Original Research

Design and Advantages of a Bioretention Area as a Best Management Practice for Low Impact Development on The University of Texas at San Antonio

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ABSTRACT

Rainfall on urban areas causes polluted runoff water to contaminate the ground. A bioretention basin can minimize this problem. In this project a bioretention basin was designed for future precipitation changes regarding climate change. The bioretention basin was designed for new development on The University of Texas at San Antonio Main campus and includes an economic analysis comparing three different scenarios regarding media and materials. The basin includes sand and crushed glass as media and Cedar Elm and Muhly grass plants as flora, which are native to San Antonio, to achieve the pollution removal needed. After calculating the drainage area and future average precipitation, the TSS removal required by the BMP was obtained. The equivalent depth, water quality volume treated, and the footprint area were then calculated. Recycled water from a current building at UTSA was tested and was suitable for irrigation. The results were as expected regarding the future average precipitation and the size of the basin.

KEY WORDS: Environmental Engineering

INTRODUCTION

The construction of the built environment (e.g. roads, buildings) affects natural ecosystem processes and results in negative impacts to the environment. Some examples of negative impacts are seen during rainfall events when runoff creates floods that are generated by impervious areas causing polluted water to stay on top of the developed area instead of percolating into the ground. These problems can be mitigated when making use of stormwater management strategies such as Low Impact Development (LID) (Dorman, et. al., 2013). LID strategies are structural stormwater Best Management Practices (BMPs) and planning techniques intended to reproduce predevelopment hydrologic conditions. An example of a LID is a bioretention basin, which channels water during a storm event to reduce flooding and filters water to clean it from pollutants carried from developed areas such as parking lots (Dorman, et. al., 2013).

Bioretention is a common LID practice because it mimics hydrologic conditions and enhances biodiversity and water quality. In areas such as Bexar County, it is important to implement BMPs located on the Edward's Aquifer such as The University of Texas at San Antonio (UTSA) to avoid polluted water to percolate into the ground and pollute the aquifer. The university can take advantage of the use of a bioretention basin as a LID strategy to clean polluted water, reduce flooding, and comply with the Edward's Aquifer regulations (Center for Research, 2011). Currently, the university has several sand filters built, but this project focuses on the design of a bioretention basin, which as an advantage uses vegetation to clean pollutants, in an area where new buildings are proposed to diminish the impact of increased impervious areas. LIDs can easily be integrated into existing development and built into new development (Dorman, et. al., 2013). In order to effectively select a BMP for a specific area, its characteristics and features should be understood; in addition, the design process must be planned and followed in order to accurately meet all the BMP objectives.

The design of a bioretention basin on UTSA main campus is addressed in this project. This basin was designed to be incorporated into new development on campus to help with problems related to the lack of natural systems by reproducing predevelopment hydrologic conditions. This project is important because it deals with conditions that could become major issues such as an increase in rainfall intensities due to climate change and pollution of the environment by contaminated water runoff from future buildings to be built on campus (Dorman, et. al., 2013). To fulfill the goal of this project, the design includes research on climate change in recent years to address intensity concerns. There are four objectives addressed in this project which are: 1) the calculation of the treatment volume and equivalent depth of the basin, 2) the footprint area of the proposed development, 3) the selection of the basin's media and flora, and 4) conducting an economic analysis of the different basin designs.

LITERATURE REVIEW

Stormwater Management Strategies

Rainfall over developed areas carries pollutants to the ground by surface runoff, which can become a problem. Therefore, stormwater management strategies are needed to address this problem and to reduce the peak runoff rates and runoff volumes of storms (Center for Research, 2011). There are several BMPs such as bioretention areas, sand filters, bioswales, green roofs, etc. used to convey, infiltrate, and treat stormwater runoff, which differ in effectiveness regarding the climate and area in which they are built. These low impact developments (LID) have different maintenance cost and overall cost, which need to be compared to design the most efficient one. In addition, the drainage area that the LID will receive is an important characteristic that needs to be considered when choosing an LID since they have different drainage area limits. For example if the LID's drainage area limit is smaller than the drainage area it will receive, then a combination of LIDs is needed to achieve effective results. All BMPs have drainage area limits but more than one system can be used in parallel to cover all the drainage area necessary (Center for Research, 2011).

