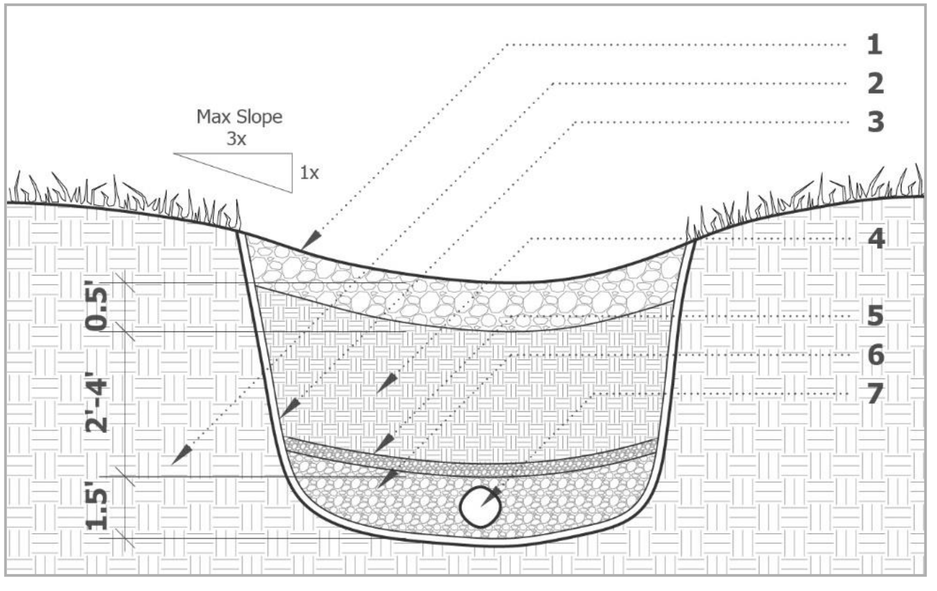
A rock infiltration swale is a shallow rock-lined channel designed to improve stormwater quality and reduce runoff volume through filtration and infiltration.

Applications

- Sites where infiltration and filtration but not necessarily efficient conveyance of stormwater are desirable.
- As part of a series of LID practices on larger sites.

Components

1. Cobble stone
2. Undisturbed soil
3. Impervious liner (where applicable)
4. Engineered soil media
5. 2-4 inches of washed sand over 2 inches of choking stone
6. Drainage layer (for larger stone)
7. Underdrain system (lined systems only)



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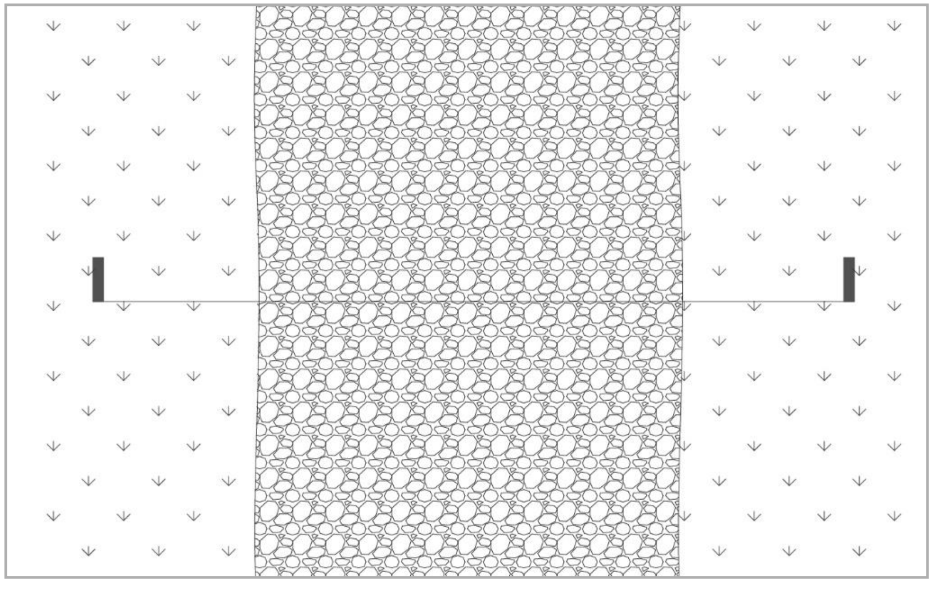


Plan

Site Design Requirements

Drainage Area
< 5 acres

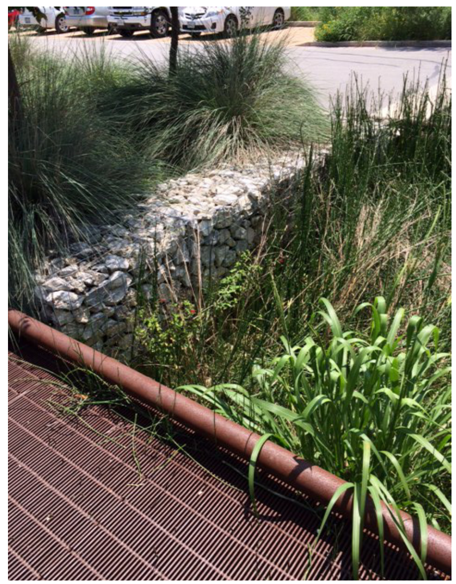
Head Requirements
> = 2.5 to 3.5 ft. elevation difference between inlet and outlet

Slopes
- < = 15% for slopes draining into bioretention area
- < = 3:1, horizontal : vertical for side slopes
- < = 2% for internal longitudinal slopes

Operation & Maintenance

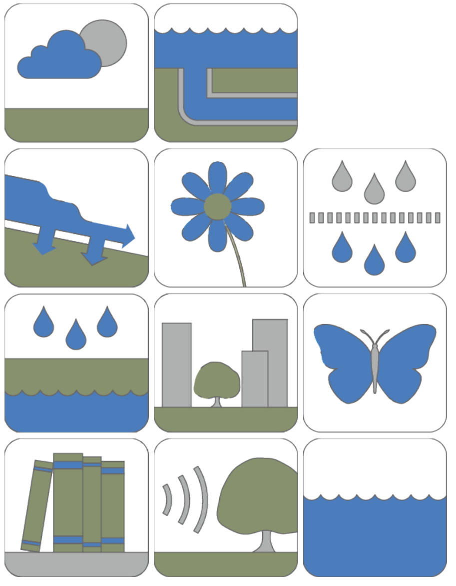
- Catchment and inlet inspections as well as litter removal should occur weekly or biweekly with routine property maintenance.
- Outlet inspection should occur twice annually.
- Temporary watering may be necessary once every 2 to 3 days for the first 1 to 2 months.

Figure B.2.7: Bioretention Swale located in Phil Hardberger Park, San Antonio, Texas.
Source: with permission of San Antonio River Authority SARA (2016)



Treatment Efficiency		
Runoff Volume (unlined)		High
Runoff Volume (lined)		Low
Detention Storage		Med
Pollutant Removal	Trash/ Debris	High
	Sediment	High
	Nutrients	Med
	Pathogens	High
	Metals	High
	Oil & Grease	High
	Organics	High

Vegetated Swale



Description

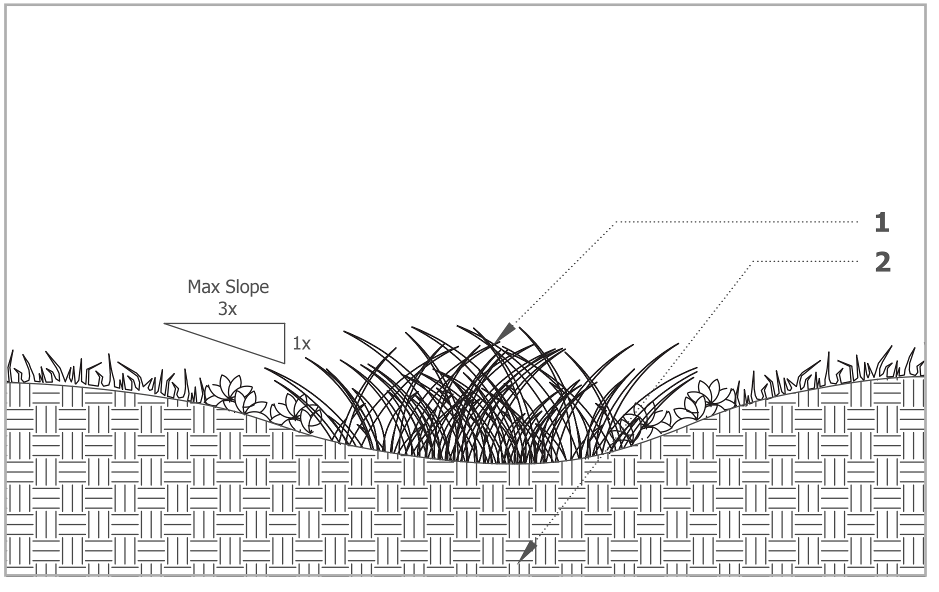
A vegetated swale is a shallow plant-lined channel designed to remove pollutants by filtering stormwater through vegetation and reduce runoff volume through infiltration. Unlike bioretention systems, vegetated swales do not necessarily include an engineered soil media component, although one can be added to improve treatment effectiveness.

Applications

- Sites where infiltration and filtration but not necessarily efficient conveyance of stormwater are desirable.
- Areas needing noise reduction, heat island mitigation, pollution reduction or added landscape interest.
- As part of a series of LID practices on larger sites.

Components

1. Vegetation
2. Undisturbed soil



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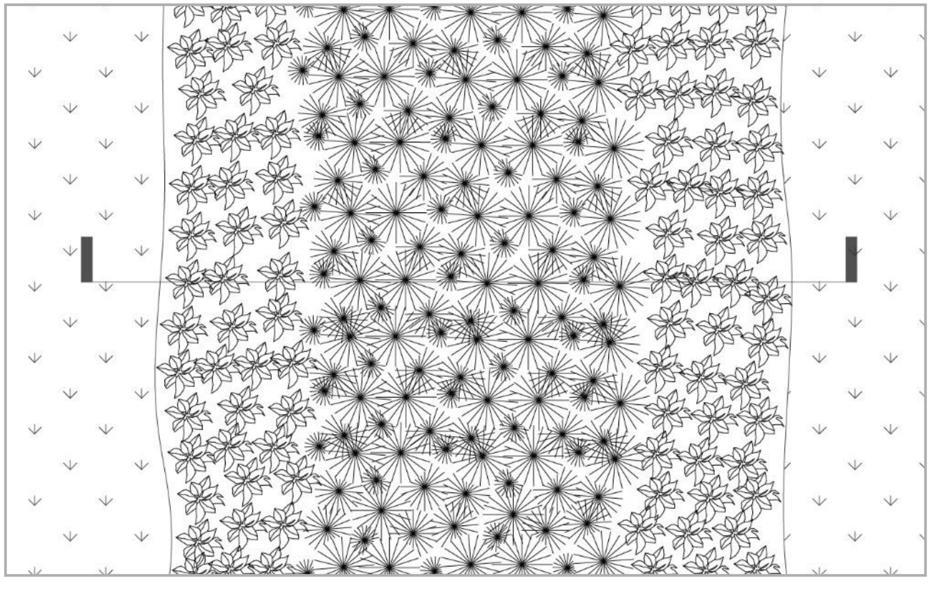


Plan

Site Design Requirements

Drainage Area
< 2 acres
Available Space
10% to 20% of upstream drainage area
Slopes

- < = 3:1, horizontal : vertical for side slopes
- 1% to 6% (1% to 2% optimum) for overall slope
- < = 2.5:1, horizontal : vertical for freeboard area side slope
- Minimum swale bottom width 2 ft.
- Minimum treatment area width: 6 ft.
- Treatment area depth: 6 in.

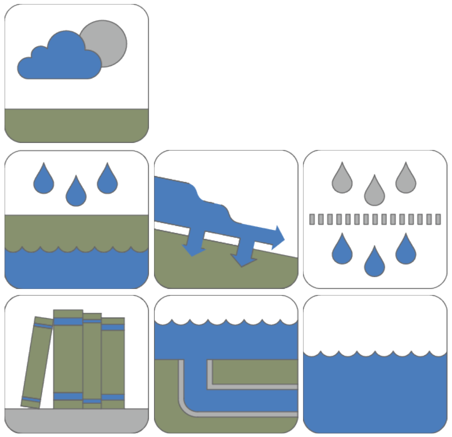
Operation & Maintenance

- Catchment, soil media, liner, inlet, outlet and vegetation should be inspected twice annually.
- Invasive and dead vegetation removal should occur as needed.
- Litter removal should occur as needed.
- Mowing should occur twice annually or as needed.
- Check dams should be inspected prior to wet season and monthly during wet season.
- Temporary watering should occur regularly during first two years, especially during dry months, and then sporadically after establishment.
- Fertilization should occur once initially.

Figure B.2.8: Vegetated Swale in the MIT Campus, Cambridge, Massachusetts.

Treatment Efficiency		
Runoff Volume (unlined)		Low/ Med
Detention Storage		Med
Pollutant Removal	Adsorption	Med
	Microbial Degradation	Low/ Med
	Filtration	Med
	Plant Uptake	Med
	Evapotranspiration	Low/ Med
	Trash/ Debris	High
	Sediment	Med
	Nutrients	Low
	Pathogens	Low
	Metals	High
	Oil & Grease	High
	Organics	High

Sand Filter



Description

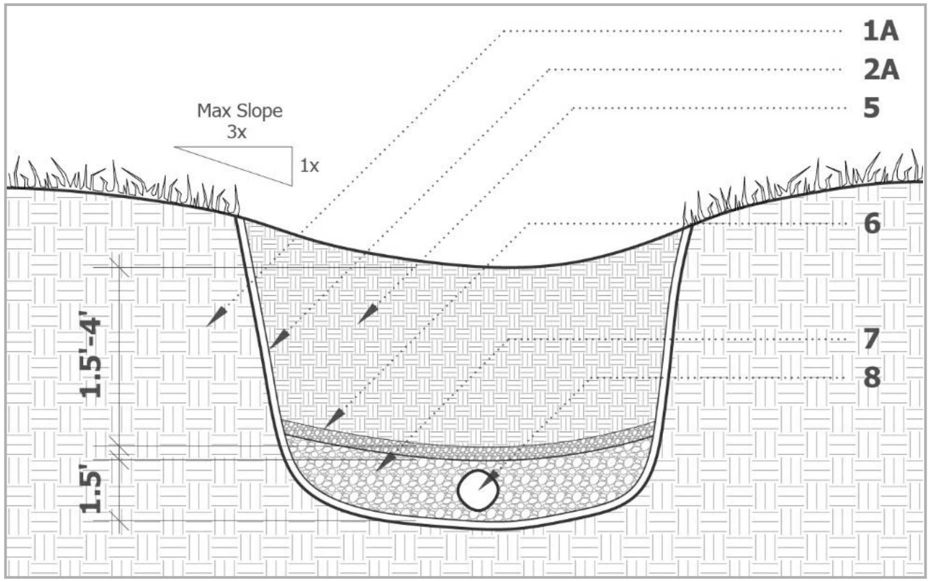
A sand filter is a surface or subsurface chamber that improves stormwater quality by filtering it vertically through a sand media.

Applications

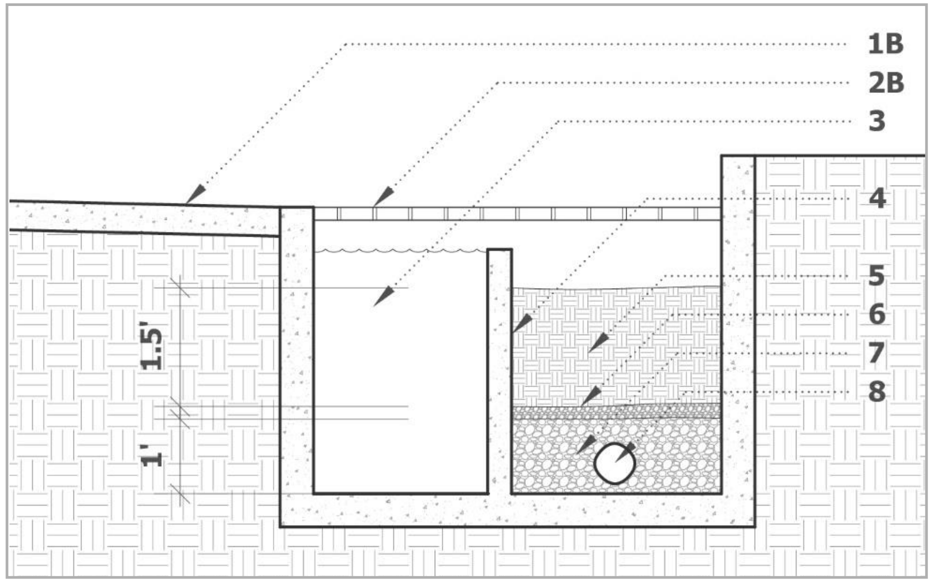
- Sites where infiltration and filtration are desirable.
- As part of a series of LID practices on larger sites.
- Sites where spatial constraints necessitate a compact stormwater treatment mechanism.

Components

1. A. Undisturbed soil, 1B. Adjacent runoff generating surface
2. A. Impervious liner (where applicable) 2B. Metal grate
3. Sedimentation chamber
4. Slotted weir dam
5. Washed concrete sand
6. 2 inches of choking stone
7. Drainage layer (larger stone)
8. Underdrain system



Section (naturalized version)



Section (Compartmentalized version)

Site Design Requirements

Water Table & Bedrock
Minimum 10 ft. separation between bottom of subgrade and water table

Infiltration
Sites with soil infiltration rates of ½ in. per hour or less should incorporate and under drain system

System Types

- Surface sand filters: require pretreatment of stormwater by other LID practices
- Subsurface sand filters: must incorporate a pretreatment forebay.

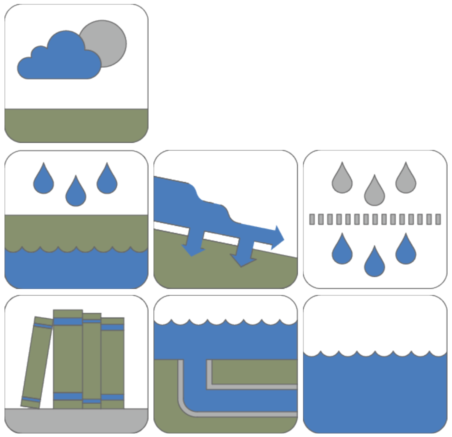
Operation & Maintenance

- Catchment inspection should occur weekly or biweekly with routine property maintenance.
- Inlet and outlet inspection should occur once after first major rain each season and then monthly following.
- Sedimentation forebay inspection should occur bimonthly

Figure B.2.9: Sand Filter in the main campus at UTSA, San Antonio, Texas.

Treatment Efficiency		
Runoff Volume (unlined)		Low/ Med
Detention Storage		Low/ Med
Pollutant Removal	Adsorption	Med/ High
	Microbial Degradation	Med
	Filtration	High
	Plant Uptake	Low
	Evapotranspiration	Low
	Sediment	Med
	Nutrients	Low
	Pathogens	Med
	Metals	Low
	Oil & Grease	Med
	Organics	Med

Permeable Pavement



Description

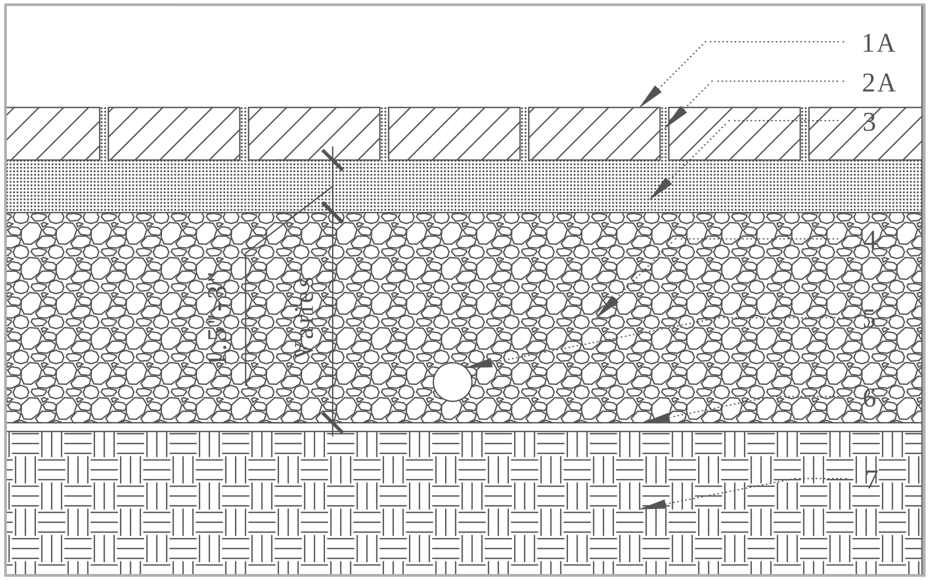
Permeable pavement is hardscape that improves stormwater quality and promotes infiltration by allowing percolation of stormwater through subsurface aggregate.

Applications

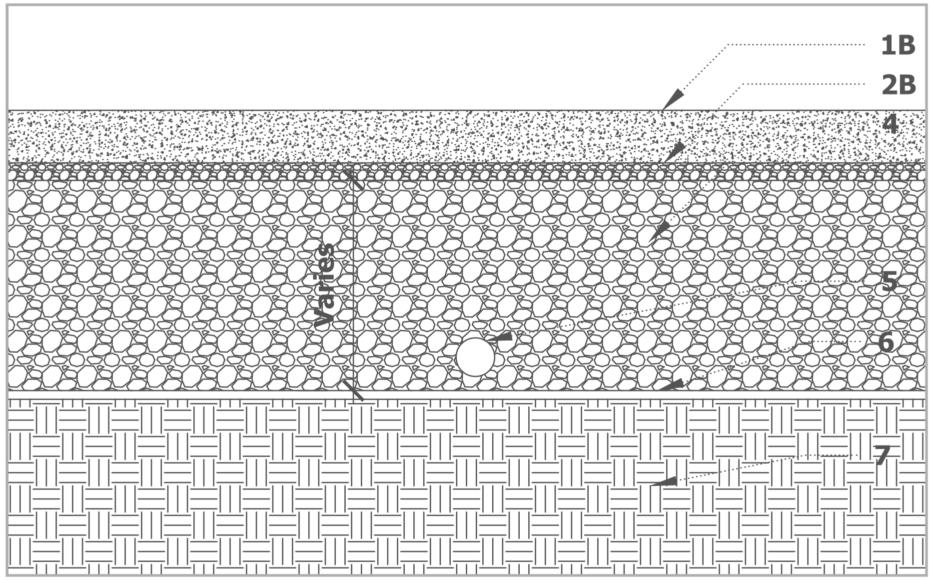
- Sites requiring detention, filtration and slow release of stormwater.
- As parking or driving surfaces where low traffic volume is expected

Components

1. A.Concrete pavers, 1B. Pervious asphalt or concrete pavement
2. A. Fine sand, 2B. 1 inch choker course
3. Washed sand
4. Drainage layer (larger rock)
5. Underdrain pipe
6. Impervious liner (where applicable)
7. Undisturbed soil



Section (concrete pavers)



Section (pervious asphalt or

Site Design Requirements

Drainage Area
1:1 ratio
Slopes
< = 20:1, horizontal : vertical
Setbacks
- 10 ft. from structures & foundations
- 100 ft. from septic fields & water wells
- 50 ft. from steep slopes

Operation & Maintenance

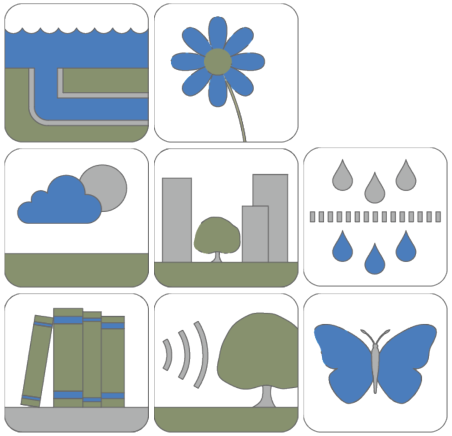
- Miscellaneous upkeep and inspection required with routine property maintenance.
- Preventative vacuuming should occur twice per year.
- Restorative vacuuming should occur as needed or 1 to 2 times per year.
- Litter and debris removal should occur as needed.
- Fill material replacement should occur as needed.

Figure B.2.10: Permeable Pavement in Frederick Park, San Antonio, Texas

Figure B.2.11: Permeable Pavement in Phil Hardberger Park, San Antonio, Texas.

Treatment Efficiency		
Runoff Volume (unlined)		High
Runoff Volume (lined)		Low
Detention Storage		Low/ Med
Pollutant Removal	Adsorption	Med/ High
	Microbial Degradation	Low/ Med
	Filtration	Med/ High
	Plant Uptake	Low
	Evapotranspiration	Low
	Sediment	Med
	Nutrients	Low
	Pathogens	Med
	Metals	High
	Oil & Grease	Med
	Organics	Low

Green Roof



Description

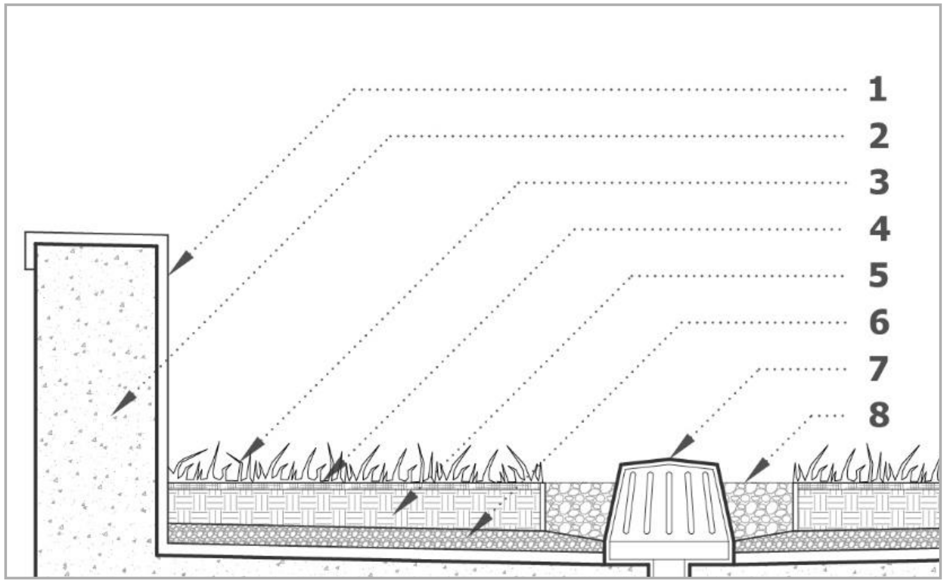
A green roof consists of drought tolerant plants grown in a thin layer of media underlain by a liner and drainage components installed on a flat or gently sloped roof to reduce stormwater runoff volume.

Applications

- Sites where stormwater volume reduction is desirable.
- Areas needing heat island mitigation, pollution reduction, improved habitat or on buildings that would benefit from evaporative cooling.
- As part of a series of LID practices on larger sites.

Components

1. Membrane roofing system
2. Building structure
3. Vegetation
4. Mulch layer
5. 3-4 inch soil media
6. Drainage layer
7. Roof drain
8. 12 inch wide (minimum) gravel ballast separation



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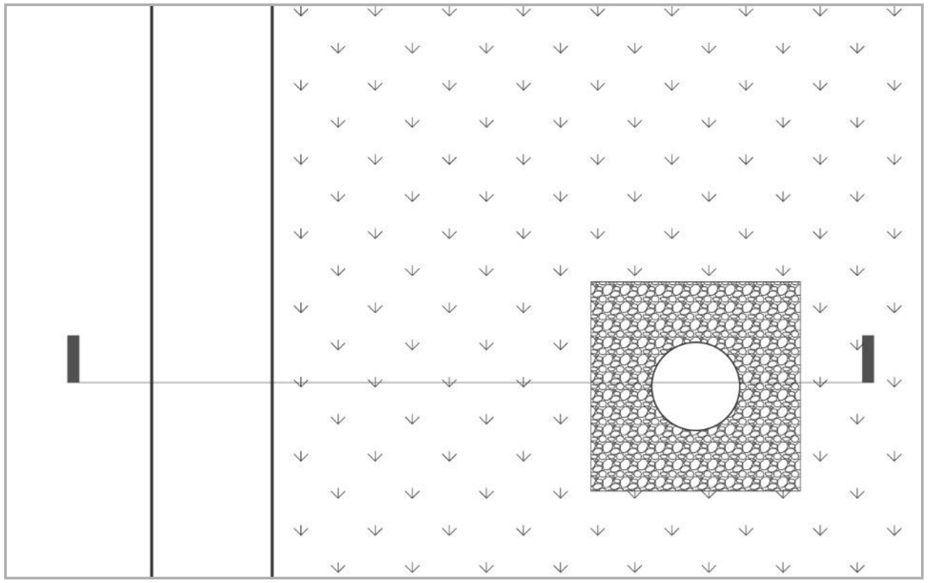


Plan

Site Design Requirements

Drainage Area
Varies from a few square feet to several acres.