Complying with the Regulations of the Edward's Aquifer

BMPs are required when building over the Edward's Aquifer region (Barrett, 2005). The Edward's Aquifer recharge zone is an area of about 1500 square miles that includes part of Bexar County (City Council of San Antonio, 1994). In this area, vertical faults occur exposing fractured Edward's limestone at the land surface. The aquifer receives water from the flow crossing the drainage area and from water that percolates from major streams in the region. The University of Texas at San Antonio is located over the recharge zone of the Edward's Aquifer. The Edward's Aquifer is unique in its ability to recharge large quantities of water quickly, and most of the water comes from infiltration of rainwater that falls over the recharge zone (Barrett, 2005). Consequently, the city of San Antonio has passed a resolution for protection of the aquifer that is enforced as high priority for construction on the recharge zone.

The Edwards Aquifer Rules regulate the activities that could potentially pollute the waters associated with the aquifer and they apply to recharge zones in Bexar County (Barrett, 2005). The use of permanent BMPs is required on areas over the aquifer to prevent pollution caused by contaminated stormwater runoff from the site. One of the requirements established by the aquifer's regulations is that at least an 80% reduction of TSS (total suspended solids) on runoff water needs to be achieved by the BMPs in constructions over the aquifer (Texas Commission on Environmental Quality, 2008). Studies indicate that bioretention basins and sand filters as BMPs remove TSS by 89% in average, which comply with the aquifer's rules (Dorman, et. al., 2013).

Sand Filter and Bioretention Basin Design

Sand filters and bioretention basins are two stormwater management strategies that are used to minimize problems related to water runoff. Sand filters are basins that capture and filter stormwater runoff by using a layer of sand and they generally have a high rate removal for phosphorus, BOD, zinc, copper, lead, nitrogen, and fecal coliform. Sand filters consist of a bed of sand that removes sediments and pollutants. In these filters, bacteria slime is formed and helps remove nutrients, organics, and coliform bacteria from the water. Additionally, sand filters can adapt to thin soils, limited-space areas, and dry areas. Sand filters do not include flora in its design (Barrett, 2005).

Bioretention basins use adsorption, plant uptake, microbial activity, filtration, and sedimentation to remove pollutants, and provide high removal of sediment, metals, and organic material (Dorman et. al., 2013). Bioretention basins consist of a pretreatment system, a surface ponding area, a mulch layer, and a planted soil media; Figure 1 shows a schematic diagram of a bioretention system. The vegetation that needs to be included in the surface of the basin is generally a combination of small to medium-sized trees, shrubs, and groundcover. The flora can adapt to size constraints and take advantage of the semi-arid climate for evapotranspiration in the San Antonio area (Barrett, 2005). In addition, several physical, biological, and chemical processes are applied in a bioretention area to effectively remove pollutants (United States Environmental Protection Agency, 2015).

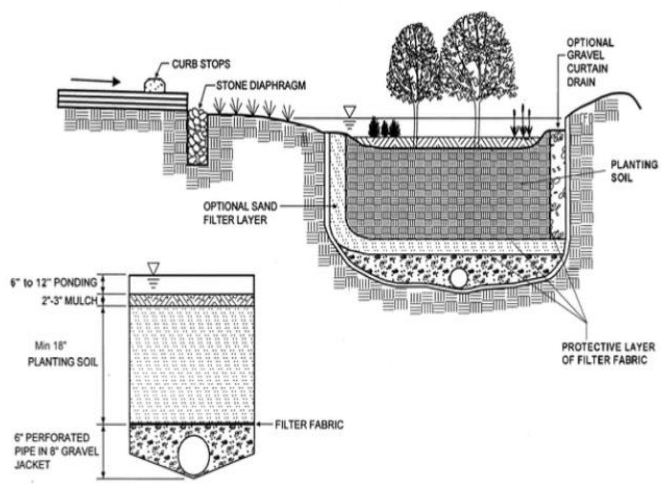


Figure 1. Schematic Diagram of a Bioretention System.

The design of a LID, including bioretention basins and sand filters, includes the following steps. The size of the basin is first determined followed by the selection of media required to achieve the performance necessary. There are different approaches to determine the water quality volume and the method discussed here follows the rational method (Dorman, et. al., 2013). The volume-based method depends on the runoff coefficients regarding the hydrologic soil group. It was also developed to achieve total suspended solids reduction targets regarding annual rainfall volume. For this method, rainfall depth is needed to get the volume necessary to meet the treatment goals. Additionally, hydrologic evaluations graphs are used to define rainfall depth that must be treated to meet the desired pollutant reduction goals (Dorman, et. al., 2013). On the other hand, flow based design methods are usually used for configuring inlets, sizing, conveyance, or settling hydraulic control (Dorman, et. al., 2013).

Bioretention Basin Advantages

Some of the advantages of a bioretention basin include the removal of suspended solids, metals, pollutants, nitrogen, phosphorus, and pathogens from the water. They also reduce the peak runoff rates for storms, reduce runoff volumes, and can potentially recharge ground-water after filtering it from pollutants (Dorman, et. al., 2013). In addition, they are flexible to adapt to urban retrofits and can be used in recharge zones, karst, clays, and hotspots. Another important characteristic of these basins is that they are well suited for small areas and if multiple distributed units are constructed, they can provide treatment in large areas (Dorman, et. al., 2013). Bioretention basins also enhance aesthetics and provide habitat for different species. In addition, in a bioretention basin the standing water is only present for 12-24 hours, minimizing vector control concerns (Dorman, et. al., 2013).

Research has shown that removal of TSS, phosphorus, nitrogen, and fecal coliform is more successfully achieved when vegetation is included in a BMP such as in a bioretention basin. Bioretention systems typically achieve a TSS reduction of 89% efficiency (Center for Research, 2011 and Dorman, et. al., 2013). Likewise, pollutant removal is more achievable when BMPs include media and robust vegetation rather than just sand or a single plant species (United States Environmental Protection Agency, 2015). With the construction of a bioretention basin, the UTSA main campus could become more sustainable. Additionally, a bioretention basin can be incorporated into a development easily and its vegetation provides shade, wind breaks, and absorbs noise (Center for Research, 2011 and Dorman, et. al., 2013). Besides its aesthetic benefits and its flexible design, its implementation at UTSA can also benefit it economically.

Additional benefits include the gaining of credits for the Leadership in Energy and Environmental Design (LEED) certification. LEED credits are divided into sections and a bioretention basin could earn credits in the Sustainable Sites and Water Efficiency sections. First of all, a bioretention basin could help the new project earn up to three credits of Rainwater Management subsection. Also, for the Heat Island Reduction subsection it could earn up to two credits by providing shade to nearby developments with the flora planted. For the Water Efficiency section, the BMP can earn up to two credits in the Outdoor Water Use Reduction section (*USGBC*, 2016). Since the flora used in the basin will be native of the area, not much water is going to be needed; the water that will be needed is going to be obtained from the recycled AC condensate water from the new building developments on UTSA, as further explained in section 3.3.

Economic Benefits of a Bioretention System

Municipalities usually encourage developers to incorporate LID by offering incentives for planned and existing developments (United States Environmental Protection Agency, 2015). The four most common categories of local incentives are fee reductions, development inducements, best management practices installation subsidies, and awards and recognition programs. Also, municipalities often charge stormwater fees depending on the impervious surface area on a property, but when a LID system is used to reduce the amount of runoff and clean for pollutants, the federal government can help with the payments of this fee (United States Environmental Protection Agency, 2015). Likewise, incentives could be available for developments using only LID practices. This may incorporate propositions to waive or decrease permit fees, accelerate the permit procedure, or allow for higher density developments. Furthermore, communities could offer programs that subsidize the cost of the materials that are used to construct the bioretention system. Recognition programs are held by the community to encourage LID innovation. For example, the university could be featured in articles, websites, and utility bill mailings about their implementation of LIDs increasing its prestige (United States Environmental Protection Agency, 2015).