Slopes

- Minimum roof slope: ¼ in. per ft.
- Maximum roof slope: 4:12 pitch, vertical : horizontal
- Green roofs with a pitch greater than 2:12 should include measures to prevent sliding

Operation & Maintenance

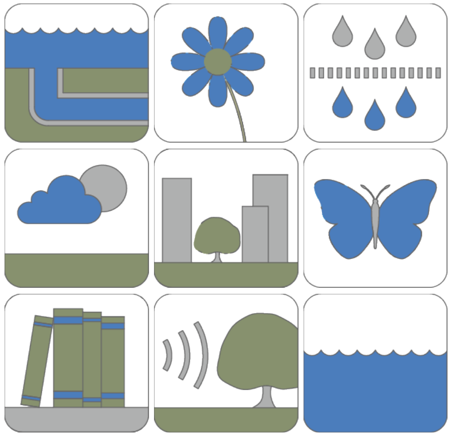
- Soil media and other system components should be inspected twice per year.
- Invasive or dead vegetation should be removed or replaced 1 to 2 times per year.
- Temporary watering should occur once over 2 to 3 days for first 1 to 2 months.

Figure B.2.12: Green Roof above ticket booth in LBJ Wild Flower Center, Austin, Texas.

Treatment Efficiency

Runoff Volume (unlined)		Med
Detention Storage		Med/ High
Pollutant Removal	Adsorption	Med
	Microbial Degradation	Med
	Filtration	Med/ High
	Plant Uptake	Med
	Evapotranspiration	Low/ Med
	Sediment	Low/ Med
	Nutrients	Low
	Pathogens	Low
	Metals	High
	Trash/ Debris	Med

Flow-Through Planter



Description

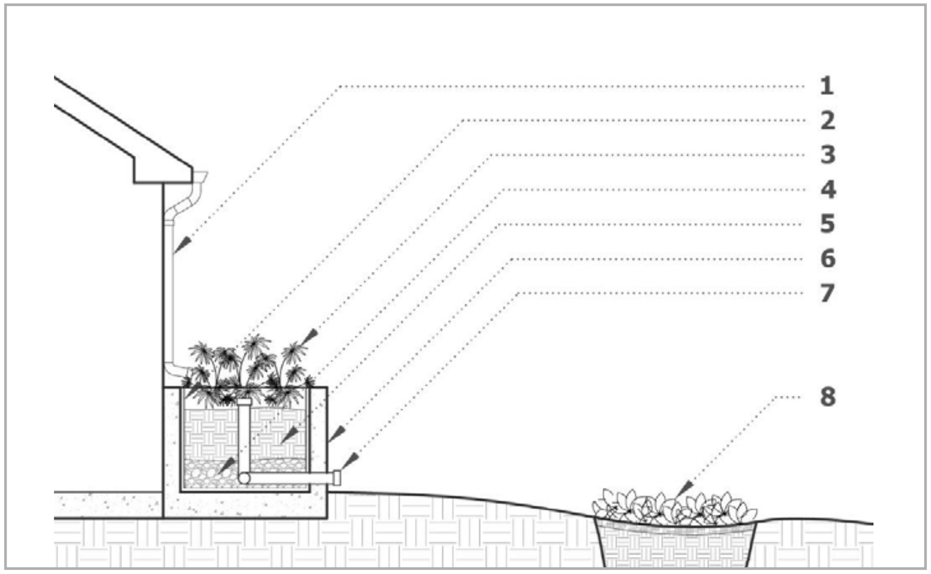
A flow-through planter is a planter box that captures, temporarily stores and filters stormwater runoff.

Applications

- Areas needing noise reduction, heat island mitigation, pollution reduction or added landscape interest.
- Sites where spatial constraints necessitate a compact stormwater treatment mechanism.
- As part of a series of LID practices on larger sites.

Components

1. Downspout
2. Impervious liner
3. Vegetation
4. Drainage layer, separated from engineered soil media above by filter fabric layer
5. Engineered soil media
6. Planter box
7. Overflow and under drain system
8. Downhill overflow catchment and treatment area



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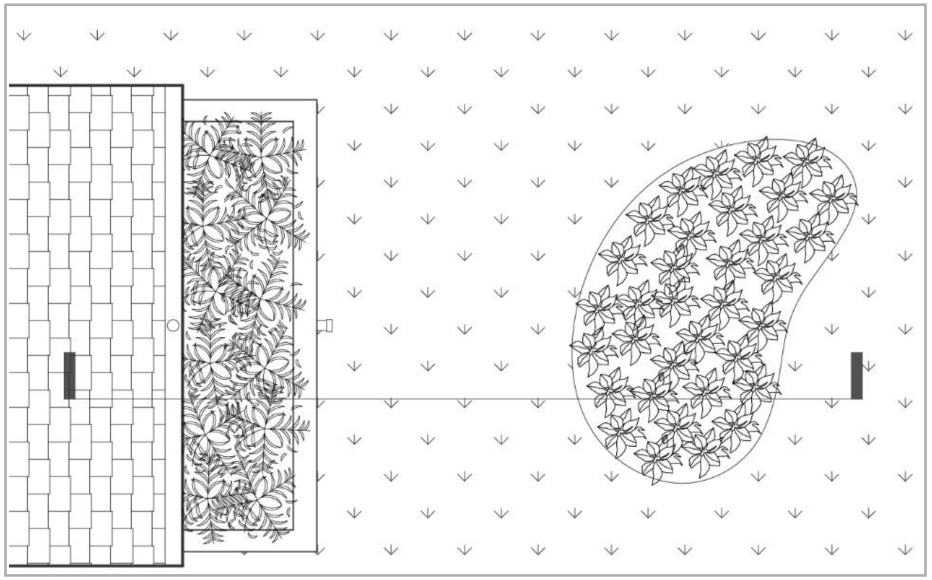


Plan

Site Design Requirements

Drainage Area
< 0.35 acres

Sizing
> = 6% of impervious surface served

Available Space
- Any shape desired
- Minimum planter width: 30 in.
- Minimum treatment depth in growing medium: 18 in.

Slopes
- < = 0.5% for internal longitudinal slopes

Setbacks
- 10 ft. from structures & foundations for planters without an impermeable liner
- No setback required from buildings or structures where planters are lined with waterproofed concrete or a 60 mil. PVC liner to prevent infiltration

Operation & Maintenance

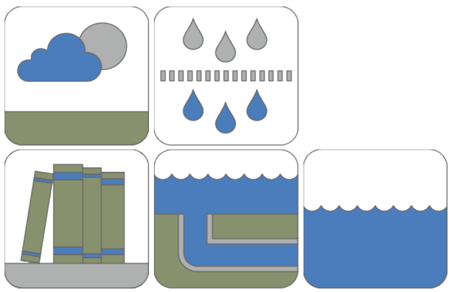
- All system components should be inspected weekly or biweekly with routine property maintenance and during major rainfall events for proper functioning.
- Invasive or dead vegetation should be removed or replaced as needed.
- Litter and debris removal should occur biweekly or with routine property maintenance.
- Temporary watering should occur once every 2 to 3 days for first 1 to 2 months and for first two years during summer months.
- Pruning should occur 1-2 times per year.

Figure B.2.13: Above ground flow-through planter at the Riverside County Flood Control and Water Conservation District, Riverside, CA
Source: http://countyofriverside.maps.arcgis.com/apps/MapTour/index.html?appid=23596d603ef14c128e765ac698e54f8c#

Treatment Efficiency

Runoff Volume (unlined)		Low
Pollutant Removal	Sediment	Med/ High
	Nutrients	Med
	Pathogens	High
	Metals	High
	Oil & Grease	High
	Organics	High

Rainwater Harvesting



Description

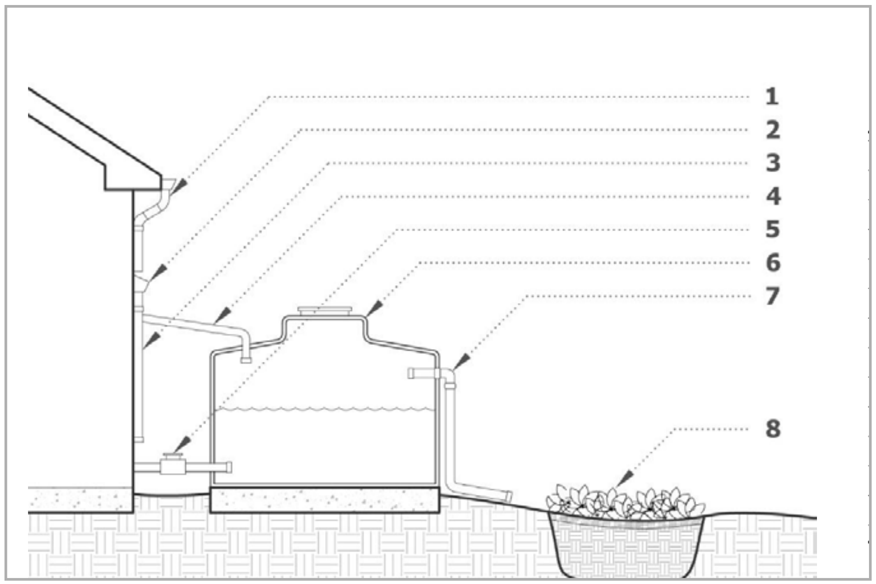
Rainwater harvesting involves the use of water storage vessels that can collect and store rooftop runoff from a downspout for later use.

Applications

- Sites where stormwater volume reduction is desirable.
- Facilities that would benefit from reuse of captured rainwater for irrigation or potable use if purified.
- Sites where spatial constraints necessitate a compact stormwater treatment mechanism.
- As part of a series of LID practices on larger sites.

Components

1. Downspout
2. Self-cleaning filter
3. Flush diverter
4. Conveyance line
5. Domestic use intake line and pump
6. Access hatch
7. Overflow pipe
8. Downhill overflow catchment and treatment area



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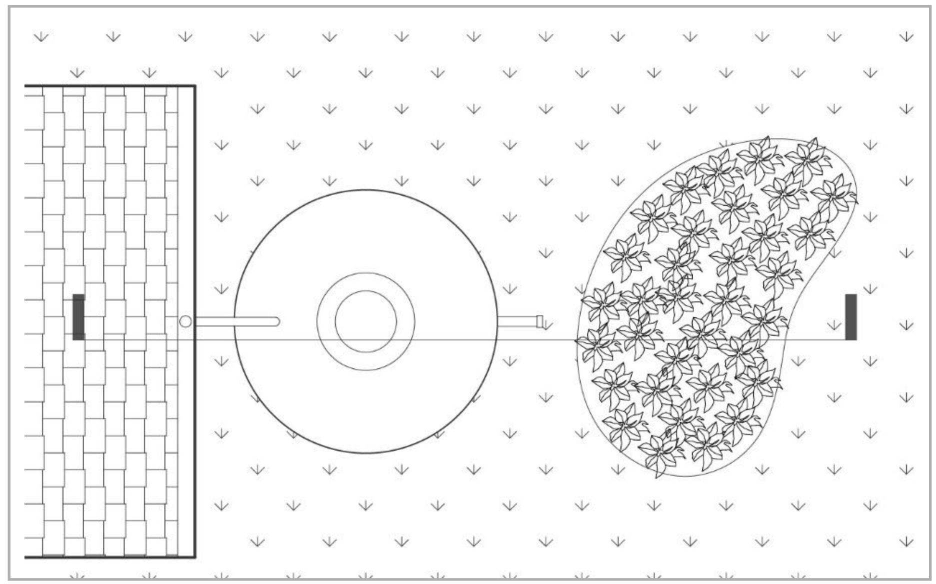


Plan

Site Design Requirements

Setbacks

- 5 ft. from structures and foundations for cistern overflows

Operation & Maintenance

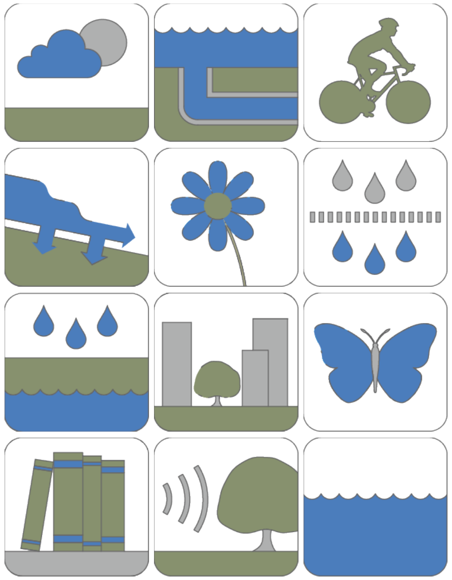
- Miscellaneous upkeep and inspection of system components should occur 1 to 2 times per year and before heavy rainfall events.
- Debris removal should occur monthly.
- If needed, ballast should be added to water storage tanks before major wind-related storms.

Figure B.2.14: Rainwater Harvesting, A Container Directs the Water to Underground Cistern, Phil Hardberger Park, San Antonio, Texas.

Figure B.2.15: Rainwater Harvesting in LBJ Wild Flower Center, Austin, Texas.

Treatment Efficiency		
Detention Storage		High
Pollutant Removal	Absorption	Low
	Microbial Degradation	Low
	Filtration	Low/ Med
	Evapotranspiration	Low
	Sediment	Med

Vegetated Filter Strip



Description

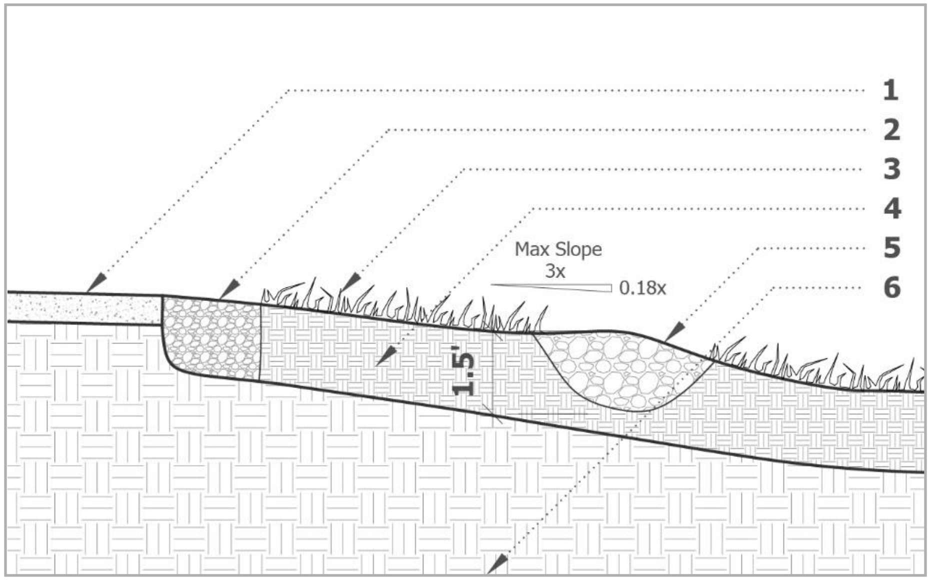
A vegetated filter strip is a band of dense vegetation situated between a pollution source and a downstream receiving water body or conveyance mechanism.

Applications

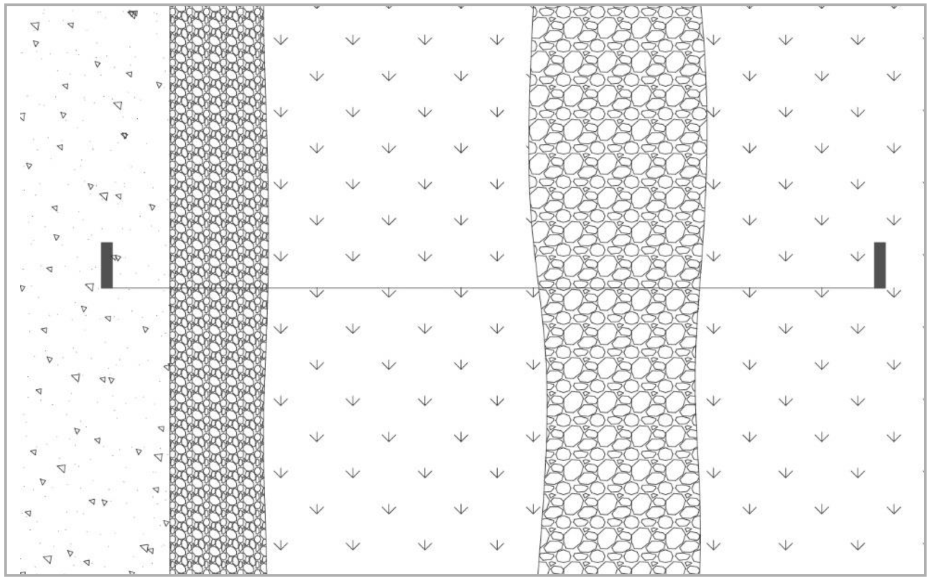
- Sites where filtration and slowing of runoff are desirable.
- Areas needing noise reduction, heat island mitigation, pollution reduction or added landscape interest.
- Adjacent to roadways, parking lots and rooftop downspouts
- As part of a series of LID practices on larger sites.

Components

1. Adjacent runoff generating surface
2. Gravel trench
3. Vegetation
4. Engineered soil media
5. Check dam or berm
6. Undisturbed soil



Section



Plan

Site Design Requirements

Available Space
> = 6% of the size of the catchment area for sites with an infiltration rate less than 2 in./hr. Ratio could be less if infiltration rate existing soil is greater than 2 in./hr. or if amended soil depth is increased

Slopes
- Flow path to filter: < = 75 ft. for impervious ground cover, < = 150 ft. for pervious ground cover unless energy dissipaters and/or flow spreaders are employed
- Minimum width of strip: 5 ft. measured parallel to direction of stormwater flow

- Miscellaneous upkeep and inspection should occur monthly and especially during the rainy season.
- Accumulated sediment should be removed when depth exceeds 3 in.
- Invasive or dead vegetation removal, litter and debris removal, mowing and pruning should occur as needed.
- Temporary watering should occur during first 2 years, especially during dry months.

Figure B.2.16: Vegetated Filter Strip
http://robmaday.com/landscape-miscellany/

Treatment Efficiency		
Runoff Volume (unlined)		Med
Detention Storage		Low/ Med
Pollutant Removal	Adsorption	Med
	Microbial Degradation	Low/ Med
	Filtration	Med
	Plant Uptake	Med
	Evapotranspiration	Low/ Med
	Sediment	Low

B.3 Site Selection: Scope & Process

Introduction

The implementation of BMPs including LID practices is regulated by state and local policies that regulate specific stormwater management standards including quality of infiltrated water as well as runoff volume. The regulatory requirements largely include flood control in the form of peak runoff rate attenuation, providing groundwater recharge, or a reduction in pollutant loads found in the runoff. Preliminary research of the engineered BMPs constructed on the EARZ, albeit inaccurate and needing further verification, showed that approximately 15% of these structures are noncompliant with the requirements set by the water inspectors[1]. These records will be encompassed in the scope of the site selection process developed in this report. The records will be examined through geospatial analysis tools. According to Cheng et al. (2009)[2], an analysis approach for BMPs should highlight the following:

1. Benefit of BMP management, whether engineered structures or LID practices?
2. Differences between management and challenges associated with site and construction specifications of engineered BMPs and LID practices?
3. Cost per unit and benefits of implementing different types of engineered BMPs and LID practices

A thorough review of tools and measures discussed in scientific studies that focused on systematic site analysis processes is largely helpful to professional designers and planners as well as state and federal regulatory reviewers. Such a process could also assist the public including business and home owner associations. For this report, the research team reviewed the scientific methods of five published studies selected based on their relevance to the scope and purpose of site selection pertinent to the criteria identified in section B-1 of this report. However, several modeling techniques, especially hydrological tools, were excluded from this report due to irrelevance to the scope, which is only concerned with identifying sites for developing criteria and guidelines for implementing LID at locations where engineered BMPs already exist. Although these studies examine different approaches to identify site suitability for implementing BMPs, a faultless gap in the methods of evaluating and prioritizing existing dysfunctional BMPs exists. Therefore, in this section, our endeavor is to build on the evidence from these studies, establish a systematic process for evaluating existing BMPs that are located on the EARZ, and embed easy-to-track attributes within the method so that it can be applied on a wide spectrum of land uses and communities.

Background

The studies reviewed to develop a site selection method incorporate different quantitative and spatial analysis tools. Five primary articles were thoroughly reviewed. Two of the articles discussed the utilization of Geographic Information System (GIS) as a decision-making tool[2 3] through: 1) integrating a Decision Support Systems (DSS) approach that examines site suitability for placing Best Management Practices (BMPs) on specific sites; and 2) creating Analytic Hierarchy Process (AHP) as a decision-making tool for selecting stormwater management BMPs. Another study[4] utilized Heuristic optimization techniques coupled with a watershed model in order to identify the optimal placement and design of BMPs so that their combined effect is most cost-effective. Two of the articles focused on developing a systematic evaluation and ranking of BMP alternatives, based on a wide range of attributes to create a multi-criteria index system (MCIS) or an Analytic Hierarchy Process (AHP)[5 3].

Considering that enormous public investment may be needed for Non-Point Source (NPS) pollution control, it is therefore necessary to develop a systematic approach for the stormwater control systems (SCS) planning and design at the watershed level, which could lead to significant cost savings[4]. The primary benefit of these BMPs is storage and infiltration. Secondary processes must be considered when evaluating volume or water quality benefits, including processes associated with filtration, settling of sediment, and pollutants decay, which is beyond the scope of this report.

Like any site selection process, selecting stormwater BMPs could be an inherently subjective process susceptible to personal experience, bias, and judgment. For many years, the detention-based approach has been the predominate means by which stormwater management is addressed on land development projects. The essential criteria for BMP selection largely varies among a project's stakeholders. While a site owner or developer may view annual BMP maintenance cost as the paramount selection consideration, the stormwater management designer likely views any number of unique site characteristics and technical performance goals as more critical to the BMP selection process.

Decision making through the use of GIS was developed by Cheng, et al. (2009)[2] for Prince George's County, Maryland, in the Washington D.C. metropolitan area. A BMP Decision Support System (BMPDSS) was utilized at both the site scale and the watershed levels. The BMPDSS is a decision-making tool for placing BMPs at strategic locations in urban watersheds on the basis of integrated data collection and hydrologic, hydraulic, and water quality modeling. In addition to GIS, the system uses time series data for watershed runoff flow and pollutant concentration (generated by the watershed model), integrates BMP process simulation models, and applies system optimization techniques for BMP planning and selection. With a slight difference, the Blacksburg, Virginia study by Young, et al. (2010)[3] discusses the development of a software -aided approach based on the Analytic Hierarchy Process (AHP) as a decision-making tool for selecting stormwater BMPs.

Figure B.3.1: A structural BMP (sand filter) located along the southern boundary of the UTSA main campus in San Antonio, TX

The AHP does not possess an objective function, penalty function, or randomization procedure. Rather, it is a procedure for systematic evaluation and ranking of BMP alternatives, based on a wide range of criteria for selection and implementation of BMPs. The AHP can provide an objective, mathematically-based alternative to the existing, often subjective BMP selection approaches. An AHP decision support software was applied in a demonstration site. The AHP algorithm has potentially significant benefit when utilized as a decision-support tool in the BMP selection process.

AHP multi-criteria decision-making algorithms is a process that is applied to BMP selection in an attempt to satisfy all selection criteria while adhering to the respective weights assigned to each criterion by the user. This attempt to simultaneously satisfy potentially conflicting criteria may yield results that do not fully satisfy each criterion individually. Therefore, the BMPs ranking attained by employing the AHP must be critically scrutinized.

The paramount benefit of the AHP as it relates to BMP selection is its ability to objectively and simultaneously consider an unlimited number of these criteria. Selective inclusion of the criteria depicting physical site characteristics enables the user to adapt the selection process so that the chosen BMP is feasible and appropriate for the site. Inclusion of the relevant performance goals contributes to achieving local, state, and federal regulatory stormwater management requirements. The performance goals for this report were determined in consultation with a select group of stakeholders who attended several meetings with the project director.

In an effort to compare the performance of stormwater management models, various performance-related metrics were identified by Young et al. (2010)[3]. These metrics include peak runoff rate reduction and removal of Total Suspended Sediment (TSS) and Total Phosphorus (TP). These performance metrics were evaluated at the downstream outfall of the demonstration site. At an identified location, the centralized and distributed stormwater management alternatives were compared against the baseline (no runoff management) model. Within the three models, pollutant buildup and wash off was established as a function of proposed land cover. Identical buildup and wash off functions were applied to each of the three models.

Considering the impacts of surrounding areas on pollutants loading, the study by Zhen, et al. (2004)[4] focused on an important aspect of the watershed strategy by finding the optimal placement and design of BMPs so that their combined effect is most cost-effective. An innovative method was presented for optimizing the placement and configurations of BMPs at the watershed scale. Heuristic optimization techniques were coupled with a watershed model, which is the Agricultural Nonpoint Source Pollution model (AnnAGNPS) in this case, and BMP simulation module to find a least cost set of solutions that meet the pollutant load reduction requirements.

Potential BMP sites were preselected based on an inventory of NPS critical pollution source areas and other factors such as land availability, geographical conditions, and site specific legal, jurisdictional considerations. As a general rule, if feasible, potential BMP sites considered ''critical'' (e.g., areas with high unit area NPS pollution loadings) should first be selected before noncritical areas for BMP implementation. This selection process allows the elimination of any obviously infeasible solutions and provides a good starting point for the optimization process.

Finally, to quantify the assessment of BMP sites, the two studies by Jia, et al. (2013)[5] and Scholes (2005)[6] have developed numeric and weighted metrics for the BMPs assessment. In Jia, et al. (2013)[5], the authors established an index system for BMP ranking using a multi-criteria index system (MCIS) that aims to provide a simple, yet comprehensive tool for selecting BMPs. MCIS, which involves the following four steps, could be used as a screening tool for a preliminary siting and BMP implementation plan:

1) Establish the basic or key criteria categories that the selection system was based upon. The study considered BMP site suitability, runoff control benefits, and cost and maintenance as the three basic categories for formulating the MCIS. The suitable BMPs were first selected according to the site suitability criteria, and then these selected BMPs were further evaluated and ranked according to the indices in runoff control benefits category and cost and maintenance category. 2) Select a level of index factors within each criteria category. Each of the selected index factors was further broken down into several second-level index factors. 3) Establish the benchmark of each index. 4) Develop a ranking mechanism that integrates every index factor.

In Scholes et al. study (2005)[6], the authors focused on BMP performance. They established criteria for predicting the potential for removal of selected stormwater priority pollutants (SSPPs) in BMPs through combining different data sets for pollutants removal processes and the relative importance of the removal mechanisms. Their approach adopted a designated high, medium and low scale for the numeric values assigned as 3, 2 and 1, respectively.

Results of the five reviewed articles, as well as the summary of their methods and attributes (see Table B.3.1) provide an understanding of the differences between constraints and purposes of each study. They also offer a systematic and numeric approach for site selection. The different processes, criteria, and attributes discussed in each article were analyzed and compared with the context of this report in order to identify the process and metrics needed for BMPs.

Hint: For the method-only- section and discussion of the limitations, see Appendix C, pp. 140-143.

Table B.3.1: Methods and attributes developed in the five reviewed studies

Study	Scope	Method(s)	Attributes
Cheng, et. al, (2009)	Prince George's County, MD	Best management Practice Decision Support system BMPDSS) model (GIS)	Annual maintenance cost
Young, et. al, (2010)	Blacksburg, VA	Analytic Hierarchy Process (AHP) using (GIS)	Site characteristics Performance measures Peak runoff rate reduction Removal of total suspended sediment (TSS) and total phosphorus
Zhen, et. al, (2004)	Hypothetical region	Analysis of Agricultural Nonpoint Source Pollution (AnnAGNPS)	NPS critical pollution source areas Land availability Geographical conditions Site specific legal jurisdictional considerations
Jia, et. al, (2013)	Foshan, Guangdong Province, China	Multi-criteria index system (MCIS)	Site suitability Runoff control benefits Cost and maintenance
Scholes, et. al, (2005)	Hypothetical region	Numeric values & weighting assigned to pollutants removal within BMPs	Pollutants removal processes Importance of the removal mechanisms

Proposed Site Selection

The site selection criteria identified for the Low Impact Development project (shown in Figures B.3.4 and B.3.5) were generated using an analogy from Austin's working group task committee (see sections A.6 & B-1 of this report). The criteria were then used as a key to establish two main parameters that constitute the site selection model. Upon a review of relevant studies from scholarly published work, discussed in the previous section, two parameters were determined as a key component of the site selection process:

Methods and attributes used to measure similar parameters identified in the five reviewed studies were compared and a list of attributes

1. **Site characteristics, and**
2. **Pollutants loading.**

Part A

Part B

Part C

pertaining to watershed of the EARZ was developed. The geographic boundary identified as the watershed, or the broader scope of analysis for this report, was determined based on consultation with the research sponsors and partners, and was defined as the area of the Edwards Aquifer Recharge Zone (EARZ) located within Bexar County, Texas.

Building on both the numeric values and ranking system discussed in Jia, et al. (2013)[5], Young, et al. (2010)[3], and Scholes (2005)[6], in addition to the pollutant load reduction model proposed by Zhen et al. (2004)[4], this report proposes a multi-criteria site selection process using urban and built environment attributes associated with site characteristics and pollutants loads. A five-step process is proposed for this report. The process is based on the various scales model discussed in Cheng et al. (2009)[2] and is comprised of various scales of analysis, from watershed to BMP site.

The process is materialized through a problem-solving and analytical/design approach emerging from spatial analysis of ecological and environmental problems. The approach, known as Geodesign, combines multiple attributes and is commonly applied in various topics[7] [8] to select one or more sites that are mostly coinciding with criteria identified according to the scope of each study or by stakeholders. As the selection process starts with omitting undesired areas, the selectable sites (parcels, blocks, or as in this report, a BMP) becomes the most appropriate area that meets the needs of the stakeholders, and therefore, the process is referred to as site suitability assessment. Geodesign provides a design framework and supporting technology for various users in order to create a process that leverages geographic information, resulting in a designs that are most compatible with the natural systems[9].

Geodesign is a holistic design process, by which researchers and designers could easily align seemingly disparate data and produce a cohesive design through graphic language that can tell a story far more powerfully than its individual parts[10]. “It is a process by which

Figure B.3.2: Vegetated Swale in the MIT Campus, Cambridge, Massachusetts.

researchers and designers can integrate environmental assessment into the design process in real time, resulting in a self-correcting design that reduces or avoids costly mitigating data"[10]. It combines geographic science, credible metrics, and GIS technology with design methodologies to produce data-driven solutions for smart and sustainable communities[8].

Geodesign: A five-step Process

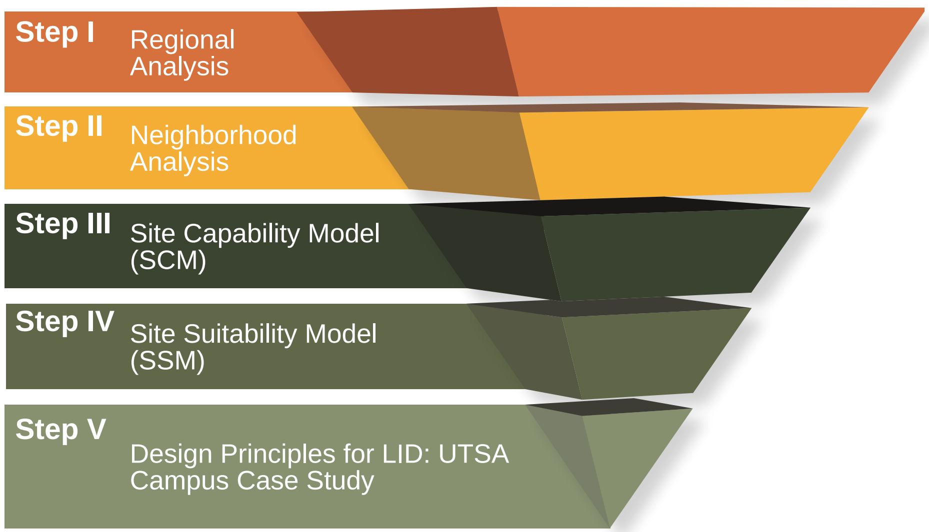


Figure B.3.3: Geodesign Model: A Five-step Process.

The proposed scope of analysis was demonstrated in the following five consecutive steps ranging from the regional (macro) to a smaller (micro) scale, and concluding with design principles for Low Impact development (LID) practices. The process, as explained in Figure B.3.3 and Appendix C, entails:

Step I, regional analysis (Bexar County, Texas), with an emphasis on the portion of the EARZ within the county. An analysis of all BMP records was conducted, and a selection of five basins located in the main campus of the University of Texas at San Antonio concluded this step. It must be noted that, for future application of this process, stakeholders and project partners' input is necessary for prioritizing BMP sites. Future partners could include: mixed use developers, retail and business owners, parking lot users, and residential blocks or home owner association tenants/owners. The analysis provided in this step includes a geospatial analysis of the BMP locations and their compliance with local water inspectors' guidelines.

Step II focuses on a smaller (micro) scope, the neighborhood, which is defined in this report as the areas, including all parcels, and land uses around the main campus of the University of Texas at San Antonio.

Step III encompasses shortlisting neighborhood-level BMP records according to three preliminary attributes. In this step, three attributes were defined as primary and necessary components of any BMP site, including appropriate slope, floodplain, and exposure. Using GIS spatial analysis, the three attributes were integrated into one model, a ranking system was created for the five existing BMPs, and a Site Capability Model (SCM) was constructed.

Step IV encompasses additional attributes to measure two parameters: 1) site characteristics, and 2) pollutant loadings, and includes creating a multi-criteria ranking of the existing BMPs. Using stakeholders' feedback, a Site Suitability Model (SSM) was established.

Step V is the concluding phase of assessing the selected BMPs, based on the previous models, to match the attributes with design requirements for specific LID practices (see a full list of LID practices in section B-2 of this report).

Hint: For the method-only- section and discussion of the limitations, see Appendix C, pp. 140-143.

Part A

Part B

Part C

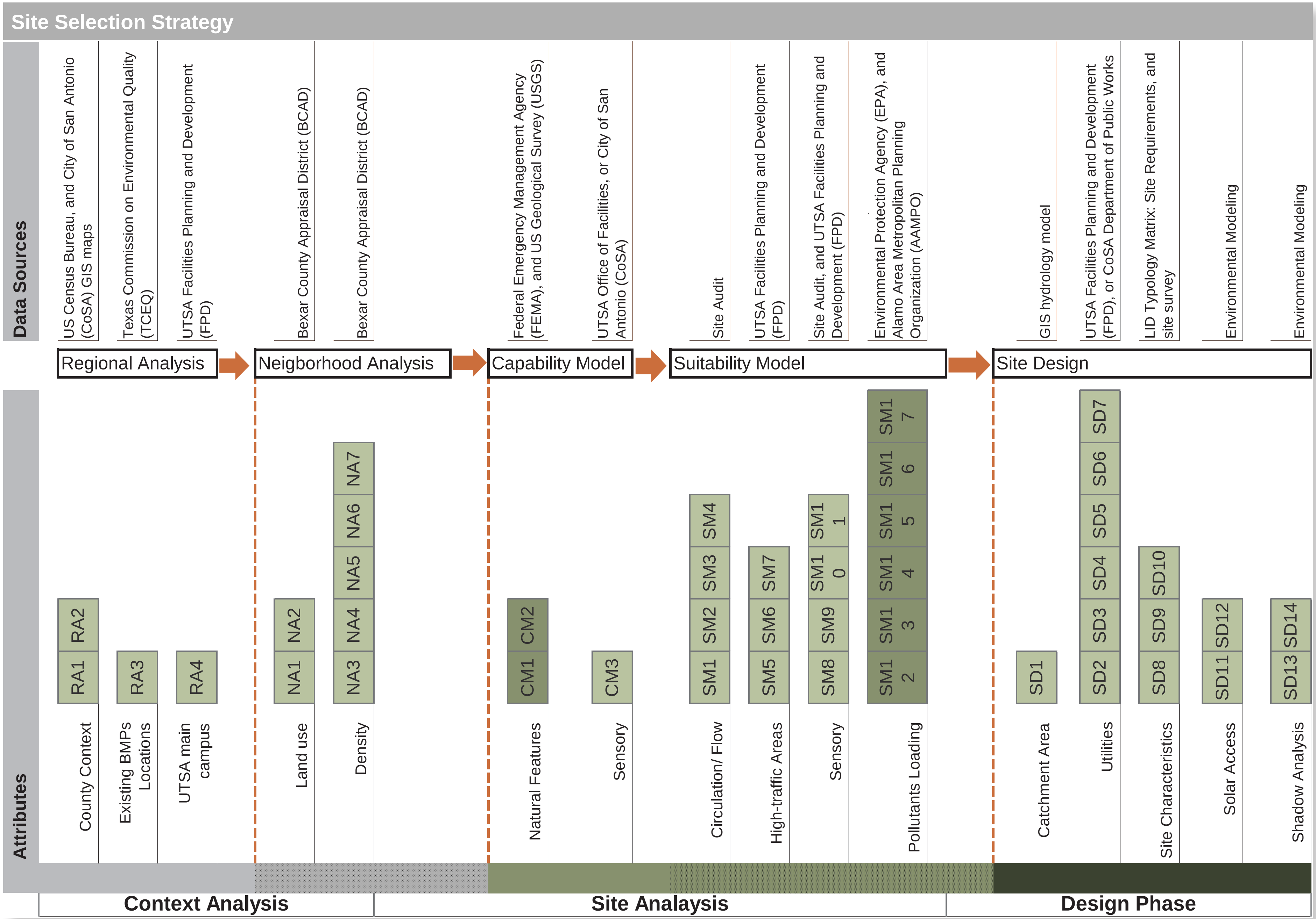


Figure B.3.4: Site Selection Strategy

Themes & Attributes

Regional Analysis			
	County Context		
RA1		Edwards Aquifer Recharge Zone (EARZ)	
RA2		Bexar County	
	BMPs		
RA3		Bexar County BMPs	
	Selected Area		
RA4		UTSA Central Campus	
Neighborhood Analysis			**Weighting Mean**
	Land use		
NA1		Residential only & Mixed-use (with Residential)	2.10
NA2		Commercial only or other (non-residential)	0.00
	Density		
NA3		Multi-family Residential (MFR)	2.13
NA4		Single-family Residential (SFR)	1.80
NA5		Mixed-use (MXD)	2.47
NA6		Manufactured Housing	1.40
NA7		Neighborhood Preservation*	2.17
Capability Model			
	Natural Features		
CM1		Floodplain	2.40
CM2		Slope	2.53
	Sensory		
CM3		Exposure: areas with direct visibility	2.47

Suitability Model			
	Circulation/ Flow		
SM1		Pedestrian	2.33
SM2		Bicycles & Skateboards route	1.73
SM3		Vehicle	1.53
SM4		Bus/shuttle	2.47
	High-traffic Areas		
SM5		Nodes	1.80
SM6		Main Passage (Paseo)**	2.60
SM7		Bus/shuttle stops	1.73
	Sensory		
SM8		Proximity to activity areas (walking, standing, sitting, and sporting)	2.67
SM9		Academic buildings	2.42
SM10		Primary Zones	2.87
SM11		External sources of noise	1.33
	Pollutants loading		
SM12		Nitrogen Oxide (NO)	Equal Weight
SM13		Nitrogen Dioxide (NO2)	
SM14		Particulate Matter (PM2.5)	
SM15		Volatile Organic Compounds (VOCs)	
SM16		Total suspended solids (TSS)	
SM17		Total Phosphorus (TP)	
Site Design			
	Catchment Area		
		Maximum allowed	
	Utilities		
SD1		Stormwater	
SD2		Water	
SD3		Sewer	
SD4		Gas	
SD5		Electricity	
SD6		Communication	
	Site characteristics		
SD7		Setback	
SD8		Head requirements (Inlet/Outlet)	
SD9		Dimensions (width/length)	
	Solar Access		
SD		Summer (AM & PM))	
SD		Winter (AM & PM)	
	Shadow Analysis		
SD		Summer (AM & PM))	
SD		Winter (AM & PM)	

* In the "Neighborhood Analysis" phase, NA 7: neighborhood preservation (NP) was excluded prior to the analysis due to absence of parcels within the immediate vicinity of the main campus that are designated as neighborhood preservation land use. However, in future applications of this model, this report recommends including NP if the parcels surrounding the analyzed BMP sites support this type of land use. Also, Single Family Housing was included in the model due to the high concentration of communities with single family housing in the immediate surrounding of the main campus, and the fact that a lot of students rent SFH units within these communities.

Figure B.3.5: Themes & Attributes


Bioretention Swale located in Phil Hardberger Park, San Antonio, Texas.

Step I: Regional Analysis

TCEQ Texas Central Registry Query

The regional scale is identified as the portion of Bexar County, Texas located on the Edwards Aquifer Recharge Zone (EARZ). Within this geographic boundary, existing Best Management Practices (BMPs) are defined as the potential sites from which a sample will be selected and proposed for redesigning using Low Impact Development (LID) techniques. Environmental concerns regarding water quality have necessitated the development of an assessment tool for selecting and improving existing Best Management Practices (BMPs) in Bexar County. On this regional scale, we utilized two data sets:

1. Online records of Texas Central Registry Query, obtained on March 28, 2016[11], showing 3,029 records.
2. Edwards Aquifer Authority (EAA)[12] inventory of Bexar County's BMPs registration showing a little over 400 records.
3. Inspection records of Stormwater Quality Basins, obtained from San Antonio Water System Corporate Records for the period of January-to-December, 2015[1].

After collaboration with San Antonio River Authority researchers, and upon reviewing the stormwater BMPs data sets, a conclusion was made that many challenges preclude identifying a verified number and location of the constructed stormwater BMPs over the Edwards Aquifer. The principal issue with the data is that only one data set is believed to be truly comprehensive and that is the TCEQ data. However, the records of the TCEQ data set encompass the development plans which have been submitted to the TCEQ for Registration Number (RN). TCEQ then sent these plans to EAA and SAWS for comment. However, these records lack a distinction between the construction, and the proposed BMPs plans, and therefore this comprehensive data set is incomprehensible.

The data set from SAWS is the most detailed but only includes BMPs inspected in 2015. The data set from EAA is a more verified version of the TCEQ data, because of its inclusion of only constructed BMPs. Some reservation on this data makes it incomprehensive though. The BMPs of the EAA data are mapped by site address, not by X/Y (long/lat.) coordinates of the location of each individual BMP. For example, Figure B.3.6 shows an example where the EAA and SAWS data have duplicate data but the SAWS data lists the location of the eight different BMPs constructed on the site, yet the EAA records show one point for the entire site, making EAA data inappropriate for depicting the location of a single BMP record.

With the current data available it is possible to only get an approximate sense of how many BMPs are out there and where they are located, but with a limitation of indistinguishable constructed versus non-constructed BMPs. The San Antonio River Authority has identified the lack of verified BMP data as a problem and is planning to lead a multi-organizational effort to create a centralized –verified and traceable- data set in the future.

Figure B.3.6: Discrepancy of BMP Locations in EAA and SAWS Geodatabases
Source: With permission of San Antonio River Authority (SARA, 2016)

SAWS Records of Stormwater Quality Basins

The inspection records of San Antonio Water System (SAWS) were assessed by delineating the locations of the BMPs and whether they are within or outside Neighborhood Associations (NAs) boundaries, and then by assessing the current condition of the BMPs (i.e., compliant versus not compliant with current regulations), (see Figure B.3.7).

In order to implement the assessment tool, an Excel spreadsheet of regulated water basins inspected by San Antonio Water System (SAWS) between January 1, 2015 and December 31, 2015, the Master Inspection List (MIL) was obtained, along with a spreadsheet of these basins which were found to be noncompliant (NC). GIS data for the inspected BMPs was also obtained. ArcMap 10.3.1 was utilized to delineate the shapefile of NAs boundaries located within the EARZ, which was obtained from the City of San Antonio (CoSA) Geographic Information System (GIS) portal and the Greater Edwards Aquifer Alliance (GEAA), respectively. All data was then imported into ArcMap for analysis. Quality control of the data included comparing the attribute tables of basins' shapefile to the spreadsheets of the basins records.

The first step of quality control was to verify that all of the NC basins were included in the MIL. The next step was to check the spreadsheet lists for duplicate basin IDs (BIDs). After analyzing the two spreadsheets, the following items were discovered:

- Of the 115 records in the NC basins spreadsheet, one basin was listed that was neither on the master inspection list nor was it geocoded in the shapefile
- Of the 882 records listed in the MIL, there were nine BIDs associated with 24 records and 20 geocoded shapefile points:
    1. Eight of the records, with four different BIDs, had four geocoded points in the shapefile (four records were not geocoded)
    2. Eight of the records had the BID# of 0.0 (possibly no assigned BID?) and each was uniquely geocoded in the shapefile
    3. Eight of the records, with four different BIDs, were eight uniquely geocoded points in the shapefile
    4. It was determined that there were 878 uniquely geocoded basins inspected in 2015, and that 114 of those basins were identified as NC (12.98%).

GIS analysis was then performed to determine how the basins, both NC and compliant, were distributed across the region of interest.

For the purpose of this report, no regional analysis was conducted and the five basins located within the the Central Campus- of the UTSA Main Campus were advanced for further analysis at the following level, as explained next (see section B-3, Step II).

Of the 878 inspected basins:

- 737 (83.94%) are located within the EARZ
- 64 (7.28%) are located within NAs (both within and outside of the EARZ)

Of the 114 NC basins:

- 93 (81.58%) are located within the EARZ. Out of the 93 basins, 6 (6.45%) are also within NAs
- 11 (9.65%) are located within NAs

Of the 764 compliant basins:

- 644 (84.29%) are located within the EARZ
- 53 (6.94%) are located within NAs

Hint: It must be noted that for future application of the regional analysis process of this model in commercial, mixed use, or residential sites, further analysis of BMP locations and compliance status will be required. Decisions based on these two factors might be critical for those involved, including funding partners, developers, and users.

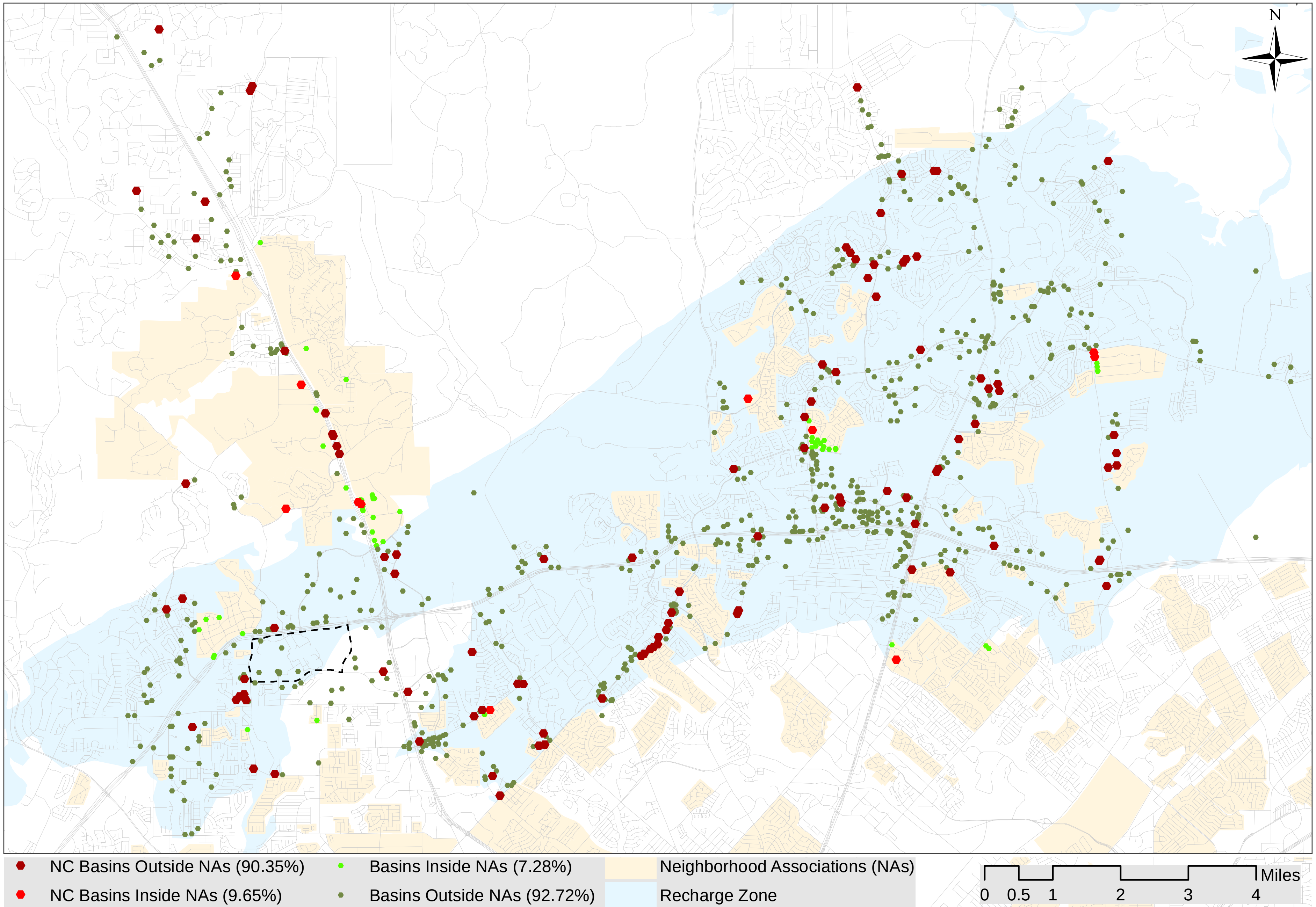


Figure B.3.7: Analysis of SAWS records

Step II: Neighborhood Analysis
(UTSA Campus BMPs)

In this report, the neighborhood scope is defined as the areas, including all parcels, and land uses surrounding the campus zone, known as the Central Campus of the University of Texas at San Antonio's Main Campus (see Figure B.3.8).

The UTSA Main Campus is well along in a transition from a purely commuter campus to an urban residential campus. A thorough review of the master plan was conducted, and special attention was given to two primary issues: growth management and quality of physical environment[13]. The goal established for the 2009 UTSA Campus Master Plan is to add approximately 10 million gross square feet of space to the three campuses. 78 percent of the total space, 9.9 million gsf of projected additions to the University campuses, is proposed to be in the Main Campus. The additional space is meant to accommodate the increasing student enrollment as well as addressing the existing Educational and General (E&G) space deficit[14] (see Figures B.3.8 and B.3.9).

To evaluate the campus, as the neighborhood scale of the proposed model, it is important to incorporate the stakeholders' input, which will help prioritize the criteria for any LID project. A process to quantify the input of involved parties (San Antonio River Authority, Edwards Aquifer Authority, and Greater Edwards Aquifer Alliance) was developed by the research team. The method builds on the lessons learned from the Green Infrastructure program of the City of Austin, and the Green Infrastructure Working Group (GIWG) process for establishing priority areas[15]. LID site criteria identified in section B-1 of this report highlighted the priorities of LID practices as inferred from discussions and meetings with stakeholders. Specific input was also included in an input log developed by the research team (see Figure B.3.5), which concludes with a ranking of the attributes used in the neighborhood analysis as well as capability and suitability models.

Figure B.3.8: Existing Master Plan and BMP locations, UTSA central Campus

Figure B.3.9: Future Expansion and BMP locations, UTSA Central campus

Figure B.3.10: A structural BMP (sand filter) located in the south boundary of the UTSA main campus in San Antonio, TX

Stakeholders' Weighted Overlay (WO)

Weighted overlay is a method used to quantify the relative importance of the criteria considered in suitability analysis. It is a result of an intersection of standardized and differently weighted layers[16]. For this report, an inventory of attributes associated with three levels of analysis was created: neighborhood, site capability, and site suitability. The inventory was shared with the research partners and sponsors to rank all attributes. Using a scale of one to three (least important to most important), each attribute was ranked by eight members representing three partners. An average score was calculated using an equal weight for each attribute/ participant. Attributes with the highest score -in all three levels- were advanced for further analysis and inclusion in the site selection model.

A review of scholarly work discussing and analyzing sites on the neighborhood scale was used to develop quantified metrics for the attributes associated with campus site. The work of Jan Gehl (2011)[17] and Michael Messner (2012)[10] was useful in developing a list of attributes associated with the criterion of: "Maximizing exposure to raise users' awareness about LID benefits". This criterion is one of the site characteristics and LID design strategies (explained in section B-1 of this report). On the neighborhood scale, Figure B.3.5 highlights four selected attributes that scored an average of (2.10) or higher, which were selected as priority attributes for neighborhood analysis.

UTSA Central Campus Attributes

The concentration of population in the surrounding areas is a good measure for the population density, which is a primary predictor of pedestrian flow and presence of communities. On this scale, we used four measures of population concentration that are related to land uses that encompass residential medium-density (mixed use, multi-family residential, neighborhood preservation zones, and single family residential). GIS analysis was used to separate land uses, and a separate map for each land use was created. It should be noted that the neighborhood preservation (NP) map was excluded prior to the analysis due to absence of parcels within the immediate vicinity of the main campus that are designated as neighborhood preservation land use. However, a single family residential (SFR) map was included in the analysis despite the low weight of the SFR communities in the stakeholder input (shown in Figure B.3.5). This is justified by the higher percentage of students residing in those communities. However, further research is needed to get an accurate estimate of their count.

Measures

The five BMP basins were compared based on their proximity to each of the three land use types (mixed use, multi-family residential, and single family residential). Proximity was measured by the shortest distance between each basin centroid and each of the land use types. Basins were then ranked by the proximity on a scale of 1-5 (worst to best), considering that the shorter the distance the higher the score a basin receives. Of the five BMPs, three water quality basins (WQBs): B, C, and D received high score (shown in Appendix C). Due to the limited sample size of BMPs analyzed in this report, we opted not to omit any basin at this stage, and advanced all BMPs to the next stage of analysis, the Site Capability Model (SCM).

Caveat: For future applications of this model, it is highly recommended to select only the BMPs with highest scores at this stage, and advance them to be examined by applying the SCM.

Site Capability & Suitability Models

Analysis	Parameter	Attributes	Weight*
Capability Mode	Site Characteristics	Floodplain	2.40
		Slope	2.53
		Exposure: areas with direct visibility	2.47
Suitability Model	Site Characteristics	Proximity to areas with high levels of Activities (walking, standing, sitting, and sporting)	2.67
		Bus/shuttle stops	2.47
		Pedestrian	2.33
		Primary Zones	2.87
		Main Passage (Paseo)**	2.60
		Academic buildings*	2.42
	Pollutants Loading	Nitrogen Oxide (NO)	Equal weight***
		Nitrogen Dioxide (NO2)	
		Particulate Matter with a diameter of 2.5 micrometers or less (PM2.5)	
		Volatile Organic Compounds (VOCs) benzene, toluene, and m/p-xylene.	
		Total suspended solids (TSS)	
		Total Phosphorus (TP)	

* Based on the means of stakeholders input on a scale of 1-3 (least important -most important)

** Main Passage (Paseo) will be replaced by neighborhood main street/or commercial street

*** Equal weight was cautiously assigned to all pollutants due to the limitation of data on standardized measures for the intensity of specific pollutants in the area around the University's main campus.

Figure B.3.11: Attributes of the Two Models (SCM and SSM).

Single Family Residential

Multi-family Residential

Mixed Use

Figure B.3.13: Mixed Use

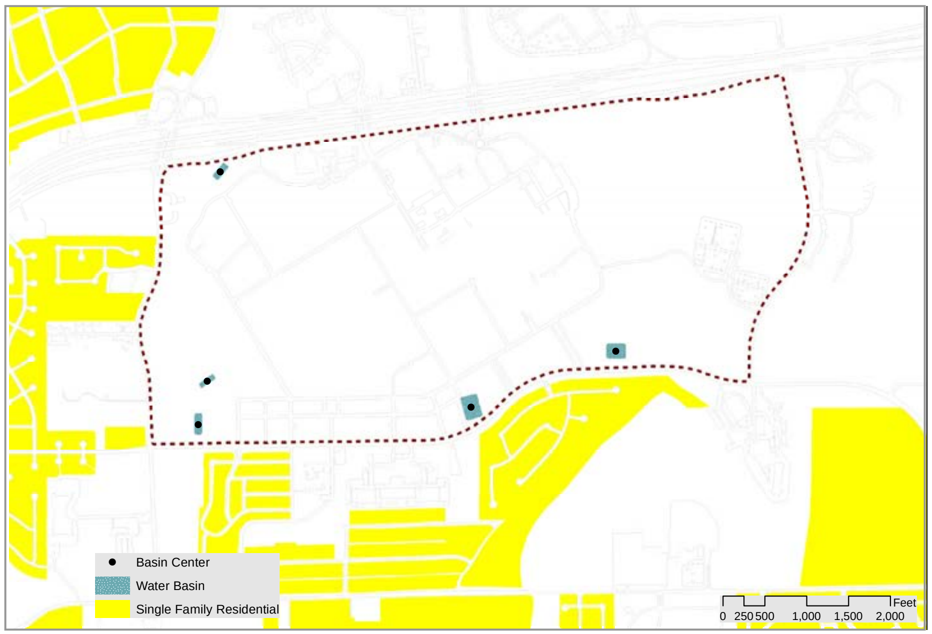


Figure B.3.12: Residential Land Uses

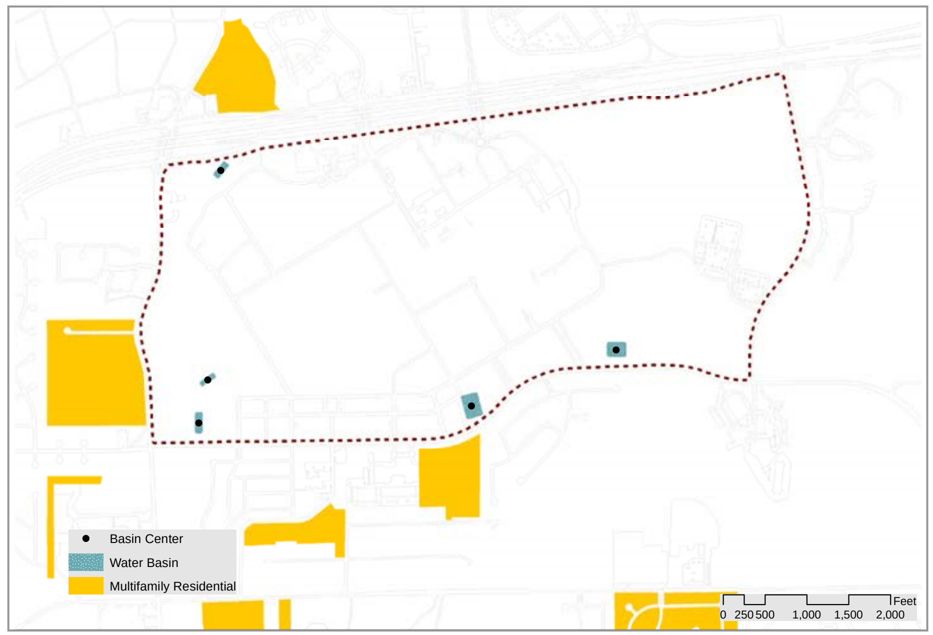


Figure B.3.14: Multifamily Residential Land Uses

Step III: Site Capability Model (SCM)

In the first step of the analysis, we were more concerned with defining the primary attributes that would make a site qualify for LID implementation. Therefore, BMPs and their surrounding drainage area were analyzed for their capability to support the site requirements of LID practices, which were explained in detail in the LID practices matrix (see section B-2 of this report). Establishing a site capability model for the UTSA campus and –in future- for other areas and communities is a process used to provide an insight on the portions of the site that don't comply with specific LID requirements. For that purpose, we utilized a process based on the geodesign approach used by Messner (2012)[10] and Stevens (2015)[8]. Attributes associated with three LID project criteria were identified to establish a Site Capability Model (SCM). These attributes include the following (see also Box B.3.2, and Appendix C for detailed calculations):

a) Slope, and Floodplain which are related to the criterion: "Increase stormwater quantity".

b) Exposure of BMP/and nearby sites through users' direct visibility which are related to two criteria: 'Maximize exposure to raise users' awareness about LID benefits, and enhance outdoor activities".