The city of San Antonio has implemented a comprehensive plan for improving the sustainability of the city by 2020. The SA2020 is a nonprofit organization to allow San Antonio citizens to work with the city government to achieve mutual goals. Moreover, the SA2020 program's financial support for green infrastructure such as LIDs comes from private rather than public funding (Economides, 2014). The San Antonio River Authority is also promoting the construction of LID systems as green infrastructure with several initiatives. To name one, the Mission Verde Sustainability Plan is investing in energy saving initiatives that innovate and encourage green engineering such as the LID systems (Office of Mayor Phil Hardberger, 2009). Furthermore, San Antonio has existing government and non-profit programs each year to implement a green infrastructure plan such as a bioretention basin. The city of San Antonio Office of Sustainability will also integrate green infrastructure in the future, saving costs for developers and the city in forthcoming construction of LIDs (Economides, 2014).

LID approaches can be easily integrated into capital improvement programs. One of the city's initiatives that indirectly support stormwater management is the Tree Challenge Program through the Parks and Recreation Department (Economides, 2014). This program aims to expand the tree canopy in San Antonio to increase stormwater infiltration rates and reduce the urban heat island effect. Through this program, the city offers energy tax rebates when planting trees on a property (Economides, 2014). Although the program takes stormwater management as a secondary benefit, it directly recognizes the value of tree canopy. The design of a bioretention basin at UTSA includes vegetation and media that could be registered in the Tree Challenge Program for CPS energy tax rebates.

LID and green infrastructures result in multiple financial, environmental, and social benefits. Financial case studies for LID implementations were made for Milwaukee, Portland, Philadelphia, and the Sun Valley watershed of Los Angeles County, which monetized benefits using non-market economic valuation techniques (U.S. Environmental Protection Agency, 2013). In these benefit-cost analyses, it was discovered that public benefits of an LID, such as a bioretention basin, include management cost, habitat creation, improved air quality, and reduced carbon emissions. On the other hand, private benefits include stormwater volume reduction, reduced energy demand for heating and cooling, and less stormwater facility costs (U.S. Environmental Protection Agency, 2013). In another analysis, it was demonstrated that for an equal investment amount and similar overflow volume reductions, LIDs would provide 20 times more benefit than traditional stormwater infrastructure such as stormwater pipes (U.S. Environmental Protection Agency, 2013). A bioretention basin will additionally increase community aesthetics, increase wildlife habitat, reduce heat island effect, and create a possible reuse of the water for different activities that will also benefit UTSA directly.

METHODS

To achieve the goal of designing a bioretention basin for future building developments in UTSA Main campus, the project has been broken-up into four objectives. This chapter discusses the methods that were used to carry-out these objectives. The objectives are: 1) determine the treatment volume and the equivalent depth of water stored following design formulas, 2) obtain the footprint area of the basin, 3) select the media and flora, and 4) conduct economic analysis on the proposed basins. For the fourth objective, three bioretention basins were designed with different media and materials to select the most productive and the most economical design. Climate change has been an important factor for variations in rainfall depth for the last few years and this factor is taken into account in the design of the bioretention basin.

Determining the Contributing Drainage Area

The contributing drainage area is one of the fundamental values needed to design a bioretention basin. It defines the portion of the site in acres that is contributing runoff to the BMP. This area is utilized to determine the water quality volume. The contributing runoff was obtained based on the drainage contours of the Texas Natural Resources Information System (TNRIS) using Google Earth. First, from the TNRIS webpage, the 2010 TNRIS 5ft Contours Elevation GIS data was downloaded along with the StratMap Elevation Contours. The first represents the green contour lines and the second one the red contour lines in Figure 2. These contours were imported with a 2013 Bexar Metro 911 Image in ArcMaps version 10. The 2 contours give different approaches to the elevation of the terrain and they both specify where the lowest point in the section is going to be and thus, where the LID is going to be located to receive all the runoff. In Figure 2, the future development location is enclosed by the black box and the basin's location and lowest point in the terrain is where the blue circle is. After determining where the water is going to flow, the contributing drainage area was obtained using the Google measuring function.

Figure 2. Contour Lines and Bioretention Basin Location.