Slope Floodplain Exposure

In this step, we synthesized data obtained from various agencies to create the Site Capability Model (SCM). The model compares the five Water Quality Basins (WQBs) located in the central campus of the UTSA main campus according to three attributes of site characteristics (slope, floodplain, and exposure).

The data used in this step are explained in Box B.3.1 below. Each basin was ranked according to LID slope criteria explained in Box B.3.2, and the detailed metrics for exposure and floodplain. Basins were then ranked on a scale of 1-5 (worst to best). In this step, WQBs B and D received the highest score. No basin was omitted at this stage due to the low number of BMP sites. However, in future applications of this model, it is advised to omit sites that receive a low score at this stage.

Box B.3.1: Data used for the Capability Model

- CAD files, obtained by permission from the UTSA Office of Facilities.
- ArcGIS data (both shapefiles and dbf files), obtained by permission from the UTSA Office of Facilities
- Campus existing water basins from the UTSA Office of Facilities.
- Campus proposed locations of water basins, approved by the Texas Commission on Environmental Quality (TCEQ), and obtained from the UTSA Office of Facilities
- Aerial views of the campus (obtained through a free-access to Google Earth).
- Slope using LIDAR data, obtained by permission from the UTSA Office of Facilities.

Box B.3.2: Capability Model Attributes

1. Floodplain: Outside projected FEMA 100-year Flood Zone
2. Exposure: (Direct: Yes); (Distance: shortest)
3. Slope: according to the following conditions.

Group-1
Bioretention Area
Bioretention Swale
Rock Infiltration Swale

→ Slopes draining into bioretention: 15% or less (unless incorporating grade control).
Side slopes: 3:1 or flatter (H:V)
Internal longitudinal slope: 2% or less

Group-2
Vegetated Swale
Permeable Pavement
Green Roof
Rainwater Harvesting
Vegetated Filter Strip

→ Overall slope: 1%-5%
Side slopes: 3:1 or flatter (H:V)

Group-3
Sand Filters
Flow-Through Planter

Figure B.3.16: BMP Exposure Analysis

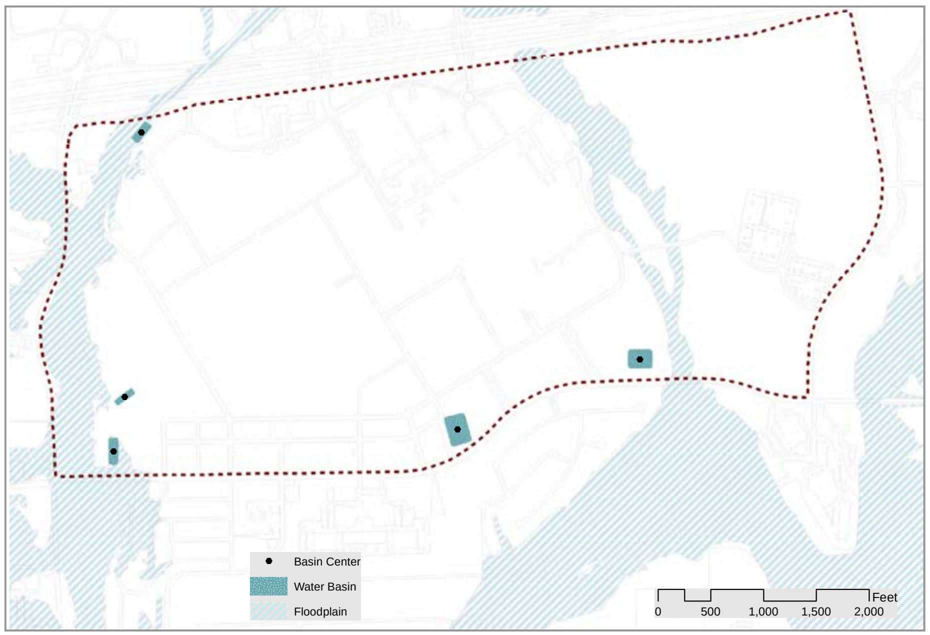


Figure B.3.15: Floodplain at the UTSA Main Campus

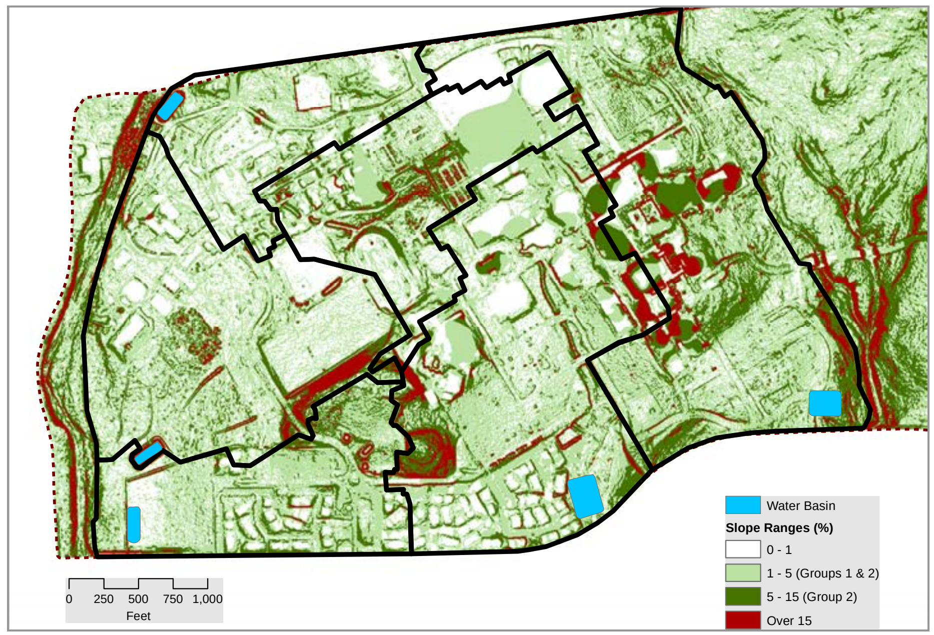


Figure B.3.17: Slope Analysis and appropriateness for LID typologies

Step IV: Site Suitability and Appropriate LID Practices

Suitability analysis is a process for evaluating the suitability of a location or an area for a certain purpose. Suitability analysis combines a number of intersected factors including ecological, physical, biological, social, economic, or other criteria. Suitability model is a series of maps that each represent one or more factors, altogether displaying the spatial distribution of the determined values in a graphical form GITTA (2015a)[16].

A thorough review of scholarly article was conducted to determine a number of most relevant attributes for suitability analysis model (as shown in section B.3, Background, and Site Selection Strategy of this report), in addition to a set of criteria for site characteristics and LID design strategies identified in section B.1 of this report. Based on the discussion of the five articles, and to help attain the goals of design strategies, the following attributes are deemed to be key for accomplishing the purpose of this report:

a) Site Characteristics including: activity areas, high-traffic nodes of buses and pedestrians, primary zones, academic areas, and main passage. These attributes will help comply with the criterion of :“Maximizing exposure to raise users’ awareness about LID benefits”.
b) Pollutants load predicted from various features of the built environment and nonpoint sources where pollutants could accumulate. Depicting, and quantifying the sources and locations of air and water pollutants will help comply with the criterion: “Increasing stormwater quality”.

Data utilized to process the Site Capability Model (SCM) was also used in the SSM. However due to its limitation to measure several site characteristics, primary data using on-site documentation was necessary. Data was acquired using systematic observations of areas with activities and circulation/flow at entry points to the main campus. The following discussion highlights the tools used for systematic observations, documentation, and mapping using GIS technology.

Site Characteristics using Audit Form

To measure site characteristics attributes required for generating a SCM, we developed a systematic observation tool using audit form. The form was utilized to document several activities and human behaviors. Audit forms are commonly used for the assessment of public spaces, streets, and activities. System for Observing Play and Recreation in Communities (SOPARC) protocol[18 19] as well as Pedestrian Environment Data Scan (PEDS) established in 2004[20] were utilized in active living studies to measure activity types and magnitudes.

For tracking and documenting the types and magnitude of different attributes within the UTSA campus, a similar approach using a newly-developed form was materialized by the research team to document and then predict four components of site characteristics of the UTSA main campus.

Observations were conducted at two peak times (morning from 8:00 am to 9:00 am; and afternoon from 4:00 pm to 5:00 pm) at 10-minute intervals. Data log was then entered into a spreadsheet. (See data log in Appendix C). Points of observations were cautiously selected as major pathway intersections and existing open spaces. These points were geocoded to create a GIS shapefile, which was manipulated to incorporate spreadsheet data. GIS spatial analysis tools were then used to produce maps shown in Figures B.3.18 to B.3.22.

Activities were documented and analyzed using Gehl (2011)[17] classification of type and intensity. Type of activity includes: sitting, walking, standing, or engaging in sport; and intensity includes the count of persons by each type during the 10-minute interval. A minimum of 45 was considered the threshold of accepted intensity. Accessibility by location and means (vehicle, pedestrian, bikes, and buses) as well as site visibility and nodes were documented using similar systematic observations during the same intervals and times. Counts of observed activities were then digitized using GIS, mapped, and analyzed using similar audit forms.

Figure B.3.18: BMP proximity to nodes and open spaces with sitting activity (a.m. & p.m.)

Figure B.3.20: BMP proximity to nodes and open spaces with walking activity (p.m.)

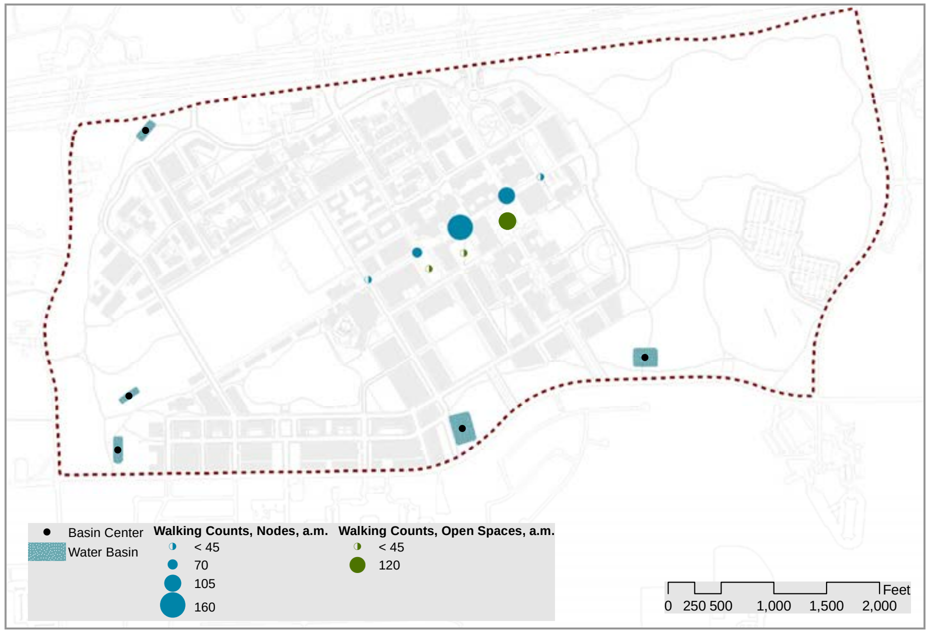


Figure B.3.19: BMP proximity to nodes and open spaces with walking activity (a.m.)

Figure B.3.21: BMP proximity to bus/shuttle stops

Figure B.3.22: BMP proximity to pedestrian flow points

Figure B.3.24: BMP Distance to Main Passage *(Paseo)*

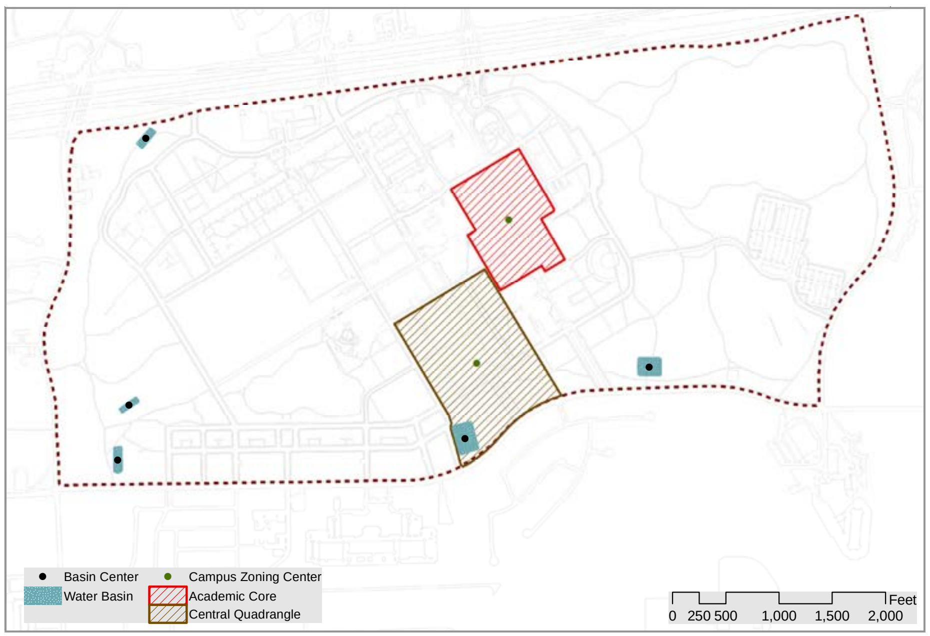


Figure B.3.23: BMP proximity to campus primary zones (academic, and central quad)

Figure B.3.25: BMP Proximity to Existing Academic Buildings

Pollutants Load

To develop a list of attributes pertaining to pollutants measures from the built environment and landscape as major contributors to water contamination, we reviewed multiple metrics of air and water pollution in scholarly articles.

Air pollution has significant detrimental effects on health, both short-term (acute symptoms) and long-term (chronic illnesses). The objective of the air pollution analysis is to understand the various factors that cause air pollution in a particular location. The selection of relevant estimation models is important in making accurate assessments of a local population's pollutant exposure. An estimation model is relevant if it was developed for a region with similar characteristics, such as population, traffic patterns, land use types, and topography. Models developed in two studies will be reviewed and an estimate of pollutant loads around campus BMPs will be estimated.

Stormwater runoff negatively impacts the economy and the environment. The generally high percentage of impervious ground cover in urban and suburban areas often leads to runoff during and after precipitation events. Economic effects range from the long-term costs of building and maintaining stormwater sewer systems to the costs of cleaning-up and rebuilding after flood damage. Environmental effects include erosion and pollution of waterbodies and groundwater. Two studies focusing on two important pollutants of runoff, including Total Suspended Solids (TSS) and Total Phosphorus (TP) will be reviewed, in addition to measures of total nitrate, and heavy metals (zinc, chrome, copper and cadmium).The estimate of these pollutants around the campus BMPs will then be calculated, and included in the Site Suitability Model (SSM).

Air Pollution

The studies for air pollution analysis were selected based on their similarity to The University of Texas at San Antonio's (UTSA) main campus land use pattern, a low density urban environment. The two following studies were conducted using passive air samplers, geographic information systems (GIS) and land use regression models (LUR).

1. Sarah B. Henderson et al., 2007[21]: The study conducted in Vancouver, British Columbia, Canada provided a method for estimating traffic-related long-term concentrations of airborne nitrogen oxide (NO), nitrogen dioxide (NO2), and particulate matter with a diameter of 2.5 micrometers or less (PM2.5).
2. H. Oiamo et al., 2015[22]: The study conducted in Ottawa, Ontario, Canada provided a method for estimating the traffic and industrial contributions to airborne NO2 and the volatile organic compounds (VOCs) benzene, toluene, and m/p-xylene.

Regression analyses were performed by Henderson et al. (2007)[21] and Oiamo et al. (2015)[22] to determine the impact of numerous expected contributors at radii from 100 to 8000 meters (328.1 ft. to 26,246.7 ft.) to the listed airborne pollutants. All non-VOC pollutants were expected to be impacted by traffic activity, land use, and population. VOC levels were expected to be impacted by traffic activity and proximity to VOC-emitting facilities. The final land use regression (LUR) models were derived using stepwise linear regression[21] or stepwise multiple ordinary least squares regression[22] (as shown in Tables B.3.2 & B.3.3). In both studies, attributes that were insignificant to the explained variance in the coefficient of determination (R2) were eliminated from the models.

- Intersection counts and centerline lengths of highways and major surface roads; GIS/CAD raw files were obtained from Alamo Area MPO, CoSA and UTSA Office of Facilities.
- Areas of land devoted to commercial, industrial, or residential land use; Bexar County Appraisal District (BCAD) for Landuse maps were updated by the authors,
- Population data; obtained from ACS (2010-2014 5-year estimates) of the U.S. Census Bureau[24]
- Locations of VOC-emitting (in general) and toluene-emitting (specifically) facilities; locations and types of emissions were obtained from the U.S. Environmental Protection Agency.[25]

Part A

Part B

Part C

Table B.3.2: **Factors in the levels of NO, NO2, and PM2.5**, the relevant ranges of impact, and LUR-derived measures and equations (based on road length). Source: Based on Henderson et al. (2007)[21]

Pollutant	Buffer		Metric		
	Meters	Feet	Variable	Measure	Equation
logNO (ppb)	100	328.1	Highways (LH_100)	Centerline length	+1.65 x LH_ 100
	100	328.1	Major roads (MJ_100)	Centerline length	+ 2.19 × MJ_100
	1000	3280.8	Highways (LH_1000)	Centerline length	+0.037 x LH_1000
	2500	8202.1	Population density (POPd_2500)	Persons per hectare	+0.007 x PoPd_2500
NO_2 (ppb)	100	328.1	Highways (LH_100)	Centerline length	+ 10.5 × LH_100
	200	656.2	Major roads (MJ_200)	Centerline length	+ 4.24 × MJ_200
	750	2460.6	Commercial (COM_750)	Land use in hectare	+0.116 × COM_750
	1000	3280.8	Highways (LH_100)	Centerline length	+0.275 × LH_1000
	2500	8202.1	Population density (POPd_2500)	Persons per hectare	+0.074 × POPd_2500
$PM_{2.5}$ (μg/m3)	300	984.2	Commercial (COM_300)	Land use in hectare	+ 2.58 × COM_300
	300	984.2	Industrial (IND_300)	Land use in hectare	+0.319 × IND_300
	750	2460.6	Residential (RES_750)	Land use in hectare	+0.035 × RES_750

Table B.3.3: **Factors in the levels of NO2, benzene, toluene, and m/p-xylene**, the relevant ranges of impact, and LUR-derived measures and equations. Source: Based on Oiamo et al.2 (2015)[22]

Pollutant		Buffer		Metric		
		Meters	Feet	Variable	Measure	Equation
NO_2 (ppb)		100	328.1	Intersections (IC_100)	Total count	+ 0.433 × × IC_100
		600	1968.5	Industrial (IND_600)	Land use in hectares	+ 0.059 × IND_600
		1500	4921.3	Population (POP_1500)	Total count	+ 0.093 × POP_1500
VOCs	Benzene (μg/m3)	100	328.1	Intersections (IC_100)	Total count	+ 0.023 × IC_100
		300	984.2	Highways (LH_300)	Centerline length	+ 0.209 × LH_300
		2500	8202.1	Population (POP_2500)	Total count	+ 0.002 × POP_2500
		4000	13123.4	VOC facilities (VOCFacC_4000)	Total count	+ 0.028 × VOCFacC_4000
	Toluene (μg/m3)	100	328.1	Intersections (IC_100)	Total count	+ 0.215 × IC_100
		350	1148.3	Highways (LH_350)	Centerline length	+ 0.762 × LH_350
		4000	13123.4	VOC facilities (VOCFacC_4000)	Total count	+ 2.19 × VOCFacC_4000
		8000	26246.7	Toluene facilities (TFacC_8000)	Total count	+ 0.333 × TFacC_8000
	m/p-Xylene (μg/m3)	100	328.1	Intersections (IC_100)	Total count	+ 0.079 × IC_100
		350	1148.3	Highways (LH_350)	Centerline length	+ 0.262 × LH_350
		4000	13123.4	VOC facilities (VOCFacC_4000)	Total count	+ 0.049 × VOCFacC_4000

To measure the impacts of pollution sources around each of the five BMPs, referred to as water quality basins (WQB), buffers of the following radii (in meters) were created: 100, 200, 300, 350, 600, 750, 1000, 1500, 2500, 4000, and 8000. Calculations for each of the attributes were completed using GIS tools (ESRI's ArcMap 10.3.1).

1. The 100m buffer is a range where all pollutants (except PM2.5) were predicted according to the following metrics:
   - NO: Centerline lengths (km) of highways and major roads
   - NO2: Centerline lengths (km) highways and intersection counts
   - VOCs: Intersection count
2. The 200m buffer is a range where NO2 was predicted using the following metric: Centerline lengths (km) of major roads
3. The 300m buffer is a range where PM2.5 and benzene were predicted using the following metrics:
   - PM2.5: Total areas of commercial and industrial land uses (hectares, ha)
   - Benzene: Centerline lengths (km) of highways
4. The 350m buffer is a range where toluene and m/p-xylene were predicted using the following metric: Centerline lengths (km) of highways
5. The 600m buffer is a range where NO2 was predicted using the following metric: Total area of industrial land use (ha)
6. The 750m buffer is a range where NO2 and PM2.5 were predicted using the following metrics:
   - NO2: Total area of commercial land use (ha)
   - PM2.5: Total area of residential land use (ha)
7. The 1000m buffer is a range where NO and NO2 were predicted using the following metrics:
   - NO: Centerline lengths (km) of highways
   - NO2: Centerline lengths (km) of highways
8. The 1500m buffer is a range where NO2 was predicted using the following metric: Population
9. The 2500m buffer is a range where NO, NO2, and benzene were predicted using the following metrics:
   - NO: Population density (persons/ha)
   - NO2: Population density (persons/ha)
   - Benzene: Population
10. The 4000m buffer is a range where all three VOCs were predicted using the following metric: Total count of VOC emitting facilities
11. The 8000m buffer is a range where toluene was predicted using the following metric: Total count of toluene emitting facilities

Water Pollution

The objective of water pollution analysis is to understand the various factors that contribute to the amount of TSS and TP in stormwater runoff. The amount of pollutants in runoff is often measured in terms of load (mass/event) and/or concentration (mass/volume). Pollutant concentration varies significantly between events and during the course of an event. Therefore, in order to calculate runoff pollutant concentrations, numerous runoff samples are collected and combined (as either time-weighted or flow-weighted) to arrive at an Event Mean Concentration (EMC). Load can be determined by multiplying the EMC by the event's total runoff volume. To predict an estimate of two of these pollutants, we reviewed the two following studies: Florida Water Management District report (2002)[26], and Brezonik and Stadelmann (2002)[27].

The South Florida Water Management District report (2002)[26] concluded that the general order of pollutant loading from urban land uses (highest to lowest) was:

1. Industrial and commercial,
2. Highway,
3. Higher density residential,
4. Lower density residential,
5. Open land.

A correlation and stepwise multiple linear regression study by Brezonik and Stadelmann (2002)[27], completed in the Minneapolis-St. Paul, Minnesota metropolitan area, found that the "most important" attributes for predicting storm event loads are precipitation amount, precipitation intensity, and drainage area. Since the surface area covered by

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the UTSA main campus is relatively small, precipitation amounts and intensities are assumed to be the same across all five BMPs. Therefore, the differentiating attribute is the drainage area for BMPs. The Brezonik study also concluded that pollutant EMCs were generally higher when the length of time between events increased (pollutants tend to collect on surfaces before being washed off) and lower for longer duration storms (due to more diluted runoff). The South Florida report listed median EMCs by land use category. We assumed that land use categories relevant to the main campus are Residential and Mixed use:

TSS Event Mean Concentration (EMC):
- Residential = 101 mg/L
- Mixed = 67 mg/L

TP Event Mean Concentration (EMC):
- Residential = 0.383 mg/L
- Mixed = 0.263 mg/L

Additionally, active construction has generally short-term impacts, it can produce far higher loads of TP in soil and TSS than in any finished land use. Therefore, the major sources of TSS in stormwater runoff include:[26]

1. Construction activities - Erosion from exposed soil (i.e., vegetation or other covers have been removed),
2. Street pavement - Substances from daily traffic and road degradation (aggregate material, asphalt binder, fillers, etc.),
3. Motor vehicles - Vehicle components (e.g., tire particles and brake linings) collected on roads and parking lots, and ‘dirt’ adhered to vehicles (which is later washed onto pavement),
4. Atmospheric deposition - Dust and particles from industrial processes, planes, cars, exposed land, etc.,
5. Land use - The type of land cover and amount of vehicular and pedestrian traffic

Major sources of TP in stormwater runoff include:[26]

1. Atmospheric deposition - Dust and particles from industrial processes, planes, cars, exposed land, etc.,
2. Land use - The type of land cover and amount of vehicular and pedestrian traffic,
3. Chemicals - Fertilizers, insecticides, and herbicides used in landscaping, agricultural fields, roadside areas, yards, etc.,
4. Wastewater - Storm flooding induced overflow of septic tanks or sanitary sewer systems and improper connections between sanitary sewers and stormwater drainage systems (may result in discharge of sewage waste directly to waterbodies).

Data on most of these attributes will not have a great effect on the assessment due to the fact that the five BMPs are located in the same campus. Also, Campus BMPs are not near railroads, ports or airports, and therefore there is no evidence of increased level of heavy metals[28] in stormwater. The amount of fertilizers[29] from the campus green spaces on the level of nitrate in groundwater will not have a significant effect on the selection process, since all basins are presumed to be surrounded by equal amount of green spaces. Therefore, this report focuses only on developing a method for estimating and comparing the impacts of TSS and TP EMCs for each BMP. A GIS analysis for the weighting of relevant land use portions of each BMP drainage area was conducted, and results and ranking of BMPs is included in Appendix-C. (Drainage areas were obtained from UTSA Office of Facilities).

Site Suitability Model (SSM)

A comprehensive assessment was conducted for the five BMPs using the attributes of site characteristics as well as air and water pollutants loads. A ranking system for each BMP using a scale of 1-5 (worst to best) was applied. A Total score for each BMP was calculated using an equal weighting system for all attributes. The sum of each BMP’s suitability score was then calculated (as explained in detail in Appendix C, spreadsheets). The total score yielded a higher score for two BMPs: WQB-B and WQB-D, and therefore both basins were advanced for further design of LID practices.

Figure B.3.26: logNO calculated for 100m buffer based on Henderson et al. (2007)

Figure B.3.28: NO2 calculated for (100 and 200)m buffers based on Henderson et al. (2007)

Figure B.3.27: logNO calculated for (1000 and 2500)m buffers based on Henderson et al. (2007)

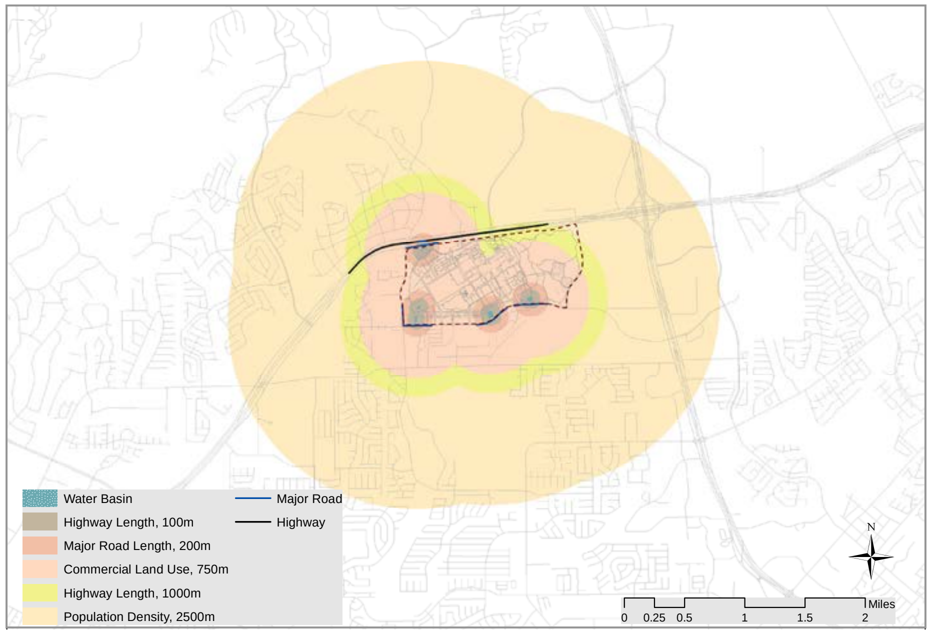

Figure B.3.29: NO2 calculated for (100, 200, 750, 1000, and 2500)m buffers based on Henderson et al. (2007)

Figure B.3.30: PM2.5 calculated for 300m buffer based on Henderson et al. (2007)

Figure B.3.32: NO2 calculated for 100m buffer based on Oiamo et al. (2015)

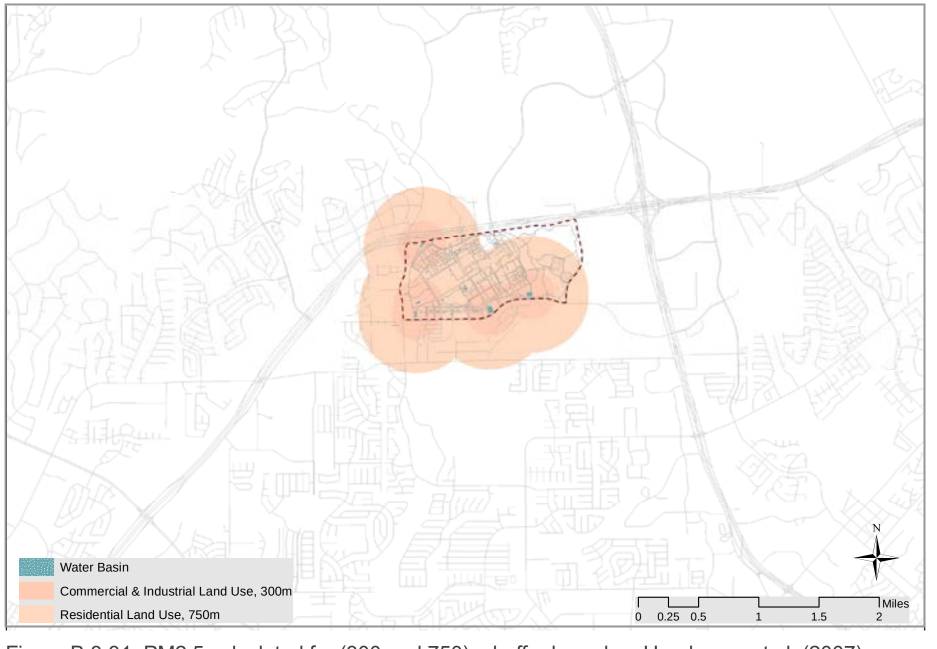

Figure B.3.31: PM2.5 calculated for (300 and 750)m buffer based on Henderson et al. (2007)

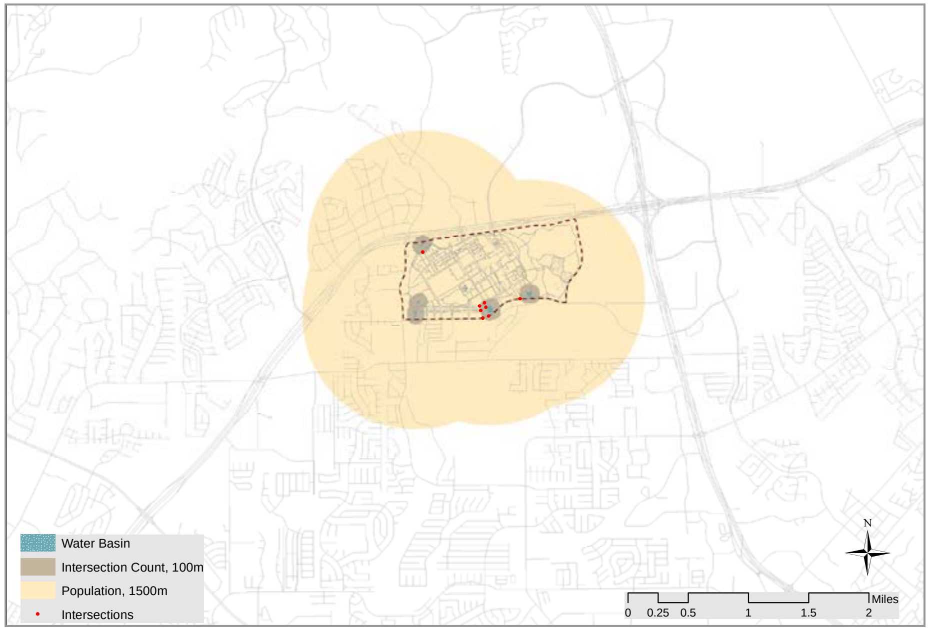

Figure B.3.33: NO2 calculated for (100 and 1500)m buffer based on Oiamo et al. (2015)

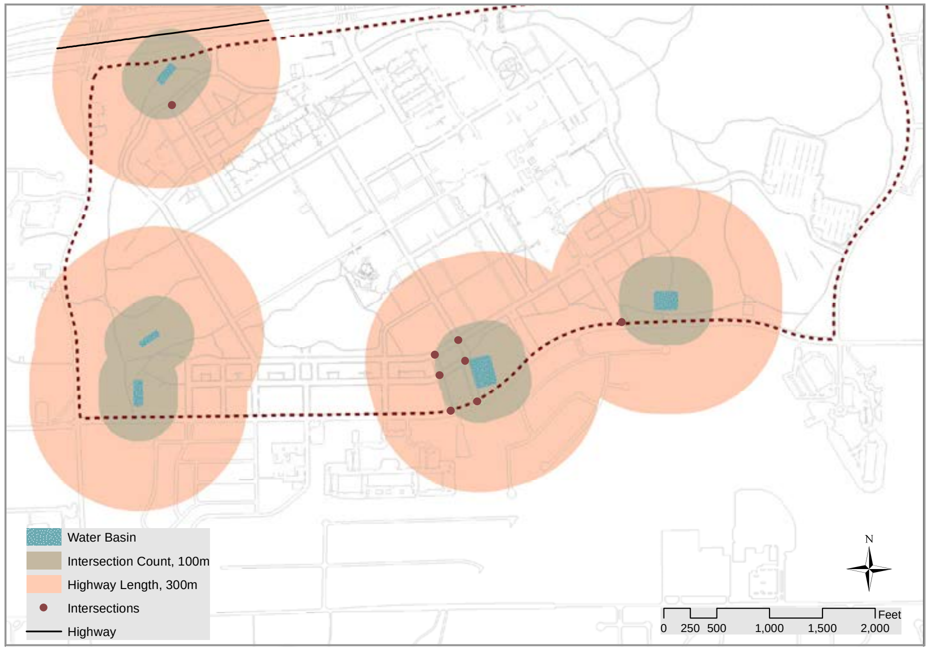

Figure B.3.34: VOCs Benzene calculated for (100 and 300)m buffer based on Oiamo et al. (2015)

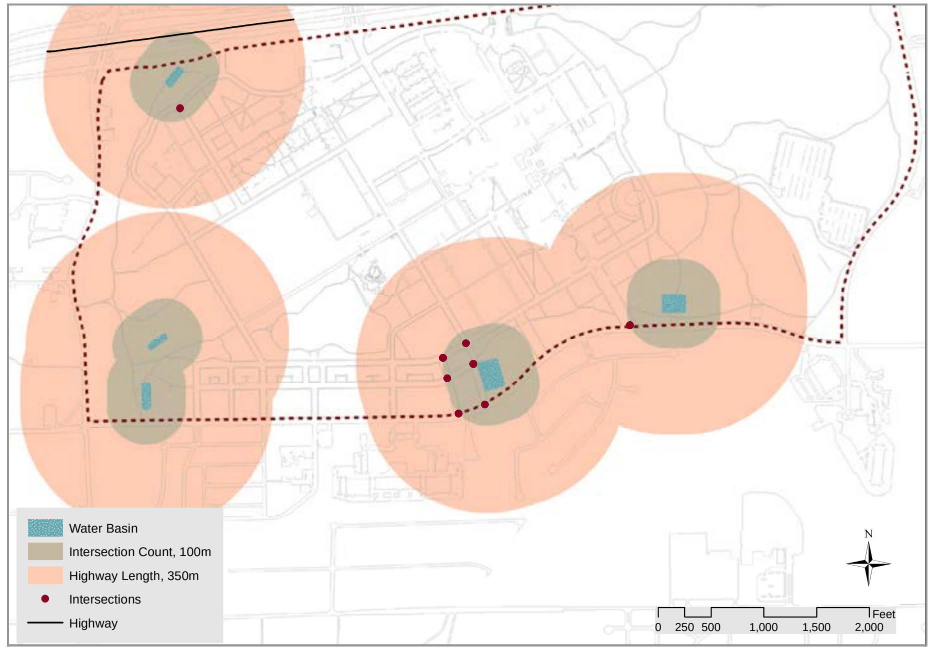

Figure B.3.36: VOCs Toluene calculated for (100 and 350)m buffer based on Oiamo et al. (2015)

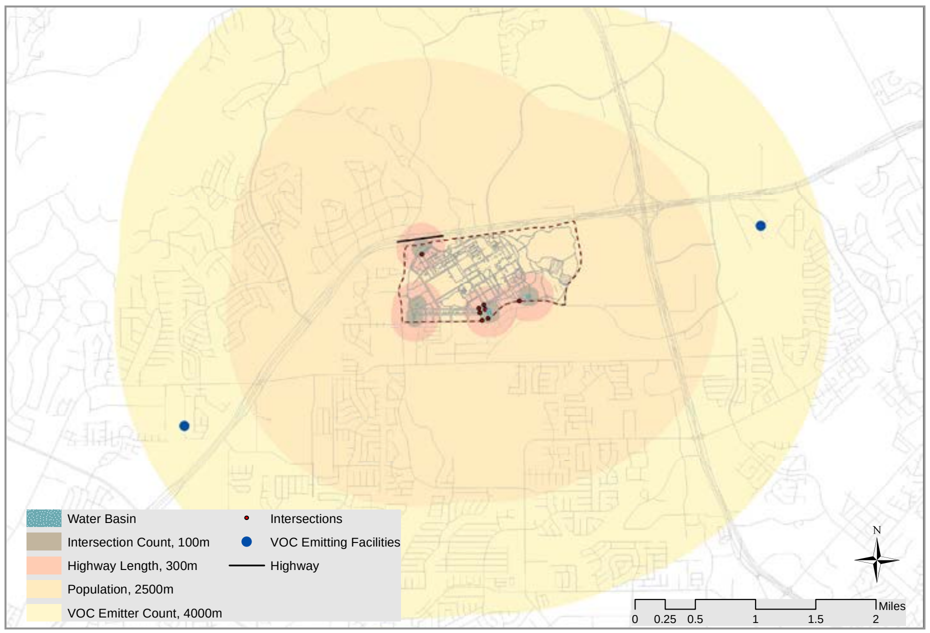

Figure B.3.35: VOCs Benzene calculated for (100, 300, 2500 and 4500)m buffer based on Oiamo et al. (2015)

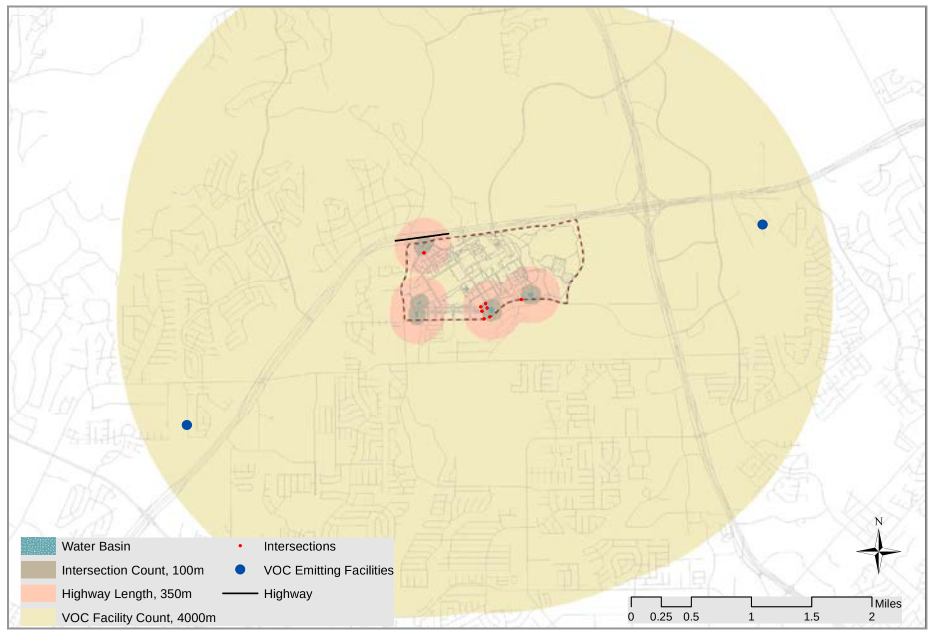

Figure B.3.37: VOCs Toluene calculated for (100, 350 and 4000)m buffer based on Oiamo et al. (2015)

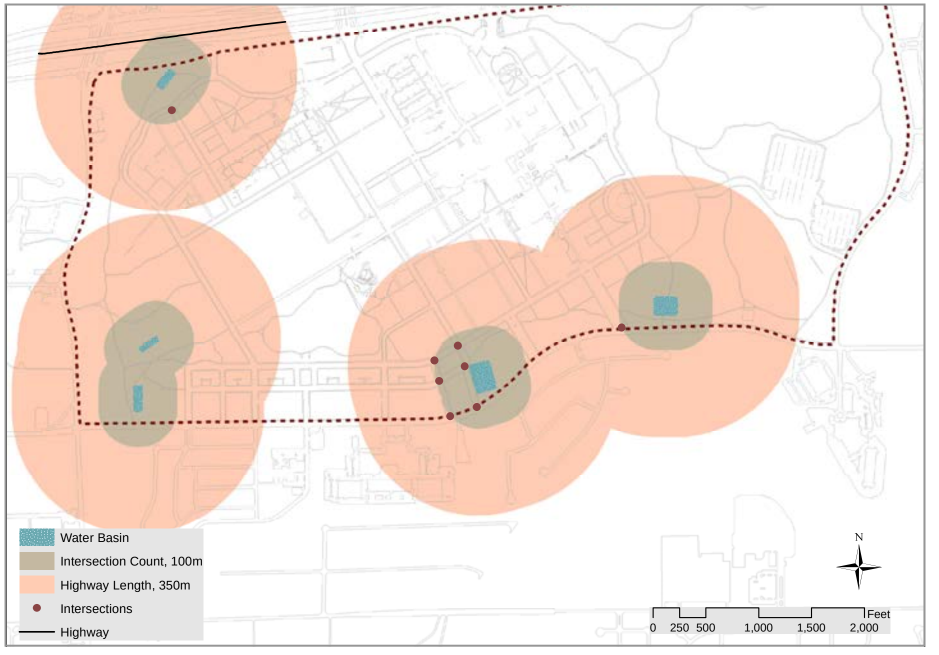

Figure B.3.38: VOCs m/p-Xylene calculated for (100 and 350)m buffer based on Oiamo et al. (2015)

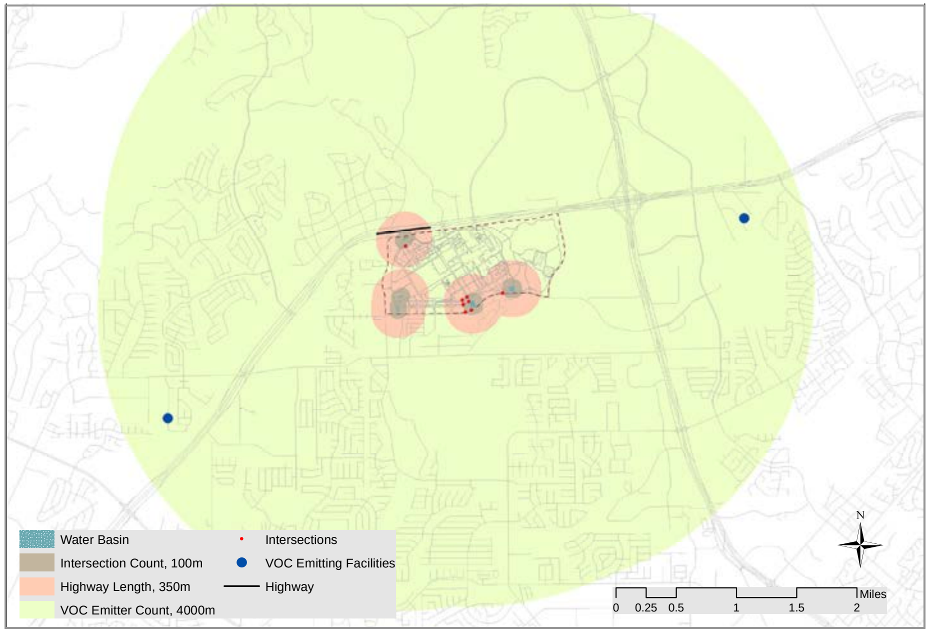

Figure B.3.39: VOCs m/p-Xylene calculated for (100, 350 and 4000)m buffer based on Oiamo et al. (2015)

Step V: LID Design Principles: UTSA Campus Case Study

Due to the broad size of the catchment areas of the two selected BMPs (WQB-B and WQB-D), the proposed LID design will need to include a series of LID typologies in order to reach an efficient capacity of treatment, filtration, and infiltration. As noted in the site capability model, one of the primary criteria for efficient performance of any LID typology is to have a five acre maximum catchment area. Therefore, each polygon of the approved TCEQ catchment areas needs to be divided into smaller catchment areas, so that each will allow the treatment of water through a separate LID feature (or a set of features). The overall techniques proposed for each catchment area are based on the slope requirements that support LID features, which was used as a basis for developing the SCM. We used the principles of treatment train, including LID techniques (i.e. permeable pavement, curb cuts, green roofs, rain gardens, gabions, bioswales, and bioretention areas) to redesign the two sites. The proposed features will mostly be lined practices, with the expectation of the final destination (bioretention areas in WQB-B, and bioswale in WQB-D) that is proposed to be unlined. Unlined LID practices will be proposed as a pilot project to infiltrate water into the aquifer, and measure water quality before and after entering the recharge zone.

WQB-B

The Student Reach, a proposed LID design for WQB-B (shown in Figure B.3.40) takes advantage of a steep slope parallel to the main passage (Paseo) to terrace the hill. Terracing is a process to adjust the natural slope to the site requirements for LID practices (Group 1 & 2) with a maximum of 15% of the area around the basin, and a maximum of 1:3 (V:H) for the riparian areas. The proposal comprises a series of LID typologies that altogether will improve water quality before the water reaches the final destination, the unlined bioretention basin (see appendix A for further details).

WQB-D

The Canalillo, a proposed LID design for WQB-D (shown in Figure B.3.41) entails a series of rain gardens, permeable pavements, and curb cuts. The proposed site is located in the campus central quad, an open space that will be the hub for a myriad of academic activities in the vicinity of sciences and engineering buildings according to the campus projects. The design utilizes the natural slope of the central quad to efficiently allow stormwater flow towards the LID practices. The Canalillo comprises a number of rain gardens, a green rook, modular cistern system, bioswale, permeable pavement, and curb cuts throughout the site to facilitate water flow from the campus roads as well as nearby roads.

- Adjust the slope of riparian areas to avoiding soil erosion, and select appropriate plants for the riparian and bioretention areas that will tolerate both the post-rain events and drought
- Provide outdoor events and activity space that will raise awareness about LID among academic community and the communities that surround the UTSA campus
- Decrease obstruction of views
- Provide sun exposure necessary as recommended for the plants
- Ease of access for frequent maintenance

Hint: For a discussion of the design principles and further design proposals of the two LID projects, see Appendix C, p.143, and appendices A & B.

Figure B.3.40: TCEQ approved area for WQB-B

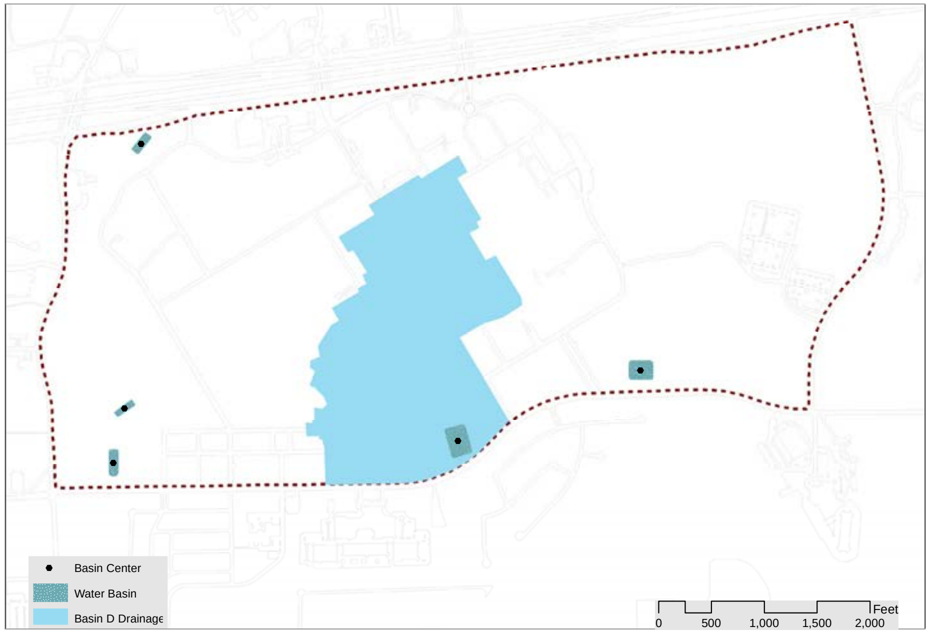

Figure B.3.41: TCEQ approved area for WQB-D

Notes

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Water Management at Mueller Community, Austin, Texas.

C

MANAGEMENT & SUSTAINABILITY

C.1 Maintenance & Operation

Components of Cost

According to Jia, et al., 2013[1], operation and maintenance is one of three primary components of overall LID facility cost and a key indicator of the site suitability of a given LID strategy that should be considered. As shown in Figure C.1.1, operation and maintenance can be subdivided into operational costs, which include material costs necessary to sustain facility operation, and maintenance costs, which include the costs of personnel, material and replacement parts. Maintenance costs are incurred less frequently than operation costs.

Background and Challenges

Managing urban stormwater runoff has become a global issue, especially in light of the increasing intensity and frequency of significant rainfall events associated with climate change. Soil compaction, increased impervious cover and the removal of flora that accompanies new development alter natural hydrological processes, sometimes negatively affecting entire watersheds[2]. Low Impact Development (LID) can help mitigate many of these negative impacts. However, the perception that LID requires more intensive and costly maintenance than conventional stormwater

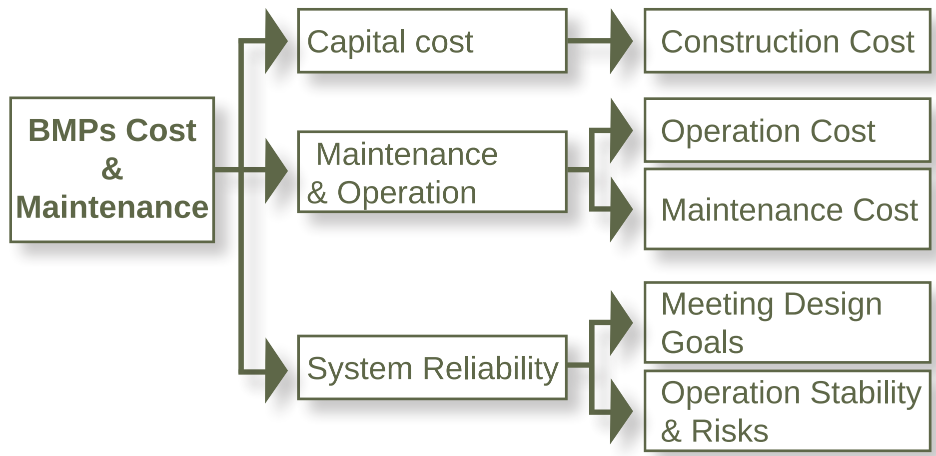

Figure C.1.1: Indicators of BMPs cost and maintenance (Haifeng Jia 2013) (Development of a multi-criteria index ranking system for urban runoff best management practices (BMPs) selection).

management approaches deters adoption by communities in many cases. Furthermore, when LID is implemented, lack of workable management and operation plans often results in subpar performance and premature facility degradation.

An inability to satisfactorily project the costs and performance of LID is the main obstacle to wider adoption. Considering that traditional landscaping has a cost associated with its M&O, when that cost is compared with LID M&O cost, the difference is minor particularly when combined with the overall cost of the stormwater management system including the capital cost and the long-term reliability of the system. Though study of the benefits of LID as well as its capital, operational and maintenance costs has increased in recent years, more work is needed in documenting and quantifying these benefits so that communities can accurately weigh LID against conventional stormwater management approaches[3, 4]. The lack of a uniform LID performance baseline for comparison to conventional stormwater management methods is a major gap in the path to wider adoption[2]. Other obstacles to adoption include limited local experience with LID, limited agency and designer experience, the perception that LID involves more complex design and construction processes as well as the need to provide special education and training to facility owners and operators[5.] Another aspect of the endeavor to encourage adoption of LID practices is determining who should be responsible for funding them. LID facilities are often deployed at the parcel level, so the question follows, is implementation the responsibility of the individual land owner, or should stormwater management through LID be considered a community responsibility regardless of the scale at which it is addressed? These questions concern how communities conceive of and act upon issues of public good[6.]

Questions concerning agency's responsibility as well as the overall effectiveness of LID notwithstanding, formulation and proper execution of facility management and operation plans is key. Development of a successful management and operation plan involves producing an inventory of facilities to be covered by the plan, determining the maintenance needs of each facility, creating an inspection and maintenance schedule, clearly establishing who will be responsible for performing inspection and maintenance, and establishing a realistic maintenance budget. However, during the design and construction phases, care should be taken by designers, engineers, and installers to ensure facility maintainability, accessibility and durability[7.]

Keys to Ensure Ease of Maintenance

- **Maintainability**
- **Accessibility**
- **Durability**

Figure C.1.2: Mueller Community, Austin, Texas.

Planning for Maintenance and Operation

LID facilities designed to be easy to care for from the beginning are more likely to be properly maintained, leading to better performance over time. The three keys to ensuring ease of maintenance are maintainability, accessibility and durability.

Maintainability

Three principles of maintainability should be kept in mind by LID designers including minimizing, simplifying and reducing the complexity of design and process. Through thoughtful consideration of facility location, shape, configuration and materials, the amount of maintenance a facility will require can be greatly minimized. Simplicity in design also enables maintenance personnel to more easily understand how a facility is intended to function, making it more likely malfunctions or premature degradation will be recognized. Additionally, replacing non-native water-hungry plants with native plants as well as protecting and using on-site natural features such as highly infiltrating soils or curb-cuts to undisturbed green areas, paired with forebays to centrally collect trash, decreases maintenance needs. In general, every effort should be made to preemptively reduce the amount of care a facility will require[8].

Accessibility

Maintenance personnel report that lack of convenient access to points of required maintenance is the most significant challenge they face. This issue of accessibility is related to the aforementioned principle of simplicity. The ability of personnel to easily walk, stand, climb and stage their materials near points of maintenance is vital. Facility designers should take into account how features like slopes, vegetation, curbs, fences and any other physical barriers will affect maintenance accessibility.

Providing amenities like hand and guard rails, gates, access paths, manholes, hatches and depressed curbs can greatly improve ease of access, translating to safer, faster and cheaper maintenance operations. Operable components such as gates, hatches and manholes should not be excessively heavily, and where necessary, hoists, lifts or other mechanical aids should be provided to ensure accessibility and the safety of personnel. Care should also be taken to avoid employing safety or accessibility features that undermine the effectiveness of other features.

Lastly, access can be inhibited by legal barriers as well. Wherever adequate access rights or maintenance easements are not provided, maintenance cannot occur. Owners, designers and design review professionals must verify during the design phase that these important features will be provided[8.]

Durability

Durability is the third facility characteristic that can reduce maintenance needs and costs. Specifying decay and corrosion resistant materials such as aluminum, stainless steel, galvanized metals and reinforced concrete where applicable will increase facility longevity. Also, implementing appropriate erosion control measures and selecting drought and disease resistant vegetation well suited to the Texas Hill Country environment will limit the amount of maintenance required[8]. Sources providing selection guidance for plants appropriate to the Texas Hill Country and South Texas region in general include the San Antonio River Basin LID Guidance Manual and the Greater Edwards Aquifer Alliance's Low Impact Development Manual. The Lady Bird Johnson Wildflower Center also offers a helpful plant selection tool on its website (www.wildflower.org) that allows users to search an extensive catalog of plants by specifying soil and climate parameters.

Facility designers should take into account how features like slopes, vegetation, curbs, fences and any physical barriers will affect maintenance accessibility.

Figure C.1.3: LBJ Wild Flower Center, Austin, Texas.

Approaches to Maintenance and Operation: Reactive vs. Proactive

Because geological, hydrological and climatic conditions as well as facility characteristics can vary widely from region to region, detailed information concerning the exact costs and timing of required maintenance tasks is difficult to obtain and scarce for most LID typologies. While the particular maintenance imperatives for all LID typologies are well understood, it is difficult to gauge how often these tasks will need to be performed, how long it will take to perform them and how much they will cost. Though speculations of anticipated maintenance and operation costs can be made if similar LID facilities exist nearby, exact knowledge of maintenance and operation costs for a particular facility or set of facilities on a given site can only be gained through direct observation and experience.

Nevertheless, two recent studies that sought to quantify the maintenance and operation needs of several stormwater management facilities in the Northeastern and Midwestern United States yielded some valuable data and principles worthy of mention.

The first study, by Houle et al, 2013, examined the maintenance demands and costs of seven stormwater management practices (two conventional and five LID) in New Hampshire over a period of four years. The facilities were constructed and maintained in a controlled environment, and included a vegetated swale, retention pond, dry pond, sand filter, gravel wetland, bioretention area and porous asphalt.

The second study, by Erickson et al, 2010[9], investigated stormwater management practice maintenance requirements and costs by surveying communities in Minnesota and Wisconsin. 28 Minnesota cities, 8 Wisconsin cities and 2 Wisconsin counties responded to the survey. These two studies provide the basis for the data and principles of operation and maintenance discussed in the following sections.

Reactive vs. Proactive Maintenance and Maintenance Complexity

Generally speaking, LID guides and reference manuals advise a prescriptive approach to facility maintenance. Certain parameters are defined for each typology that represent that typology's ideal working condition. It is then left to facility managers to continually observe and evaluate whether or not these parameters are being maintained. When ideal working parameters are violated, certain maintenance steps are prescribed. This could be referred to as a reactive approach – addressing maintenance issues as they arise. However, it is also possible to take a more proactive approach, which would involve activities more preventative, periodic and protective in nature.

This concept of reactive vs. proactive maintenance as well as the notion that there are grades of maintenance tasks varying in complexity and cost were explored in the New Hampshire study. The research revealed two key maintenance principles[4].

The first principle deals with reactive vs. proactive maintenance approaches. The New Hampshire study found that maintenance operations tend to be reactive in nature during a facility's establishment period. During this time, facility managers pass from having merely a superficial knowledge of a facility's needs to having more specific knowledge based on experience and observation. After this period, the maintenance approach typically shifts to being more proactive in nature. Now having greater knowledge of the specific needs and challenges a facility experiences, managers are better able to foresee and address issues before they arise. It was observed that proactive methods are usually less expensive and less time-consuming than reactive methods and that five out of the seven typologies studied required little to no reactive maintenance once knowledge and patterns of operation were established. The five typologies requiring minimal reactive maintenance included a vegetated swale, dry pond, sand filter, bioretention area and porous asphalt. The two requiring significant reactive maintenance included a retention pond and a gravel wetland.

The second principle, which concerns maintenance personnel, is that the number of maintenance hours required annually and the cost of those hours depends greatly upon the complexity of the work involved, which in turn, in some cases, depends on whether the work is proactive or reactive.

Overall, the two studies defined four levels of maintenance task complexity and defined them in the same way:

- **Minimal** – stormwater professional or consultant seldom needed
- **Simple** – stormwater professional or consultant occasionally needed
- **Moderate** – stormwater professional or consultant is needed about half the time
- **Complicated** – stormwater professional or consultant is always needed

How these complexity levels were found by the New Hampshire study to equate to dollars spent per hour is shown in Figure C.1.4:

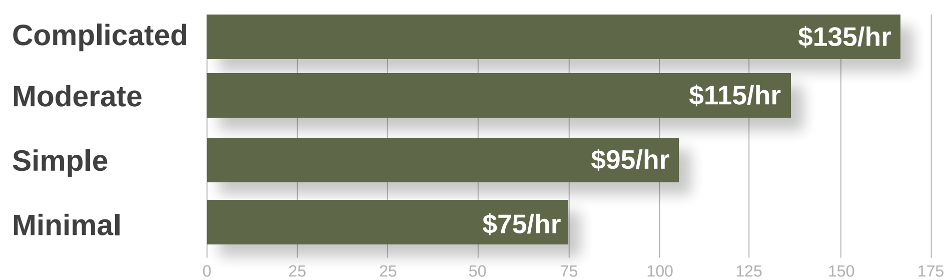

Figure C.1.4: Complexity Levels Found by the New Hampshire Study to Equate to Dollars Spent per Hour

The New Hampshire study highlights the usefulness of such a complexity ranking system in fashioning a more nuanced and therefore more accurate maintenance and operation budget as well as in appropriately allocating staff based on skill level.

The Midwestern study reported on the percentage of survey respondents who rated the maintenance complexity of certain stormwater treatment practices as minimal, simple, moderate or complex. The study's findings are listed in Table C.1.1 Survey respondents reported most maintenance tasks for all treatment practices to be minimal or simple.

Facility managers should obviously strive to situate themselves in a proactive mode of maintenance as quickly as possible after facility establishment, as this mode of operation most often involves only tasks of minimal to simple complexity.

Maintenance Frequency and Costs

Both studies offered valuable data concerning maintenance tasks, frequency and costs, including maintenance dollars spent per year, factors most frequently causing facility degradation and maintenance cost as a percentage of construction cost.

In Table C.1.2, findings from the New Hampshire study indicated that with some treatment practices, maintenance costs remain fairly constant from year to year, while with others, greater variation is possible. This is mostly due to certain treatment facilities requiring costlier maintenance tasks on only a biannual or less infrequent basis, meaning that in certain years, higher-paid consultants might need to be employed, replacement parts or materials might need to be purchased – possibly in large quantities, and/or regular maintenance personnel might be required to put in more hours.

Among factors affecting facility performance, several caused recurring significant impact among all treatment facility types.

Table C.1.3 shows these findings from the Midwestern study. Sediment buildup was the most frequent performance reducing factor across all facility types with the exception of filter strips. Litter, debris and invasive vegetation species were second and third, respectively. Table C.1.4 documents the approximate annual cost of sediment removal for each facility type – that factor being the most frequent cause for maintenance.

The Midwestern study also reported (in Table C.1.5) the general frequency with which inspection and maintenance had to occur and maintenance cost for each facility as a percentage of construction cost (Table C.1.6). Concerning inspection and maintenance frequency, most respondents reported that such activities were only required once or less than once per year for all facilities. Additionally, while maintenance costs as a percentage of construction cost did exceed projections, sometimes by a significant amount, it also fell far below projections in many cases.

Table C.1.1: **Complexity of maintenance activities**

Stormwater Treatment Practice	Number of Respondents	Maintenance Complexity (percent of responses)			
		Minimal	Simple	Moderate	Complex
Sand Filter	8	63	0	25	13
Infiltation Trench	18	33	44	11	11
Permeable Pavement	16	44	19	31	6
Rain Garden	22	41	32	9	18
Filter Strip	14	64	29	0	7

Minimal – stormwater professional or consultant is seldom needed.
Simple – stormwater professional or consultant is needed occasionally.
Moderate – stormwater professional or consultant is needed about half of the time.
Complicated – stormwater professional or consultant is always needed.

Source: Based on Erickson (2010)

Table C.1.2: Approximate annual maintenance cost in dollars per stormwater treatment practice for four years

Stormwater Treatment Practice	Year 1	Year 2	Year 3	Year 4
Vegetated Swale	3,000	2,250	2,000	2,000
Wet Pond	8,250	6,750	8,700	No data
Detention Pond	7,000	4,600	7,000	5,800
Sand Filter	7,500	7,000	No data	No data
Gravel Wetland	5,500	3,750	7,500	No data
Bioretention Area	5,600	4,900	3,000	3,000
Porous Asphalt	2,700	2,700	2,700	2,700

Source: Based on Houle (2013)

Table C.1.3: Percentage of respondents reporting listed factors as most frequently reducing performance of stormwater treatment practices

Stormwater Treatment Practice	Number of Respondents	Sediment Buildup	Litter & Debris	Pipe Clogging	Invasive Vegetation	Groundwater Level	Bank Erosion	Oil Spill	Structural Problems	Mechanical Problems
Sand Filter	10	50%	30%	10%	0%	0%	0%	10%	0%	0%
Infiltration Trench	39	36%	21%	10%	5%	13%	5%	3%	5%	3%
Permeable Pavement	9	67%	11%	11%	0%	0%	0%	11%	0%	0%
Rain Garden	27	33%	22%	7%	26%	7%	0%	4%	0%	0%
Filter Strip	19	21%	26%	5%	26%	5%	11%	0%	5%	0%

Source: Based on Erickson (2010)

Table C.1.4: Approximate annual cost of sediment removal for stormwater treatment practices in dollars per year

Stormwater Treatment Practice	Minimum	Median	Maximum
Sand Filter	300	700	1000
Trench	300	400	700
Permeable Pavement	400	1,700	3,000
Rain Garden	50	800	4,200
Filter Strip	100	400	4,000

Source: Based on Erickson (2010)

Maintenance Personnel and Volunteer Hours

As with annual maintenance costs, the New Hampshire study found maintenance hours per year to be fairly constant for some facilities while varying for others (Table C.1.7). This would again be attributable to the reality that some facility types require more involved or complex maintenance on a biannual or even less frequent basis, which typically means more personnel hours spent in certain years than in others. In Table C.1.8, respondents to the Midwestern study reported the maximum number of hours spent on maintenance per facility type. The data shows that facilities requiring vegetation management, such as weeding, plant replacement and litter removal typically require more personnel hours.

In conclusion, data from both studies, as well as some additional data on maintenance vs. capital cost and money spent on materials and contractors for the New Hampshire study, is synthesized in the two tables. It should be noted that in most cases, as shown in Tables C.1.9 and C.1.10, LID facilities turned out to be less expensive than conventional facilities. This bodes well for owners and facility managers considering implementation of LID and, though highly region specific, the data examined shows promise for similar savings in other regions as well.

Table C.1.5: Frequency of routine inspection and maintenance activities

Stormwater Treatment Practice	Number of Respondents	Less than once (percent)	Once per year (percent)	More than once (percent)
Sand Filter	9	67	33	0
Infiltration Trenches	19	21	68	11
Permeable Pavement	14	29	43	29
Rain Garden	22	23	41	36

Source: Based on Erickson (2010)

Table C.1.6: Expected and reported annual maintenance cost as a percent of total construction cost for several stormwater treatment practices

Stormwater Treatment Practice	Expected	Reported
Sand Filter	11%-13%	0.9%-9.5%
Infiltration Trench	5%-20%	5.1%-126%
Swales	5%-7%	0.7%-10.9%
Rain Garden	5%-7%	0.7%-10.9%

Source: Based on Erickson (2010)

Table C.1.7: Maintenance hours per year

Stormwater Treatment Practice	Year 1	Year 2	Year 3	Year 4
Vegetated Swale	30	25	20	20
Wet Pond	75	60	75	No data
Detention Pond	70	45	65	55
Sand Filter	75	65	No data	No data
Gravel Wetland	60	40	65	No data
Biorentention Area	60	50	35	35

Source: Based on Houle (2013)

Table C.1.8: Staff-hours spent on routine maintenance actions

Stormwater Treatment Practice	Number of Respondents	Maximum Hours	75th Percentile	Median	25th Percentile	Minimum Hours
Sand Filter	7	3	2	1	0.5	0.5
Infiltration Trench	17	60	2	1	0.5	0.5
Permeable Pavement	9	6	4	2	1	0.5
Rain Garden	13	80	16	1	1	0.5

Source: Based on Erickson (2010)

Maintenance and Operation of Student Proposals

In view of the possible implementation of one or both of the student proposals mentioned earlier in this guide, the following discussion and recommendations for their proper operation and maintenance is offered.

“Student Reach” would stretch along the Paseo, UTSA’s future primary axial promenade and would be comprised of a chain of independent rain gardens, each feeding into a bioswale running the length of the development, terminating in a final rain garden cluster and bioretention basin. The development would also include rainwater harvesting and storage systems integrated into the small open spaces between the new dorms along the Paseo as well as walkways and gathering spaces paved with permeable pavement.

“Canalillo” would occupy the proposed Central Quad on the south side of the UTSA campus created by a new library and new academic buildings. The new quad would be mostly filled by a cluster of rain gardens configured around an existing vegetated swale whose capacity and performance would be increased. Canalillo would also feature rainwater harvesting and storage system integrated into the façade systems of the five new buildings forming the perimeter of the Central Quad.

An important factor that would affect M&O costs for both proposals is the reality that they would most likely be implemented in phases. This would be most relevant to the notion of proactive vs. reactive maintenance – proactive generally being less costly and therefore the more desirable M&O pattern to assume. The main challenge that facilities managers face when trying to get into a proactive M&O pattern early in an LID project’s life is forecasting exactly what upkeep the facility will require over the course of a normal year.

Table C.1.9: **New Hampshire Study Summary**

Parameter	Vegetated Swale	Wet Pond	Dry Pond	Sand Filter	Gravel Wetland	Bioretention Area	Porous Asphalt
Original capital cost ($)	29,700	33,400	33,400	30,900	55,600	53,300	53,900
Inflated 2012 capital cost ($)	36,200	40,700	40,700	37,700	67,800	63,200	65,700
Maintenance-capital cost comparison (year)[a]	15.9	5	7	5.2	12.2	12.8	24.6
Personnel (h/year)	23.5	69.2	59	70.4	53.6	51.1	14.8
Personnel ($/year)	2,030	7,560	5,880	6,940	5,280	4,670	939
Materials ($/year)	247	272	272	272	272	272	0
Subcontractor cost ($/year)	0	0	0	0	0	0	1,730
Annual O&M cost ($/year)	2,280	7,830	6,150	7,210	5,550	4,940	2,670
Annual maintenance/capital cost (%)	6	19	15	19	8	8	4

This data was compiled from observations over a 4 year period of the above listed stormwater control measures (SCMs). The SCMs were constructed by the University of New Hampshire Stormwater Center specifically for testing purposes. The SCMs were of uniform size and shared a common watershed. Runoff from the watershed was equally divided among the SCMs.

Source: Houle (2013)

Table C.1.10: **Midwestern Study Summary**

Parameter	Sand Filter	Infiltration Trench	Permeable Pavement	Rain Garden	Filter Strip	Swales
Maintenance Complexity by Percentage of Respondents	Minimal: 63 Simple: 0 Moderate: 25 Complex: 13	Minimal: 33 Simple: 44 Moderate: 11 Complex: 11	Minimal: 44 Simple: 19 Moderate: 31 Complex: 6	Minimal: 41 Simple: 32 Moderate: 9 Complex: 18	Minimal: 64 Simple: 29 Moderate: 0 Complex: 7	No data
Top Three Performance Reducing Factors by Percentage of Respondents	Sediment buildup: 50 Litter & debris: 30 Pipe clogging: 10	Sediment buildup: 36 Litter & debris: 21 Groundwater level: 13	Sediment buildup: 67 Litter & debris: 11 Pipe clogging: 11	Sediment buildup: 33 Invasive vegetation: 26 Litter & debris: 22	Litter & debris: 26 Invasive vegetation: 26 Sediment buildup: 21	No data
Approximate Annual Sediment Removal Cost ($)	Minimum: 300 Median: 700 Maximum: 100	Minimum: 300 Median: 400 Maximum: 700	Minimum: 400 Median: 1,700 Maximum: 3,000	Minimum: 50 Median: 800 Maximum: 4,200	Minimum: 100 Median: 400 Maximum: 4,000	No data
Annual Maintenance Cost as % of Construction Cost	Expected: 11-13 Reported: 0.9-9.5	Expected: 5-20 Reported: 5.1-126	No data	Expected: 5-7 Reported: 0.7-10.9	Expected: 320 / acre maintained	Expected: 5-7 Reported: 0.7-10.9
Annual Inspection and Maintenance Frequency by Percentage of Respondents	Less than once: 67 Once: 33 More than once: 0	Less than once: 21 Once: 68 More than once: 11	Less than once: 29 Once: 43 More than once: 29	Less than once: 23 Once: 41 More than once: 36	Less than once: 54 Once: 31 More than once: 15	No data
Maintenance Staff Hours per Year	Maximum hours: 3 75th percentile: 2 Median hours: 1 25th percentile: 0.5 Minimum hours: 0.5	Maximum hours: 60 75th percentile: 2 Median hours: 1 25th percentile: 0.5 Minimum hours: 0.5	Maximum hours: 6 75th percentile: 4 Median hours: 2 25th percentile: 1 Minimum hours: 0.5	Maximum hours: 80 75th percentile: 16 Median hours: 1 25th percentile: 1 Minimum hours: 0.5	Maximum hours: 30 75th percentile: 1.75 Median hours: 1 25th percentile: 0.5 Minimum hours: 0.5	No data

This data was compiled from survey responses from 28 Minnesota cities, 8 Wisconsin cities and 2 Wisconsin counties maintaining the above listed stormwater control measures.

Source: Erickson (2010)

However, implementing a larger LID project in phases over the course of several years will allow facility managers to build familiarity and expertise during the early phases, which is estimated to be approximately a year in length, so that by the time the whole system comes online, when M&O demands will be at their highest, enough experience will have been gained to enable a mostly if not entirely proactive approach. This would be a notable advantage for the university to consider as it weighs the costs and benefits of LID, as they relate to M&O.

While "Student Reach" would involve a larger development area than "Canalillo," the two proposals implement basically the same LID typologies, and would therefore require similar maintenance tasks and schedules, if not budgets - due to the size differential. Also, as discussed earlier in this section, taking a proactive as opposed to a reactive approach to their operation and maintenance would be key in keeping M&O costs low. To that end, there are certain M&O concerns that will almost certainly be issues given the LID typologies employed by the proposals. These concerns are detailed in the following tables, where recommended design features and M&O tasks that are preemptive in nature are also given.

For rain gardens, vegetated swales and bioswales, which make up most of the new developments proposed by Student Reach and Canalillo, research has shown that sediment accumulation, litter and debris accumulation and invasive vegetation are the biggest M&O concerns. The presence of these unwanted elements can significantly reduce the performance of the proposed LID systems. Knowing this, in the event that either or both proposals become reality, great care should be taken during their design phases to ensure that sediment interception measures are incorporated. Also, inspection and maintenance activities should focus on identifying and quickly addressing sediment, debris and invasive vegetation accumulation.

Notes

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2 U. S. Environmental Protection Agency -EPA (2007). Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. Washington, D.C.: EPA Nonpoint Source Control Branch.

3 Center for Neighborhood Technology. (2010). The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits. Chicago, IL: CNT.

4 Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. J. (2013). Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Mana gement. Journal of Environmental Engineering, 139(7).

5 Bishop, K., & Dorman, T. M. (2015). Overcoming the Barriers: Helping Agencies Get Comfortable with O&M of LID Stormwater Control Measures. PowerPoint Presentation, with permission from San Antonio River Authority.

6 Carlson, C., Barreteau, O., Kirshen, P., & Foltz, K. (2015). Storm Water Management as a Public Good Provision Problem: Survey to Understand Perspectives of Low-Impact Development for Urban Storm Water Management Practices under Climate Change. Journal of Water Resources Planning and Management, 141(6).

7 University Sustainability Council: University of Maryland. (2014). Sustainable Water Use and Watershed. Technical Report, College Park, MD: University of Maryland.

8 Barrett, M. E. (2005). Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices. Report prepared for Texas Commission on Environmental Quality. Austin, Texas: Center for Research in Water Resources, the University of Texas at Austin.

9 Erickson, A. J., Gulliver, J. S., Kang, J.-H., Weiss, P. T., & Wilson, B. C. (2010, December). Maintenance for Stormwater Treatment Practices. University Council on Water Resources Journal of Contemporary Water Research & Education(146), 75-82.

C.2 Sustainability & Incentives

Introduction to Rating Systems & Incentive Programs

In consideration of what benefits LID might afford to projects seeking special designation or recognition through sustainability rating systems, several pertinent rating systems were assessed to determine the potential of LID to positively affect the scoring of a project involving LID within each rating system. Rating systems assessed include the Sustainability Tracking, Assessment & Rating System (STARS)[1] for Campuses, LEED for Neighborhood Development (LEED-ND)[2] , and the Envision Rating System for Sustainable Infrastructure . While each of the three rating systems has increasing sustainability as an overarching goal, each system focuses on a different target project type or context. STARS has more of an organizational focus, seeking to improve sustainable practices and engender cultures of sustainability on college and university campuses. LEED-ND focuses on the development of sustainable neighborhoods from design through to construction and occupation. Finally, the Envision[3] rating system focuses on the design and implementation of sustainable infrastructure regardless of context. In addition to sustainability rating systems, two pertinent economic incentive programs were considered. The City of San Antonio offers

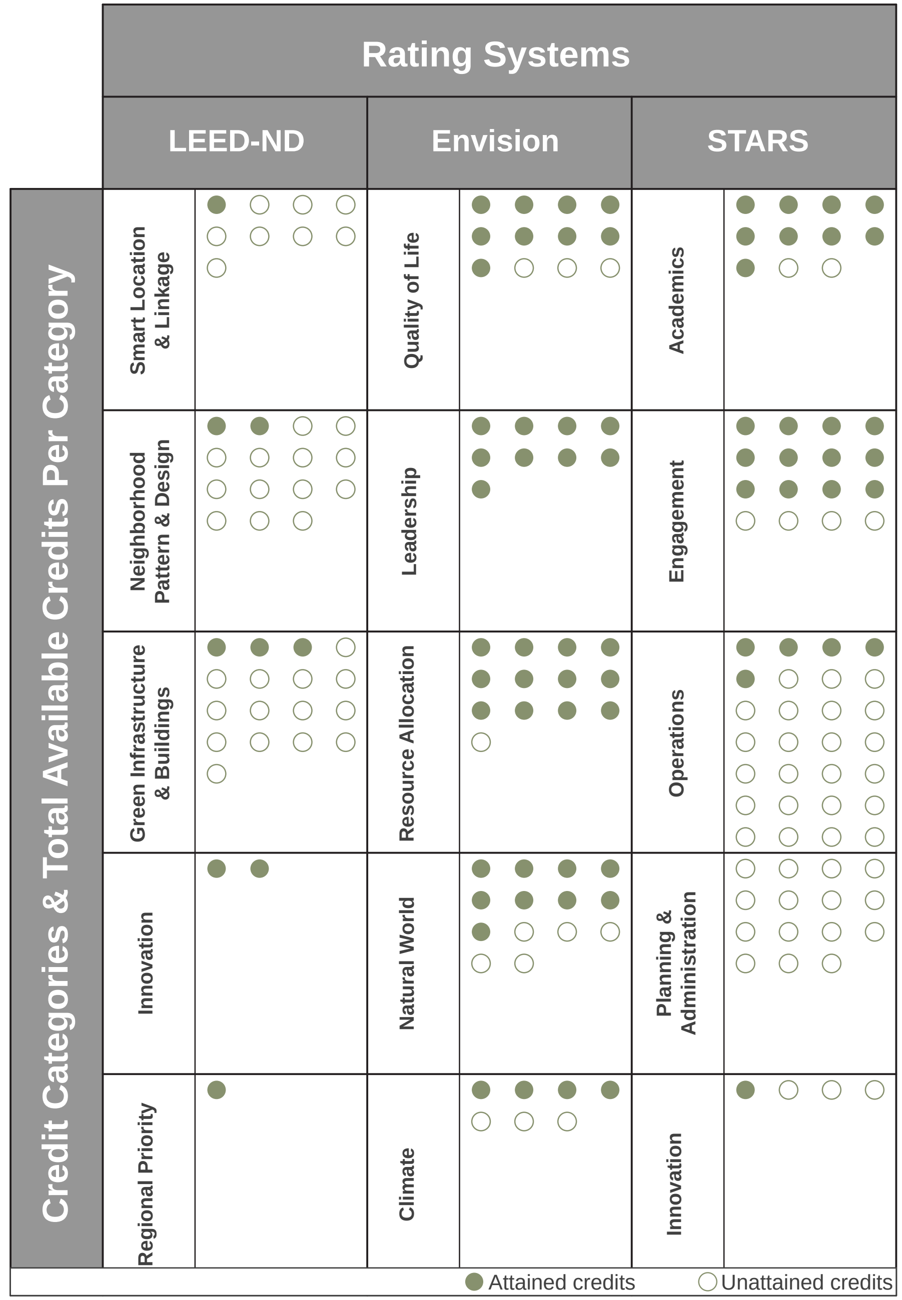

Figure C.2.1: LID Potential Credits Attained from Different Readings Systems (LEED-ND and STARS, potential credits and total credit system).

site element offsets and credits to projects incorporating LID practices providing certain levels of runoff quality and quantity control as well as storm water fee reductions[4]. The San Antonio River Authority has in recent years offered a rebate program[5] to LID projects meeting certain minimum performance levels in Bexar and some surrounding counties. Taken together, the rating systems and incentive programs surveyed as shown in Figure C.2.1 demonstrate the civic and economic benefits LID can yield.

STARS

STARS[1] stands for Sustainability Tracking, Assessment & Rating System (Tables C.2.1 and C.2.2). It provides a framework for colleges and universities to track, measure and report on their sustainability progress in the categories of Academics, Engagement, Operations, and Planning & Administration. STARS was developed by the Association for the Advancement of Sustainability in Higher Education in collaboration with numerous students, staff, faculty and administrators to provide campuses with the ability to self-assess their progress toward a more sustainable future. Similarly to other rating systems, STARS offers points for achievements in the previously mentioned categories and awards four designations correlating to levels of points earned: Bronze (25 points minimum), Silver (45 points minimum), Gold (65 points minimum) and Platinum (85 points minimum).

Table C.2.1: STARS Credit System (part 1 of 2)

Category	Sub-Category	Credit	Available Points	Notes
Academics (AC)	Curriculum	AC 1: Academic Courses	14	LID would contribute to the content of a sustainability course or courses
		AC 2: Learning Outcomes	8	LID would contribute to the learning outcome of sustainability
		AC 3: Undergraduate Program	3	LID would contribute to the coursework of an undergraduate program in sustainability
		AC 4: Graduate Program	3	LID would contribute to the content of a sustainability focused program, minor, concentration or certificate
		AC 5: Immersive Experience	2	LID would contribute to an immersive study program
		AC 7: Incentives for Developing Courses	2	LID would incentivize cross-discipline course development on the topic of sustainability
		AC 8: Campus as a Living Laboratory	4	LID would constitute an on-campus living laboratory
	Research	AC 9: Academic Research	12	LID would contribute to sustainability research
		AC 10: Support for Research	4	LID would encourage and support sustainability research through one or more of the prescribed means
Engagement (EN)	Campus Engagement	EN 1: Student Educators Program	4	LID would contribute to content of a peer-to-peer outreach and education program in sustainability
		EN 2: Student Orientation	2	LID would contribute to a student orientation program
		EN 3: Student Life	2	LID would contribute to a student life program
		EN 4: Outreach Materials and Publications	2	LID would contribute to content of outreach materials on sustainability
		EN 5: Outreach Campaign	4	LID would contribute to the content of an outreach program in sustainability to students and university employees

Source: Sustainability Tracking Assessment and Rating System (2016)

Table C.2.2: STARS Credit System (part 2 of 2)

Engagement (EN)	Campus Engagement	EN 6: Employee Educators Progam	3	LID would contribute to the content of a peer-to-peer outreach and education program in sustainability
		EN 7: Employee Orientation	1	LID would contribute to a student orientation program
		EN 8: Staff Professional Development	2	LID would contribute to the content of a staff professional development program in sustainability
	Public Engagement	EN 9: Community Partnerships	3	LID would contribute to content of partnership programs with the surrounding community that promote sustainability
		EN 10: Inter-Campus Collaboration	2	LID would form the basis for inter-campus collaboration efforts in sustainability
		EN 11: Continuing Education	5	LID would contribute to the content of continuing education courses and certificate and degree programs
		EN 12: Community Service	5	LID would offer community service opportunities to students
Operations (OP)	Buildings	OP 3: Building Operations and Maintenance	4	LID (specifically rainwater harvesting) would contribute to sustainable building operation and maintenance
		OP 4: Building Design and Construction	3	LID (specifically rainwater harvesting) would contribute to sustainable building design criteria
	Energy	OP 8: Building Energy Consumption	6	LID (specifically green roofing) would contribute to reduced energy consumption
	Grounds	OP 10: Landscape Management	2	LID would contribute to sustanable landscape management plans
	Water	OP 27: Rainwater Management	2	LID would contribute to sustainable rainwater management
Innovation (IN)	Innovation	IN 1-4: Innovation	4	Implementation of an LID pilot program would qualify as an innovative practice

Source: Sustainability Tracking Assessment and Rating System (2016)

LEED (ND)

LEED for Neighborhood Development (LEED-ND)[2] is a rating system for evaluating and rewarding exemplary neighborhood development practices (Table C.2.3). It was developed through a collaborative effort between The U.S. Green Building Council (USGBC), the Congress for the New Urbanism (CNU), and the Natural Resources Defense Council (NRDC) and operates within the framework of the LEED Green Building Rating System. LEED-ND emphasizes thoughtful site selection, design and construction practices that integrate buildings, infrastructure and the surrounding context into a sustainable, systemic whole.

Whereas other LEED rating systems feature five environmental categories with a focus on energy and potable water consumption, LEED-ND features only three: Smart Location and Linkage, Neighborhood Pattern and Design, and Green Infrastructure and Buildings. There is also an Innovation and Design Process category that addresses issues of sustainable design and construction not covered by the three core categories. Each LEED-ND category is comprised of a range of credits pertinent to that category, and each credit offers a certain number of points if satisfied. Certification levels include: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points).

Table C.2.3: LEED-ND Credit System

Category	Credit	Available Points	Notes
Smart Location and Linkage	Credit 8: Restoration of Habitat or Wetlands and Water Bodies	1	LID would constitute habitat restoration or water body protection
Neighborhood Pattern and Design	Credit 10: Access to Recreational Facilities	1	LID would provide recreational opportunities
	Credit 12: Community Outreach and Involvement	1-2	LID would provide community outreach and involvement opportunities
Green Infrastructure and Buildings	Credit 4: Water-Efficient Landscaping	1	LID would qualify as water-efficient landscaping
	Credit 8: Stormwater Management	1-4	LID would qualify as sustainable stormwater management
	Credit 9: Heat Island Reduction	1-4	LID would provide heat island reduction
Regional Priority Credit	Credit 1: Regional Priority	1-4	An unlined LID pilot project would demonstrate regional priority efforts

Source: U.S. Green Building Council (2016)

Envision

The Envision rating system[3] serves as an evaluation and planning tool for infrastructure projects (Tables C.2.4 and C.2.5). It assesses individual project performance as well as how effectively projects contribute to the efficiency and long-term sustainability of the communities in which they are located. Envision was created through a collaborative venture between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure (ISI), which is a non-profit education and research organization that was founded by the American Public Works Association, the American Council of Engineering Companies, and the American Society of Civil Engineers.

Envision is applicable as a rating system to all types of civil infrastructure including roads, bridges, pipelines, railways, airports, dams, levees, landfills, water treatment systems, and other components that make up civil works. It is comprised of a family of tools encompassing all phases of a project's life cycle including: planning, design, construction, operation, and deconstruction. Envision is made up of five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk, and each category is further subdivided into an overall total of sixty sustainability criteria or 'credits.' Infrastructure projects are rated through a performance assessment that awards points for a maximum of five achievement levels within each credit. Additional points can be earned for innovated performance.

Table C.2.4: Envision Credit System (part 1 of 2)

Category		Credit	Available Points	Notes
Quality of Life	Purpose	1.1 Improve Community Quality of Life	2-25	LID would improve community quality of life through stakeholder involvement, infrastructure enhancement and community awareness, knowledge and pride
		1.2 Stimulate Sustainable Growth and Development	1-16	Lid would enhance natural and built assets within the community, stimulating new growth and development
		1.3 Develop Local Skills and Capabilities	1-15	LID would contribute to the education, training and use of local workers as well as to community employment and education, thereby increasing community competitiveness
	Community	2.1 Enhance Public Health and Safety	2-16	LID would involve a process of ensuring and exceeding minimum standards of community health and safety
		2.2 Minimize Noise and Vibration	1-11	LID would involve provisions for minimizing noise and vibration during construction as well as to reduce ambient noise in the area after construction
	Wellbeing	3.1 Improve Historic and Cultural Resources	1-16	LID would contribute to the preservation and/or enhancement of historic and cultural resources within a community through restoration of lost features and education
		3.2 Preserve Views and Local Character	1-14	LID would contribute the protection or restoration of local view and character through landscape enhancement
		3.3 Enhance Public Space	1-13	LID would contribute to the creation and/or protection and enhancement of local public spaces
	Innovation	0.0 Innovate or Exceed Credit Requirements	8	LID would constitute implementation of innovative methods, technologies or processes that exceed industry norms
Leadership	Collaboration	1.1 Provide Effective Leadership and Commitment	2-17	LID design and construction team would provide leadership and commitment with sustainability and the promotion of sustainable practices in the community as a core project value
		1.2 Establish a Sustainability Management System	1-14	LID design and construction team would incorporate a robust sustainability management system to be operational during project implementation, ensuring the actualization of project sustainability goals
		1.3 Foster Collaboration and Teamwork	1-15	LID multidisciplinary project team would work together to maximize the projects sustainability potential
		1.4 Provide for Stakeholder Involvement	1-14	LID project team would establish a process for ensuring public and key stakeholder engagement
	Management	2.2 Improve Infrastructure Integration	1-16	LID would integrate with or provide better integration among a range of existing infrastructures as part of a comprehensive strategic plan for the area
	Planning	3.1 Plan for Long-term Monitoring and Maintenance	1-10	LID would incorporate a comprehensive monitoring and maintenance plan to ensure ongoing success and effectiveness of implemented sustainability measures
		3.2 Address Conflicting Regulations and Policies	1-8	LID pilot projects would provide basis for change in current policy against unlined LID systems over aquifer recharge zone
		3.3 Extend Useful Life	1-12	LID project team would be afforded latitude to explore and incorporate means of improving project durability, flexibility, resilience and overall usefulness
	Innovation	0.0 Innovate or Exceed Credit Requirements	6	LID would constitute implementation of innovative methods, technologies or processes that exceed industry norms

Source: Institute for Sustainable Infrastructure (2016)

Part A

Part B

Part C

Table C.2.5: Envision Credit System (part 2 of 2)

Resource Allocation	Materials	1.1 Reduce Net Embodied Energy	2-18	LID project team would work to minimize embodied energy of project
		1.2 Support Sustainable Procurement Practices	2-9	LID project team would establish a robust program for specifying supplier and material standards
		1.3 Use Recycled Materials	2-14	LID project team would ensure a certain percentage of materials on the project are from reclaimed or recycled materials
		1.4 Use Regional Materials	3-10	LID project team would ensure a certain percentage of materials on the project are from sourced from within a certain distance from the project
		1.5 Divert Waste from Landfills	3-11	LID project team would prepare an operations waste plan to divert a certain percentage of construction and operations waste from landfills
		1.6 Reduce Excavated Materials Taken Off Site	2-6	LID project would reuse a certain percentage of excavated materials on site
		1.7 Provide for Deconstruction and Recycling	1-12	LID project would be designed to ensure a certain percentage of deconstruction and recycling or recycling could occur at the end of project life
	Energy	2.1 Reduce Energy Consumption	3-18	LID project would be designed to reduce operation and maintenance energy consumption by a certain percentage
	Water	3.1 Protect Fresh Water Availability	2-21	LID project would replenish quantity and quality of fresh water surface and groundwater supplies to a predetermined level
		3.2 Reduce Potable Water Consumption	4-21	LID would reduce potable water consumption by using captured stormwater to fulfill irrigation or other needs
		3.3 Monitor Water Systems	1-11	LID would incorporate monitoring systems to ensure optimal operation of water treatment systems
	Innova-tion	0.0 Innovate or Exceed Credit Requirements	8	LID would constitute implementation of innovative methods, technologies or processes that exceed industry norms
Natural World	Siting	1.5 Preserve Floodplain Functions	2-14	LID project would maintain infiltration and water quality while also preserving floodplain functions
		1.6 Avoid Unsuitable Development on Steep Slopes	1-6	LID project would avoid siting on steep slopes
	Land & Water	2.1 Manage Stormwater	4-21	LID project would manage stormwater and protect hydrological systems
		2.2 Reduce Pesticide and Fertilizer Impacts	1-9	LID project would incorporate runoff controls to minimize ground and surface water contamination as well as minimize the need for pesticides and fertilizers
		2.3 Prevent Surface and Groundwater Contamination	1-18	LID project would incorporate on-site monitoring of water quality and provide runoff treatment to prevent surface and groundwater contamination
	Biodiversity	3.1 Preserve Species Biodiversity	2-16	LID project would improve and/or restore species habitat
		3.2 Control Invasive Species	5-11	LID project would avoid introduction of non-native, potentially harmful plant species
		3.4 Maintain Wetland and Surface Water Functions	3-19	LID project would enhance one or a range of ecosystem functions - especially the enhancement of water quality
	Innovation	0.0 Innovate or Exceed Credit Requirements	9	LID would constitute implementation of innovative methods, technologies or processes that exceed industry norms
Climate & Risk	Emission	1.2 Reduce Air Pollutant Emissions	2-12	LID project would improve air quality levels to higher than pre-development levels
	Resilience	2.2 Avoid Traps and Vulnerabilities	2-20	LID project team would work to minimize the potential for exorbitant and unexpected maintenance and operation costs
		2.5 Manage Heat Island Effects	1-6	LID project would mitigate heat island effects
	Innovation	0.0 Innovate or Exceed Credit Requirements	5	LID would constitute implementation of innovative methods, technologies or processes that exceed industry norms

Source: Institute for Sustainable Infrastructure (2016)

City of San Antonio Incentive Program

The City of San Antonio offers two kinds of economic incentives[4] to encourage the implementation of LID stormwater management practices (Table C.2.6). These incentives are detailed in section 35-210 of the City's Unified Development Code. The first incentive type offers credits or offsets towards other typically required site components when LID is implemented on a project. For example, the required area of tree canopy cover may be offset by 1.5 times the area of a vegetated LID treatment area where tree preservation is used in conjunction with the LID practice. The second type of incentive offers stormwater fee reductions to projects implementing LID. Fees can be reduced by as much as 30% if 100% of newly generated site runoff is treated by the LID system.

Table C.2.6: CoSA Incentive Program

Credit & Offset Incentives					
Credit/Offset	**Multiplier**	**Notes**			
Stream Buffer or Stream Restoration to Parkland Acre	1.5	LID would contribute to a stream buffer zone where pursued and applicable			
Stream Restoration to Tree Canopy	1.25	LID would contribute to stream restorations where pursued and applicable			
Linear Park to Parkland Acre	1.5	LID would contribute to linear park space where pursued and applicable			
LID BMP to Tree Canopy	1.5	LID would contribute to reduction in required tree canopy			
LID BMP to Streetscape Tree	1	LID would contribute to reduction in required streetscaping			
LID BMP Landscape Elective Credit	Up to 25 points	LID would contribute to accrual of landscape elective credits			
LID BMP Drainage Area to Parkland Acre	1.5	LID drainage areas would contribute to parkland acreage requirement			
Density Bonus	10%	LID would increase allowed development density			
Fee Reduction Incentive					
Percent of Water Quality Volume Managed	60%	70%	80%	90%	100%
Storm Water Fee in Lieu of Discount	5%	10%	20%	25%	30%

Source: City of San Antonio (2016)

SARA Rebate Program

Starting on 2016, the San Antonio River Authority offers a rebate program[5] in Bexar, Wilson, Karnes and Goliad counties for new and retrofit projects implementing LID practices in commercial, multi-use residential and civic projects (Table C.2.7). Projects must be designed and executed in accordance with the San Antonio River Basin Low Impact Development Technical Guidance Manual to apply. A two-step verification process is involved that ensures projects satisfy all requirements in both the design and completed stages. Minimum and maximum rebate limits per project are $15,000 and $100,000 respectively. Rebate awards are calculated based upon unit volume and unit area treated.

Table C.2.7: **SARA Rebate Program**

Eligible Project Types	Rebate Range	Notes
Commercial	$15,000 - $100,000	Projects must be located in Bexar, Wilson, Karnes or Goliad county and must be designed and constructed in accordance with the San Antonio River Basin Low Impact Development Technical Guidance Manual to apply.
Multi -Use Residential		
Civic / Public		
Rebate Calculation Formula		
Rebate = (Treated Volume/Target Volume) x Unit Volume Cost x Treated Volume (Treated Volume/Target Volume) = Percentage of target volume from 1.5" storm Unit Volume Cost = Estimate based on developer input		

Source: San Antonio River Authority (2016)

Notes

1 Higher Education Associations Sustainability Consortium- HEASC (2006). The Sustainability Tracking, Assessment & Rating System. Accessed on 4/10/2016: http://heasc.aashe.org/

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Appendix C-
SCM & SSM Data & Measures

Site Selection Method and discussion

The purpose of site selection in this report is to establish an evidence-based method for shortlisting existing Best Management Practices (BMPs) sites that will be eligible for redevelopment through Low Impact Development (LID) practices. Selection method also aims to be used and repeated for future site selection in residential, business, or mixed-use areas. For this report, the following selection criteria was developed through collaboration with our funding partners (it is anticipated that other criteria may be used in future applications of this selection process):

- Increase stormwater quality, and reduce runoff volume through infiltration
- Maximize exposure to raise users' awareness about LID benefits
- Re-naturalize the sites to emulate pre-development and enhance outdoor activities
- Design an efficient and sustainable maintenance and operation
- Assure an ease of maintenance • Enhance sustainability of site design and use of native plants and xeriscaping practices
- Integrate wayfinding elements for the site and its vicinity

Method: A five-step Geodesign Process

Method of site selection was demonstrated in five consecutive steps, explained below, ranging from the regional (macro) to local (micro) scale, and concluding with design principles for Low Impact Development (LID) practices:

Step I (Regional Analysis)

Definition and purpose: The regional scale is the portion of Bexar County, Texas located on the Edwards Aquifer Recharge Zone (EARZ). Within this geographic boundary, existing BMPs were identified for the analysis. The purpose of the analysis is to shortlist existing BMPs based on established criteria by the funding agencies and research team.

Method and Imwportant Considerations: Using Geographic Information system (GIS), a preliminary assessment of BMPs of the San Antonio Water System (SAWS) Corporate Records was performed and no comprehensive analysis of all the following records was conducted due to incoherence of BMP records in the three data sets. BMPs were categorized by location (outside/inside Neighborhood Associations- NA) and compliance status (compliant/ noncompliant). However, no selection from each category was performed due to the interest of this report in selecting the five basins in the University of Texas at San Antonio (UTSA) campus.

Data available for Regional Scale:

1. Online records of Texas Central Registry Query, obtained on March 28, 2016, showing 3,029 records.
2. Edwards Aquifer Authority (EAA) inventory of Bexar County's BMPs registration showing a little over 400 records
3. Inspection records of Stormwater Quality Basins, obtained from San Antonio Water System Corporate Records for the period of January-to-December, 2015.

Discussion: For future regional analysis, the three aforementioned records should be cross-checked, and analyzed using attributes such as land use pattern, location, density, and population or businesses served by the existing BMPs.

Also, prioritizing BMPs for redevelopment at this scale of analysis should take into account a structured-feedback of involved policy makers and stakeholders, which may have a different results than focusing only on the UTSA campus BMPs.

Step II (Neighborhood Analysis)

Definition and purpose: The neighborhood scale is defined as the areas, including all parcels, and land uses surrounding the campus zone, known as the Central Campus of the UTSA main Campus. The purpose of the analysis is to shortlist existing BMPs based on established criteria by the funding agencies and research team.

Method and Important Considerations: After a thorough review of scholarly publications, we created an inventory of attributes associated with three levels of analysis: neighborhood, site capability, and site suitability. Using weighted overlay method, a structured-form was utilized to quantify the importance of each attribute through soliciting for input of the staff members of SARA, EAA, and GEAA. Each member assigned a score between one and three (least important to most important). The average score for each attribute was calculated using an equal weight for each participant input. Three attributes that scored (2.10) or higher were selected for the analysis. Attributes include land use classifications: Single Family, Multi-family, and Mixed Use.

Using spatial analysis tools, the campus basins were compared based on their proximity to each of the three land use types (mixed use, multi-family residential, and single family residential). Basins were then ranked on a scale of 1-5 (worst to best), considering that the shorter the distance the higher the score a basin receives. Three water quality basins (WQBs): B, C, and D received high score.

Data available for Neighborhood Analysis:

1. Land use map, using Bexar County Appraisal District GIS parcel map.
2. Stakeholder Weighted Overlay using feedback from stakeholders.

Discussion: Due to the limited number of basins examined in this report, we opted not to omit any basin at this stage of analysis and to advance the five basins to the next stage of analysis, the Site Capability Model (SCM). It is advised though in the future applications of this method on other sites or neighborhoods to select only the BMPs receiving high combined score of the three attributes (Single Family, Multi-family, and Mixed Use) at this stage to be further examined using SCM. It is also worth noting that future application of the weighted overlay method may yield different attributes, which will depend on the nature of the project and the stakeholder input.

Step III (Site Capability Model -SCM)

Definition and purpose: Using data from published work on LID site requirements, three attributes were defined as primary y components of any LID: slope, floodplain, and exposure. Using GIS spatial analysis, the three attributes were integrated into one model, a ranking system was created for the five existing BMPs, and a Site Capability Model (SCM) was constructed.

Method and Important Considerations: The drainage areas of the five BMPs were analyzed for their capability to meet the site requirements of LID practices. Three attributes pertaining to requirements were identified to establish a SCM:

1. Slope and Floodplain which are related to the criterion: “Increase stormwater quantity”.
2. Exposure of BMP/and nearby sites through users’ direct visibility which are related to two criteria: ‘Maximize exposure to raise users’ awareness about LID benefits, and enhance outdoor activities”.
3. Using three groups of LID slope requirement, as well as measures of exposure and distance to floodplain, each basin was ranked on a scale of 1-5 (worst to best), and the basin’s total score was calculated.

Data available for Site Capability Model (SCM):

- CAD files, obtained by permission from the UTSA Office of Facilities.
- ArcGIS data (both shapefiles and dbf files), obtained by permission from the UTSA Office of Facilities
- Campus existing water basins from the UTSA Office of Facilities.
- Campus proposed locations of water basins, approved by Texas
- Commission on environmental Quality (TCEQ), and obtained from the UTSA Office of Facilities
- Aerial views of the campus (obtained through a free-access to google earth).
- Slope using LIDAR data, obtained by permission from the UTSA Office of Facilities.

Discussion: SCM compares the five basinslocated in the UTSA main campus. Of the five basins, B and C received the highest score. No basin was omitted at this stage due to the low number of BMPs. Future application of this method may encompass more basins based on location, scope, and interest of stakeholders. It is advised to omit sites that receive a low score at this stage, and advance only those with high scores to the next step of analysis.

Step IV (Site Suitability Model -SSM)

Definition and purpose: Suitability analysis is a process for evaluating the suitability of a location or an area for a certain purpose. Suitability analysis combines a number of intersected factors including ecological, physical, biological, social, economic, or other criteria. SSM is created using a series of maps, each represent one or more factors, and altogether show the spatial distribution of the determined values of these factors in a graphical form.

Method and Important Considerations: For the SSM, additional attributes were analyzed to compare the five basins including several measures of site characteristics and pollutant loads. A multi-criteria ranking of the basins was created using standardized measures utilized in five scientific studies and, therefore, the following attributes are deemed to be key for accomplishing the purpose of this SSM:

a) **Site Characteristics** including: activity areas, high-traffic nodes of buses and pedestrians, primary zones, academic areas, and main passage. These attributes will help comply with the criterion of “Maximizing exposure to raise users’ awareness about LID benefits”.

- Data was collected using systematic observations of variables such as activity, accessibility, and circulation/flow at entry points of the UTSA main campus
- Observations were conducted at two peak times (morning, 8:00 - 9:00 am; and afternoon, 4:00 - 5:00 pm) at 10-minute intervals for the activity types (sitting, walking, standing, or engaging in sport), and intensity (measured using the count of persons by in each type). Data log was then created. Activities were documents at major intersections and existing open spaces, geocoded to a GIS shapefile, and analyzed by type and intensity.

b) **Pollutant loads** inferred from various built environment features pertaining to nonpoint sources of contamination. Depicting, and quantifying the sources and locations of air and water pollutants will help comply with the criterion: “Increasing stormwater quality”. Measures were identified to rank BMP sites based on pollutant loads resulted from nonpoint sources of contamination for air and water

- Air contaminants include nitrogen oxide (NO), nitrogen dioxide (NO_2), particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$); and water contaminants include volatile organic compounds (VOCs) benzene, toluene, and m/p-xylene, total suspended solids (TSS) and total phosphorus (TP), total nitrate, and heavy metals (zinc, chrome, copper and cadmium).
- For air pollution, regression analyses were performed using two studies (Henderson et al., 2007) and (Oiamo et al., 2015) to determine the impact of numerous contributors at radii from 100 to 8000 meters (328.1 ft. to 26,246.7 ft.) to the listed airborne pollutants. Non-VOC pollutants were expected to be impacted by traffic activity, land use, and population. VOC levels were expected to be impacted by traffic activity and proximity to VOC-emitting facilities. The final land use regression (LUR) models were derived using stepwise linear regression or stepwise multiple ordinary least squares regression. In both studies, attributes that were insignificant to the explained variance in the coefficient of determination (R^2) were eliminated from the models, which is explained indetail in section B.3.
- For water pollution, the amount of pollutants in runoff is often measured in terms of load (mass/event) and/or concentration (mass/volume). Pollutant concentration varies significantly between events and during the course of an event. Therefore, numerous runoff samples need to be collected and combined (as either time-weighted or flow-weighted) to arrive at an Event Mean Concentration (EMC). Load can be determined by multiplying the EMC by the event’s total runoff volume. To predict an estimate of TSS and TP, we reviewed two studies: Florida Water Management District report (2002), and Brezonik and Stadelmann (2002).
- Based on Florida study, predicting storm event loads is subject to precipitation amount, precipitation intensity, and drainage area. Since the surface area of UTSA main campus is relatively small, precipitation amounts and intensities are assumed to be the same across all five BMPs. Therefore, the differentiating attribute is the drainage area for each BMP.
- We utilized Florida study of EMCs estimate by land use category and applied it to the main campus as follows::
    1. TSS Event Mean Concentration (EMC): Residential = 101 mg/L; Mixed = 67 mg/L
    2. TP Event Mean Concentration (EMC): Residential = 0.383 mg/L; Mixed = 0.263 mg/L
- A GIS analysis for the weighting of relevant land use portions of each BMP drainage area was conducted, and results and ranking of BMPs is included in Appendix-C. (Drainage areas were obtained from UTSA Office of Facilities).

- The study also concluded that the general order of pollutant loading from urban land uses (highest to lowest) was: 1) industrial and commercial, 2) highway, 3) Higher density residential, 4) Lower density residential, and 5) Open land.
- Site Suitability Model (SSM): A comprehensive assessment was conducted for the five BMPs using the attributes of site characteristics as well as air and water pollutants loads. A ranking system for each BMP using a scale of 1-5 (worst to best). A Total score for each BMP was calculated using an equal weighting system for all attributes. The sum of each BMP's suitability score was then calculated, as explained in detail in the next spreadsheets. WQB-B and WQB-D receieved higher scores, and therefore both basins were advanced for further design of LID practices.

Data available for Site Capability Model (SCM):

- GIS/CAD raw files were obtained from Alamo Area MPO, CoSA and UTSA Office of Facilities.
- Bexar County Appraisal District (BCAD) for Land use maps were updated by the authors,
- Population data; obtained from ACS (2010-2014 5-year estimates) of the U.S. Census Bureau
- Locations of VOC-emitting (in general) and toluene-emitting (specifically) facilities; locations and types of emissions were obtained from the U.S. Environmental Protection Agency.
- Primary data using on-site audit form was also acquired.

Discussion: The total score calculated for each BMP resulted in a higher total score for basins B and D, and therefore both basins were advanced for exploring design proposals of LID practices. Although, no scientific metrics for predicting the built environment attributes contributing to nitrate and heavy metals were available, research shows that heavy metals have been found in sites near railroads, ports and airports. Also, fertilizers, septic systems, animal feedlots, industrial waste, and food processing waste are sources of nitrate. The investigated campus sites are not near railroads, ports or airports, and therefore there is no evidence of increased level of heavy metal. The amount of fertilizers from the campus green spaces on the level of nitrate in groundwater will not have a significant effect on the selection process, since all basins are presumed to be surrounded by equal amount of green spaces. In future applications of this model on sites with clear disparity in green space areas, each green space should be calculated, analyzed, and a ranking system should be developed. All attributes contributing to heavy metals and nitrate should further be examined, mapped, quantified, analyzed, and included in the basin's total score and ranking.

Step V (LID Design Principles)

Definition and purpose: Step V is the concluding phase of assessing the selected BMPs, based on the previous models, to match the attributes with design requirements for specific LID practices. Due to the broad size of the catchment areas of the two selected BMPs (WQB-B and WQB-D), the proposed LID design will need to include a series of LID typologies in order to reach an efficient capacity of treatment, filtration, and infiltration.

Method and Important Considerations: The overall techniques proposed for each catchment area are based on the requirements that support LID features, which was used as a basis for developing the SCM's Group 1 & 2 attributes (see Box B.3.2.) including:

- Terracing was also used to adjust steep slopes following the requirements with a maximum of 15% of the area around the basin, and a maximum of 1:3 (V:H) for the riparian areas. We used the principles of LID treatment train when allocating LID practices (i.e. permeable pavement, curb cuts, green roofs, rain gardens, gabions, bioswales, and bioretention areas) throughout the sites.
- Two LID designs, Student Reach and Canalillo, are proposed for WQB-B (see Appendix A) and WQB-D (see Appendix B).

Data available for Site Capability Model (SCM):

- GIS/CAD files obtained from Alamo Area MPO, CoSA and UTSA Office of Facilities.

Discussion: Following the unlined practices recommendations, explained in section A.7 of this report, the proposed LID features will be lined, with the exception of the final destination of water to funnel to the EARZ (bioretention areas in WQB-B, and bioswale in WQB-D) which will be unlined. Although TCEQ require lined practices over EARZ, these two unlined LID practices are proposed as a pilot project to infiltrate water into the aquifer, and measure water quality before and after entering the recharge zone. Design features of these two pilot projects are planned to achieve water quality requirements of the TCEQ over the EARZ.

Audit Form: Data Log

	Node 1	Node 2	Node 3	Node 4	Node 5	open space A	open space B	open space C
AM	8:00-8:10am	NODE3 8:20-8:30 8:10-8:20am	NODE2 8:30-8:40 8:20-8:30am	8:50-9:00 8:30-8:40am	9:10-9:20 8:40-8:50am	8:50-9:00am	9:00-9:10 9:00-9:10am	8:40-8:50 9:00-9:20am
walking		160	103	40	24		7	120
standing								
sitting								
sports								
PM	5 4:00-4:10pm	4 4:10-4:20pm	3 4:20-4:30pm	2 4:30-4:40pm	1 4:40-4:50pm	4:50-5:00pm	5:00-5:10pm	5:10-5:20pm
walking								
standing								
sitting								
sports								

Slope Calculation by Drainage Area

	Percentage of all Cells					Explanation
Slope %†	WQB A	WQB B	WQB C	WQB D	WQB E	
< 1	13.6	12.0	7.8	10.2	7.2	The percentage of raster cells with a slope value of less than one
1 ≤ 5	71.4	67.7	68.2	64.7	58.9	The percentage of raster cells with a slope value of one to five (inclusive)
1 - 15	84.4	82.8	89.1	83.7	86.1	The percentage of raster cells with a slope value of one to fifteen (inclusive)
5 ≤ 15	19.0	20.9	30.0	25.3	35.8	The percentage of raster cells with a slope value of five to fifteen (inclusive)
> 15	2.0	5.1	3.2	6.1	6.7	The percentage of raster cells with a slope value greater than fifteen
Average*	8.8	11.2	9.1	15.9	25.9	The weighted average of all slope values within each drainage area
Range	0 - 55	0 - 91	0 - 52	0 - 223	0 - 331	The minimum and maximum slope values within the drainage area
Std Dev**	16.0	25.0	14.1	57.2	69.0	The standard deviation of unweighted mean of slope values

	Values used for calculations					Explanation
# cells = 0	8153	15729	5977	16386	12391	The number of raster cells with a slope value of zero
# cells = 1-5	42918	88694	52460	104156	100789	The number of raster cells with a slope value of one to five (inclusive)
# cells = 1-15	50710	108523	68555	134851	147370	The number of raster cells with a slope value of one to fifteen (inclusive)
# cells = 5-15	11431	27364	23119	40745	61367	The number of raster cells with a slope value of five to fifteen (inclusive)
# cells > 15	1209	6742	2427	9841	11447	The number of raster cells with a slope value greater than fifteen
total # cells	60072	130994	76959	161078	171208	The total number of raster cells in each drainage area

= Best 2 ranks (green)
= Middle 2 ranks (yellow)
= Worst rank (orange)

† Slope ranges of 1 to 5 and 5 to 15 have a slight overlap due to ArcMap's requirement for integer values in the construction of raster attribute tables.

* The weighted average is calculated using the percentage of cell counts for each slope value.
** This value indicates the variability of slope values within each drainage area; drainage areas of basins D and E have significantly higher variability than the other drainage areas.

BMPs Selection Model (Scenario-1: 5% slope and explanation)				
Analysis Phase	Parameter	Attributes	Measure	**Explanation** All calculations accomplished with GIS tools (ArcMap 10.3.1)
Neighborhood	Site Characteristics			
		Single Family Residential (SFR)	Centroid-to-point on nearest boundary	The shortest distance between each basin centroid to each of the land use types was measured.
		Mixed-use (MXD)	Centroid-to-point on nearest boundary	
		Multi-family Residential (MFR)	Centroid-to-point on nearest boundary	
		Neighborhood Preservation	Centroid-to-point on nearest boundary	The map for this measure was excluded due to the large distance of the NP area from the basins.
	Total Score			

Site Capability & Suitability Models

Analysis	Parameter	Attributes	Measure	**Explanation** All calculations accomplished with GIS tools (ArcMap 10.3.1)
Site Capability Model	Site Characteristics			
		Floodplain	Centroid to nearest edge of 100 yr.-floodplain	Distance between each basin centroid to nearest floodplain boundary was measured.
		Slope	1 - 5%	Percentage of cells with slope values from 1% to 5% (areas within this range are eligible for implementation of LID practices in Group 1 & Group 2 of the Site Capability Model, p. 99)
		Exposure: areas with direct visibility	Direct visibility (no obstruction): Binary scale (Yes=1/No=0); Visibility from centroid=C, Visibility from major path=P	Analyzed whether a basin was visible from primary open space centroids or from major paths.
	Total Site Characteristics			
Site Suitability Model	Site Characteristics			
		Proximity to areas with high levels of Activities (walking, standing, sitting, and sporting)	Centroid-to-centroid	Distances between basins and activity nodes and open spaces (with activity counts of at least 45) were averaged for basins D and E (basins A, B, and C were determined to be not relevant).
		Bus/shuttle stops	Centroid-to-point (of bus/shuttle stop)	Distance between each basin centroid to nearest bus/shuttle stop was measured.
		Pedestrian	Centroid to nearest pedestrian flowpoint	Distance between each basin centroid to the nearest pedestrian flowpoint was measured.
		Primary Zones	Centroid-to-centroid	Distances between basins and primary zones (Academic and Central Quad) were averaged for each basin.
		Main Passage (Paseo)**	Centroid-to-nearest points of path	Distance between each basin centroid to the nearest point on the Paseo was measured.
		Academic buildings*	Centroid-to-centroid	Distances between basins and academic buildings were averaged for each basin.
	Total Site Characteristics			
	Pollutants Loading			
		Nitrogen Oxide (NO)†	Relevant buffers: 100, 1000, 2500 meters (m)	The results of 'Road Length' and 'Vehicle Density' calculation methods (Henderson, et al., 2007) were averaged.
		Nitrogen Dioxide (NO_2)†, ‡	Relevant buffers: 100, 200, 600, 750, 1000, 1500, 2500 m	The results of 'Road Length', 'Vehicle Density' (Henderson, et al., 2007), and Oiamo, et al. (2015) calculation methods were averaged.
		Particulate Matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$)†	Relevant buffers: 100, 300, 750 m	The results of 'Road Length' and 'Vehicle Density' calculation methods (Henderson, et al., 2007) were averaged.
		Volatile Organic Compounds (VOCs) benzene, toluene, and m/p-xylene.†	Relevant buffers: 100, 300, 350, 600, 1500, 2500, 4000, 8000 m	The results of the calculations for benzene, toluene, and m/p-xylene (Oiamo, et al., 2015) were totaled.
		Total suspended solids (TSS)	Total basin drainage area (hectares)	"Precipitation amount, rainfall intensity, and **drainage area** (DA) were the most important variables to predict event loads" (Brezonik & Stadelmann, 2001). Therefore, DA was the only measurement used.
		Total Phosphorus (TP)	Total basin drainage area (hectares)	
	Total Pollutants Loading			
	Total Score			

*Based on the means of stakeholders input on a scale of 1-3 (least important -most important)
**Main Passage (Paseo) will be replaced by neighborhood main street/or commercial street
***Equal weight was cautiously assigned to all pollutants due to the limited data and standardized measures of the intensity of specific pollutants in the area around the University's main campus.
† Additional calculation details are available in tables **XX** and **XX**.
‡ Omitting the deductions for Distance from Highway (DH) and Distance from No_x Facilities (DNOxFac) has resulted in artificially high NO_2 measurements at all basins. Also noted is that the ranking of basin A would have been lower (1 or 2) had DH been considered.

BMPs Selection Model (Scenario-1: 5% slope and ranking)

Analysis Phase	Parameter	Attributes	Measure	Calculation					WQB Ranking: 1-5 (worst to best)				
				WQB-A	WQB-B	WQB-C	WQB-D	WQB-E	WQB-A	WQB-B	WQB-C	WQB-D	WQB-E
Neighborhood	Site Characteristics												
		Single Family Residential (SFR)	Centroid-to-point on nearest boundary	1,093	862	354	330	332	1	2	3	5	4
		Mixed-use (MXD)	Centroid-to-point on nearest boundary	3,293	864	348	3,283	4,540	2	4	5	2	1
		Multi-family Residential (MFR)	Centroid-to-point on nearest boundary	675	762	630	344	1,914	3	2	4	5	1
		Neighborhood Preservation	Centroid-to-point on nearest boundary	7,141	4,639	4,126	4,534	5,908	1	3	5	4	2
	Total Score								**7**	**11**	**17**	**16**	**8**

Site Capability & Suitability Models

Analysis	Parameter	Attributes	Measure	Calculation					WQB Ranking: 1-5 (worst to best)				
				WQB-A	WQB-B	WQB-C	WQB-D	WQB-E	WQB-A	WQB-B	WQB-C	WQB-D	WQB-E
Site Capability Model	Site Characteristics												
		Floodplain	Centroid to nearest edge of 100 yr-floodplain	0	131	0	876	272	1	2	1	5	3
		Slope	1 - 5%	71.4	67.7	68.2	64.7	58.9	5	3	4	2	1
		Exposure: areas with direct visibility	Direct visibility (no obstruction): Binary scale (Yes=1/No=0); Visibility from centroid=C, Visibility from major path=P	C=0 P=1	C=1 P=n/a	C=1 P=1	C=1 P=1	C=0 P=n/a	2	4	5	5	1
	Total Site Characteristics								11	10	13	8	4
Site Suitability Model	Site Characteristics												
		Proximity to areas with high levels of Activities (walking, standing, sitting, and sporting)	Centroid-to-centroid	n/a	n/a	n/a	2,052	1,997	2	2	1	4	5
		Bus/shuttle stops	Centroid-to-point (of bus/shuttle stop)	1,825	841	1,293	481	762	1	3	2	5	4
		Pedestrian	Centroid to nearest pedestrian flowpoint	521	861	549	316	472	3	1	2	5	4
		Primary Zones	Centroid-to-centroid	3,624	3,627	3,898	1,401	1,767	3	2	1	5	4
		Main Passage (Paseo)**	Centroid-to-nearest points of path	2,331	818	1,138	1,637	1,978	1	5	4	3	2
		Academic buildings*	Centroid-to-centroid	3,621	3,943	4,258	1,896	1,753	3	2	1	4	5
	Total Site Characteristics								13	15	11	26	24
	Pollutants Loading												
		Nitrogen Oxide (NO)†	Relevant buffers: 100, 1000, 2500 meters (m)	1.89348	1.89109	1.89251	1.89294	1.89283	1	5	4	2	3
		Nitrogen Dioxide (NO_2)†, ‡	Relevant buffers: 100, 200, 600, 750, 1000, 1500, 2500 m	165.066	198.807	209.441	194.076	173.643	5	2	1	3	4
		Particulate Matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$)†	Relevant buffers: 100, 300, 750 m	12.4036	5.248	8.87108	7.41354	12.5946	2	5	3	4	1
		Volatile Organic Compounds (VOCs) benzene, toluene, and m/p-xylene.†	Relevant buffers: 100, 300, 350, 600, 1500, 2500, 4000, 8000 m	41.9463	52.708	55.334	53.564	45.839	5	3	1	2	4
		Total suspended solids (TSS)	Total basin drainage area (hectares)	14.2983	30.4229	17.8844	37.4438	39.9626	5	3	4	2	1
		Total Phosphorus (TP)	Total basin drainage area (hectares)	14.2983	30.4229	17.8844	37.4438	39.9626	5	3	4	2	1
	Total Pollutants Loading								23	21	17	15	14
	Total Score								**44**	**45**	**38**	**53**	**43**

*Based on the means of stakeholders input on a scale of 1-3 (least important -most important)

**Main Passage (Paseo) will be replaced by neighborhood main street/or commercial street

***Equal weight was cautiously assigned to all pollutants due to the limited data and standardized measures of the intensity of specific pollutants in the area around the University's main campus.

† Additional calculation details are available in tables **XX** and **XX**.

‡ Omitting the deductions for Distance from Highway (DH) and Distance from No_x Facilities (DNOxFac) has resulted in artificially high NO_2 measurements at all basins. Also noted is that the ranking of basin A would have been lower (1 or 2) had DH been considered.

Part A

Part B

Part C

BMPs Selection Model (Scenario-5: 15% slope and explanation)

Analysis Phase	Parameter	Attributes	Measure	**Explanation** All calculations accomplished with GIS tools (ArcMap 10.3.1)
Neighborhood	Site Characteristics			
		Single Family Residential (SFR)	Centroid-to-point on nearest boundary	The shortest distance between each basin centroid to each of the land use types was measured.
		Mixed-use (MXD)	Centroid-to-point on nearest boundary	
		Multi-family Residential (MFR)	Centroid-to-point on nearest boundary	
		Neighborhood Preservation (NP)	Centroid-to-point on nearest boundary	The map for this measure was excluded due to the large distance of the NP area from the basins.
	Total Score			

Site Capability & Suitability Models

Analysis	Parameter	Attributes	Measure	**Explanation** All calculations accomplished with GIS tools (ArcMap 10.3.1)
Site Capability Model	Site Characteristics			
		Floodplain	Centroid to nearest edge of 100 yr.-floodplain	Distance between each basin centroid to nearest floodplain boundary was measured.
		Slope	5 - 15%	Percentage of cells with slope values from 1% to 5% (areas within this range are eligible for implementation of LID practices in Group 2 of the Site Capability Model, p. 99)
		Exposure: areas with direct visibility	Direct visibility (no obstruction): Binary scale (Yes=1/No=0); Visibility from centroid=C, Visibility from major path=P	Analyzed whether a basin was visible from primary open space centroids or from major paths.
	Total Site Characteristics			
Site Suitability Model	Site Characteristics			
		Proximity to areas with high levels of Activities (walking, standing, sitting, and sporting)	Centroid-to-centroid	Distances between basins and activity nodes and open spaces (with activity counts of at least 45) were averaged for basins D and E (basins A, B, and C were determined to be not relevant).
		Bus/shuttle stops	Centroid-to-point (of bus/shuttle stop)	Distance between each basin centroid to nearest bus/shuttle stop was measured.
		Pedestrian	Centroid to nearest pedestrian flowpoint	Distance between each basin centroid to the nearest pedestrian flowpoint was measured.
		Primary Zones	Centroid-to-centroid	Distances between basins and primary zones (Academic and Central Quad) were averaged for each basin.
		Main Passage (Paseo)**	Centroid-to-nearest points of path	Distance between each basin centroid to the nearest point on the Paseo was measured.
		Academic buildings*	Centroid-to-centroid	Distances between basins and academic buildings were averaged for each basin.
	Total Site Characteristics			
	Pollutants Loading***			
		Nitrogen Oxide (NO)†	Relevant buffers: 100, 1000, 2500 meters (m)	The results of 'Road Length' and 'Vehicle Density' calculation methods (Henderson, et al., 2007) were averaged.
		Nitrogen Dioxide (NO_2)†, ‡	Relevant buffers: 100, 200, 600, 750, 1000, 1500, 2500 m	The results of 'Road Length', 'Vehicle Density' (Henderson, et al., 2007), and Oiamo, et al. (2015) calculation methods were averaged.
		Particulate Matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$)†	Relevant buffers: 100, 300, 750 m	The results of 'Road Length' and 'Vehicle Density' calculation methods (Henderson, et al., 2007) were averaged.
		Volatile Organic Compounds (VOCs) benzene, toluene, and m/p-xylene.†	Relevant buffers: 100, 300, 350, 600, 1500, 2500, 4000, 8000 m	The results of the calculations for benzene, toluene, and m/p-xylene (Oiamo, et al., 2015) were totaled.
		Total suspended solids (TSS)	Total basin drainage area (hectares)	"Precipitation amount, rainfall intensity, and **drainage area** (DA) were the most important variables to predict event loads" (Brezonik & Stadelmann, 2001). Therefore, DA was the only measurement used.
		Total Phosphorus (TP)	Total basin drainage area (hectares)	
	Total Pollutants Loading			
	Total Score			

*Based on the means of stakeholders input on a scale of 1-3 (least important -most important)

**Main Passage (Paseo) will be replaced by neighborhood main street/or commercial street

***Equal weight was cautiously assigned to all pollutants due to the limited data and standardized measures of the intensity of specific pollutants in the area around the University's main campus.

† Additional calculation details are available in tables **XX** and **XX**.

‡ Omitting the deductions for Distance from Highway (DH) and Distance from No_x Facilities (DNOxFac) has resulted in artificially high NO_2 measurements at all basins. Also noted is that the ranking of basin A would have been lower (1 or 2) had DH been considered.

BMPs Selection Model (Scenario-5: 15% slope and ranking)

Analysis Phase	Parameter	Attributes	Measure	Calculation					WQB Ranking: 1-5 (worst to best)				
				WQB-A	WQB-B	WQB-C	WQB-D	WQB-E	WQB-A	WQB-B	WQB-C	WQB-D	WQB-E
Neighborhood	Site Characteristics												
		Single Family Residential (SFR)	Centroid-to-point on nearest boundary	1,093	862	354	330	332	1	2	3	5	4
		Mixed-use (MXD)	Centroid-to-point on nearest boundary	3,293	864	348	3,283	4,540	2	4	5	2	1
		Multi-family Residential (MFR)	Centroid-to-point on nearest boundary	675	762	630	344	1,914	3	2	4	5	1
		Neighborhood Preservation (NP)	Centroid-to-point on nearest boundary	7,141	4,639	4,126	4,534	5,908	1	3	5	4	2
	Total Score								**7**	**11**	**17**	**16**	**8**

Site Capability & Suitability Models

Analysis	Parameter	Attributes	Measure	Calculation					WQB Ranking: 1-5 (worst to best)				
				WQB-A	WQB-B	WQB-C	WQB-D	WQB-E	WQB-A	WQB-B	WQB-C	WQB-D	WQB-E
Site Capability Model	Site Characteristics												
		Floodplain	Centroid to nearest edge of 100 yr.-floodplain	0	131	0	876	272	1	2	1	5	3
		Slope	5 - 15%	19.0	20.9	30.0	25.3	35.8	1	2	4	3	5
		Exposure: areas with direct visibility	Direct visibility (no obstruction): Binary scale (Yes=1/No=0); Visibility from centroid=C, Visibility from major path=P	C=0 P=1	C=1 P=n/a	C=1 P=1	C=1 P=1	C=0 P=n/a	2	4	5	5	1
	Total Site Characteristics								7	9	13	9	8
Site Suitability Model	Site Characteristics												
		Proximity to areas with high levels of Activities (walking, standing, sitting, and sporting)	Centroid-to-centroid	n/a	n/a	n/a	2,052	1,997	2	2	1	4	5
		Bus/shuttle stops	Centroid-to-point (of bus/shuttle stop)	1,825	841	1,293	481	762	1	3	2	5	4
		Pedestrian	Centroid to nearest pedestrian flowpoint	521	861	549	316	472	3	1	2	5	4
		Primary Zones	Centroid-to-centroid	3,624	3,627	3,898	1,401	1,767	3	2	1	5	4
		Main Passage (Paseo)**	Centroid-to-nearest points of path	2,331	818	1,138	1,637	1,978	1	5	4	3	2
		Academic buildings*	Centroid-to-centroid	3,621	3,943	4,258	1,896	1,753	3	2	1	4	5
	Total Site Characteristics								13	15	11	26	24
	Pollutants Loading***												
		Nitrogen Oxide (NO)†	Relevant buffers: 100, 1000, 2500 meters (m)	1.89348	1.89109	1.89251	1.89294	1.89283	1	5	4	2	3
		Nitrogen Dioxide (NO_2)†, ‡	Relevant buffers: 100, 200, 600, 750, 1000, 1500, 2500 m	165.066	198.807	209.441	194.076	173.643	5	2	1	3	4
		Particulate Matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$)†	Relevant buffers: 100, 300, 750 m	12.4036	5.248	8.87108	7.41354	12.5946	2	5	3	4	1
		Volatile Organic Compounds (VOCs) benzene, toluene, and m/p-xylene.†	Relevant buffers: 100, 300, 350, 600, 1500, 2500, 4000, 8000 m	41.9463	52.708	55.334	53.564	45.839	5	3	1	2	4
		Total suspended solids (TSS)	Total basin drainage area (hectares)	14.2983	30.4229	17.8844	37.4438	39.9626	5	3	4	2	1
		Total Phosphorus (TP)	Total basin drainage area (hectares)	14.2983	30.4229	17.8844	37.4438	39.9626	5	3	4	2	1
	Total Pollutants Loading								23	21	17	15	14
	Total Score								**40**	**44**	**38**	**54**	47

*Based on the means of stakeholders input on a scale of 1-3 (least important -most important)

**Main Passage (Paseo) will be replaced by neighborhood main street/or commercial street

***Equal weight was cautiously assigned to all pollutants due to the limited data and standardized measures of the intensity of specific pollutants in the area around the University's main campus.

† Additional calculation details are available in tables **XX** and **XX**.

‡ Omitting the deductions for Distance from Highway (DH) and Distance from No_x Facilities (DNOxFac) has resulted in artificially high NO_2 measurements at all basins. Also noted is that the ranking of basin A would have been lower (1 or 2) had DH been considered.

Air Pollution Quotation Notes

Henderson, et al. (2007)

logNO (ppb):
By road length: 74.4 + 1.65LH_100 + 0.037LH_1000 + 2.19MJ_100 + 0.007POPd_2500 **- 0.003ELEV** - 0.089X - 0.123Y
By vehicle density: 116.0 + 0.001AD_100 + 0.132TD_1000 - **0.002ELEV** - 0.129X - 0.196Y

NO2 (ppb):
By road length: 42.6 + 10.5LH_100 + 0.275LH_1000 + 4.24MJ_200 + 0.074POPd_2500 + 0.116COM_750 - **0.020ELEV** - 0.591X
By vehicle density: 41.1 + 0.002AD_100 + 0.161TD_200 + 0.603TD_1000 + 0.116COM_750 + 0.068POPd_2500 - **0.017ELEV**

PM2.5 (ppb):
By road length: 0.036 + 2.58COM_300 + 0.035RES_750 + 0.319IND_300- **0.019ELEV**
By vehicle density: 1.01 + 0.002AD_100 + 2.88COM_300 + 0.025RES_750 - **0.018ELEV**

Oiamo, et al. (2015)

NO2 (ppb):
5.993 + 0.059IND_600 + 0.433IC_100 + 0.093POP_1500 - **0.134DH - 0.091DNOxFac**

Benzene (ppb):
0.466 + 0.002POP_2500 + 0.209LH_300 + 0.028VOCFacC_4000 + 0.023IC_100 **- 0.003DVOCFac**

Toluene (ppb):
1.436 + 0.762LH_350 + 2.19VOCFacC_4000 + 0.333TFacC_8000 + 0.215IC_100 - **0.002APOS_1200**

M/p-xylene (ppb):
0.715+ 0.262LH_350 + 0.079IC_100 + 0.049VOCFacC_4000 **- 0.001APOS_1400**

Where (listed in order of appearance):
LH_100 = Measured centerline length (in km) of highways within 100m buffer
LH_1000 = Measured centerline length (in km) of highways within 1000m buffer
MJ_100 = Measured centerline length (in km) of major roads within 100m buffer
POPd_2500 = Population density (persons per hectare) within 2500m buffer
ELEV = Elevation in meters above sea level
X = Latitude
Y = Longitude
AD_100 = Morning rush hour (~6-9am) automobile density (cars per hectare) within 100m buffer (estimated as 95% of total traffic÷ 3)
TD_1000 = Morning rush hour (~6-9am) automobile density (cars per hectare) within 1000m buffer (estimated as 5% of total traffic÷ 3)
MJ_200 = Measured centerline length (in km) of major roads within 200m buffer
COM_750 = Area of land (in hectares) devoted to commercial land use within 750m buffer
TD_200 = Morning rush hour (~6-9am) automobile density (cars per hectare) within 200m buffer (estimated as 5% of total traffic÷ 3)
COM_300 = Area of land (in hectares) devoted to commercial land use within 300m buffer
RES_750 = Area of land (in hectares) devoted to residential land use within 750m buffer
IND_300 = Area of land (in hectares) devoted to industrial land use within 300m buffer
IND_600 = Area of land (in hectares) devoted to industrial land use within 600m buffer
IC_100 = Number of intersections within 100m buffer
POP_1500 = Population count within 1500m buffer
DH = Distance to nearest highway (in km)
DNOxFac = Distance (in km) to nearest NO-emitting facility
POP_2500 = Population count within 2500m buffer
DVOCFac = Distance (in km) to nearest VOC-emitting facility
LH_350 = Measured centerline length (in km) of highways within 350m buffer
VOCFacC_4000 = Number of VOC-emitting facilities within 4000m buffer
TFacC_8000 = Number of toluene-emitting facilities within 8000m buffer
APOS_1200 = Area (in hectares) of parks and open spaces within 1200m buffer
APOS_1400 = Area (in hectares) of parks and open spaces within 1400m buffer

Caveat
Although the equations for pollution estimates, as published, included small factors of decrease (e.g., elevation, ELEV, or latitude, X), the authors omitted these factors (shown above in red font) from the adapted equations. This was done for two reasons: 1) the small beta values in the equations and 2) it was determined that there was little difference in measurements over the relatively small geographic area of the University of Texas at San Antonio main campus.

To measure the impacts of pollution sources around each of the five proposed water quality basins (WQB), buffers of the following radii (in meters) were created: 100, 200, 300, 750, 1000, 1500, and 2500. Calculations for each of the variables were completed using GIS tools (ESRI's ArcMap 10.3.1).

Factors in the levels of NO, NO2, and PM2.5, the relevant ranges of impact, and LUR-derived measures and equations (based on vehicle densities). Source: Based on Henderson et al. (2007)[1]

Pollutant	Buffer		Metric		
	Meters	Feet	Variable	Measure	Equation
logNO (ppb)	100	328.1	Auto Density (AD_100)	95% of Total daily traffic÷3	+0.001 × AD_100
	1000	3280.8	Truck Density (TD_1000)	5% of Total daily traffic÷3	+0.132 × TD_1000
NO_2 (ppb)	100	328.1	Auto Density (AD_100)	95% of Total daily traffic÷3	+0.002 × AD_100
	200	656.2	Truck Density (TD_200)	5% of Total daily traffic÷3	+0.161 × TD_200
	750	2460.6	Commercial (COM_750)	Land use in hectare	+0.116 × COM_750
	1000	3280.8	Truck Density (TD_1000)	5% of Total daily traffic÷3	+0.603 × TD_1000
	2500	8202.1	Population density (POPd_2500)	Persons per hectare	+0.068 × POPd_2500
$PM_{2.5}$ (µg/m^3)	100	328.1	Auto Density (AD_100)	95% of Total daily traffic÷3	+0.002 × AD_100
	300	984.2	Commercial (COM_300)	Land use in hectare	+2.88 × COM_300
	750	2460.6	Residential (RES_750)	Land use in hectare	+0.025 × RES_750

Based on this study, the following specific variables were determined to be relevant:

- Vehicle densities during morning rush hour (~6-9 a.m.); Daily traffic estimates were obtained from Alamo Area Metropolitan Planning Organization[2].
- Areas of land devoted to commercial or residential land use; Bexar County Appraisal District (BCAD) for Land use maps were updated by the authors,
- Population data; obtained from ACS (2010-2014 5-year estimates) of the U.S. Census Bureau[3]

1. The 100m buffer is a range where all pollutants were predicted using Auto Density. Auto Density = [flow (number of autos/hr) ÷ speed (km/hr)] × [total road lengths (km) ÷ buffer area (ha)]
2. The 200m buffer is a range where NO2 was predicted using Truck Density. Truck Density = [flow (number of trucks/hr) ÷ speed (km/hr)] × [total road lengths (km) ÷ buffer area (ha)]
3. The 300m buffer is a range where PM2.5 was predicted using total area of commercial land use (ha)
4. The 750m buffer is a range where NO2 and PM2.5 were predicted using the following metrics:
   - NO2: Total area of commercial land use (ha)
   - PM2.5: Total area of residential land use (ha)
5. The 1000m buffer is a range where NO and NO2 were predicted using Truck Density. Truck Density = [flow (number of trucks/hr) ÷ speed (km/hr)] × [total road lengths (km) ÷ buffer area (ha)]
6. The 2500m buffer is a range where NO2, was predicted using Population density (persons/ha)

Limitations include:

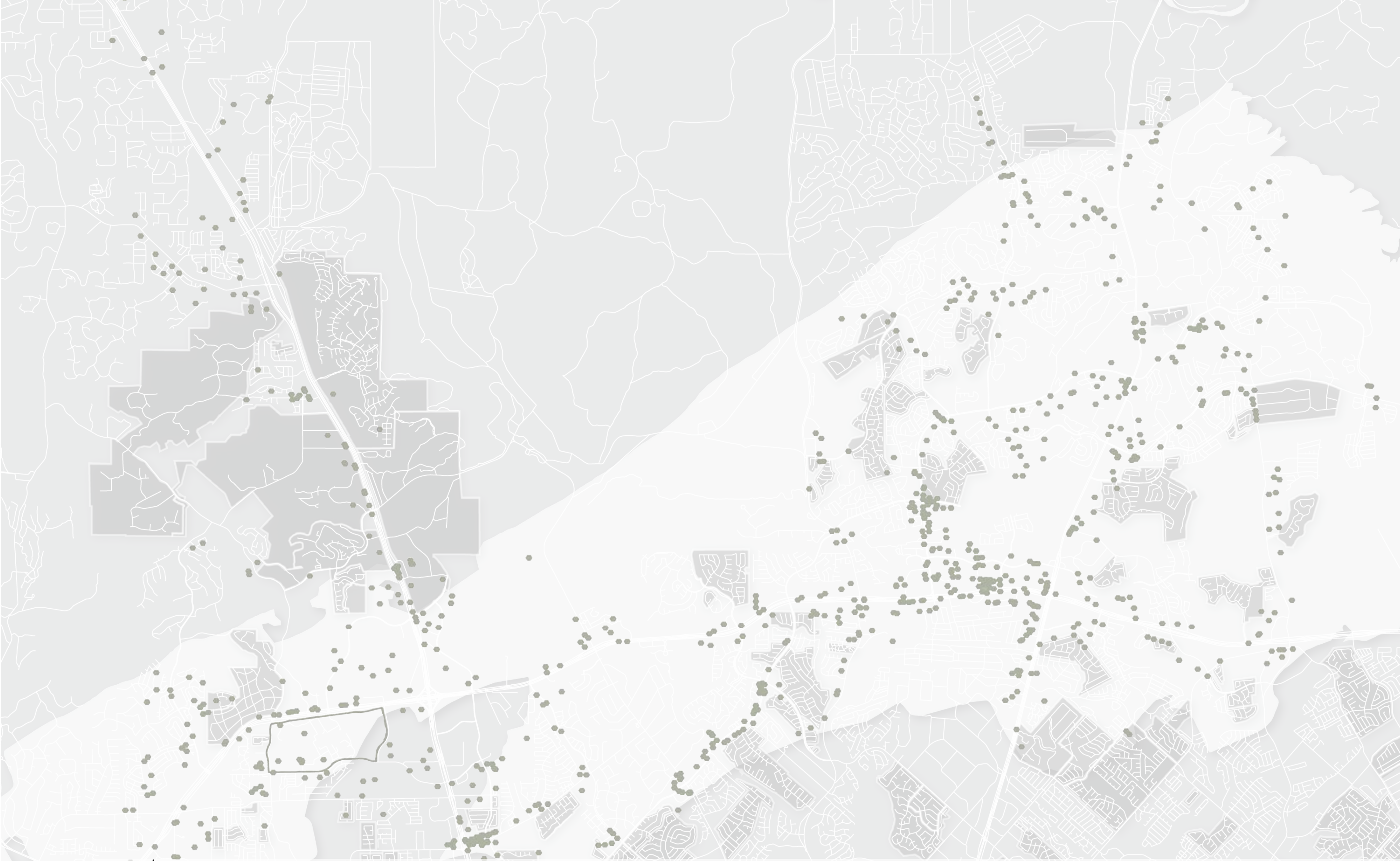
- Traffic counts are from 2010 (current counts may be significantly higher)
- Traffic counts were made in few locations:
  1. Counts in the road segments of interest were assumed to be the same as the counts further away (on the same road)
  2. Counts on Loop 1604 frontage road were assumed to be 15% of Loop 1604 counts
- Speeds were assumed to be the posted speed limit
- Most campus roads were excluded from length measurements because of a lack of traffic count data

Sources

1 Henderson, S. B., Beckerman, B., Jerrett, M., & Brauer, M. (2007). Application of land use regression to estimate long-term concentrations of traffic-related nitrogen oxides and fine particulate matter. Environmental Science & Technology, 41, 2422–2428. doi: 10.1021/es0606780. Retrieved from http://pubs.acs.org/doi/abs/10.1021/es0606780

2 Alamo Area Metropolitan Planning Organization. (2014). Alamo Area Geospatial Committee Open Data [Data file]. Available from http://aampo.mpo.opendata.arcgis.com/datasets

3 United States Census Bureau. (2015). American FactFinder [Data file]. Available from http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml



SAN ANTONIO RIVER AUTHORITY

GEAA Greater Edwards Aquifer Alliance

EDWARDS AQUIFER AUTHORITY

UTSA College of Architecture, Construction and Planning