Determining the Treatment Volume

The proposed development for which the bioretention basin is designed at The UTSA Main campus will cover an area of 7.15 acres, which will be the contributing drainage area for the basin. Figure 3 shows UTSA Main campus with some of the current sand filters marked by a star and the proposed development area for which the basin was designed is circled. The proposed development will be near roads, buildings, and parking lots; but the bioretention basin will only receive runoff from the proposed buildings due to the drainage already installed. Consequently, for this project, the basin was designed to handle the runoff received only from the new development. The drainage area limit for a bioretention basin is 10 acres and this project's drainage area falls inside the parameters (Barrett, 2005). The volume-based method was used to design the basin since it uses annual rainfall precipitation to obtain the water quality volume providing an easier way to determine the volume based on precipitation increases due to climate change (Barrett, 2005).

Figure 3. The University of Texas at San Antonio Main campus from Google Earth.

The bioretention basin was designed to account for future variations in climate. Climate change has proven to increase average precipitation throughout the years and so projections were done to account for the increase in precipitation (*Downscaled CMIP3 and CMIP5 Projections*). The projections showed an increase in future average annual precipitation due to climate change and the basin was designed to be able to function under future precipitation increases. The projections were downloaded from the Lawrence Livermore National Laboratory archive. The data from this archive is based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project Phase 3 (CMIP3). First, downscaled CMIP3 daily climate and hydrology projections developed using bias-correction and constructed analogs (BCCA) were downloaded for the specific area in which the project is located. Daily climate and precipitation data for years 1961-2000, 2046-2065, and 2081-2099 was obtained.

There were several different historical projections used to obtain the precipitation average for the future and included the possible alterations due to climate change. The historical projections obtained included five historical projections from years 1961 to 2000, three variable projections including years 2046 to 2065, and three future projections from years 2081 to 2099. After downloading them into an Excel file, the yearly average was obtained for each year and then the total average was obtained for each projection. After that, graphs were plotted for each projection showing an increase of the precipitation average throughout the years (section 4.1). In the design formulas for the bioretention basin the yearly average precipitation in inches was required so the values were converted into in/yr.

To calculate the water quality volume of the basin, the required TSS removal was obtained using equation 3-1 followed by the load removed by the bioretention basin as shown in equation 3-2. For the required TSS removal calculations, it was assumed that the appropriate runoff coefficient of impervious areas is 0.9 and 0.03 for natural areas (Barrett, 2005). The new development on campus is of 7.15 acres, which include pervious and impervious areas that were measured specifically for the calculations. The TSS concentration increases to 170 mg/L in an impervious area, and this is what was used for the design. In addition, it was assumed that the bioretention basin achieves an 89% of TSS reduction according to Table 1 (Barrett, 2005). The rainfall depth was obtained using equation 3-3, which is the fraction of annual rainfall treated by the best management practice that also determines if the BMP selected was good enough for the treated area, and table 2 (Barrett, 2005).

Equation 3-1 LM= 27.2 (AN x P)

where:

LM= Required TSS removal (pounds)
AN= Net increase in impervious area (acres)
P= Average annual precipitation (inches)

Equation 3-2 LR= (BMP efficiency) x P x (Ai x 34.6 + Ap x 0.54)

where:

LR= Load removed by BMP
BMP efficiency= TSS removal efficiency (from table 1)

Ai= impervious tributary area to the BMP (ac)
Ap= pervious tributary area to the BMP (ac)
P= average annual precipitation

Equation 3-3 F= LM/ΣLR

where:

F= Fraction of the annual rainfall treated by the BMP
LR= Load removed for each BMP (from equation 3-2) (pounds)
LM= Required load reduction (from equation 3-1) (pounds)

BMP	TSS Reduction (%)
Retention/Irrigation	100
Ext. Detention Basin	75
Grassy Swales	70
Vegetated Filter Strips	85
Sand Filters	89
AquaLogic™ Cartridge Filter System	95
Wet Basins	93
Constructed Wetlands	93
Bioretention	89
Permeable Concrete with underdrain	93
Permeable Concrete without underdrain	100
Wet Vault	Sizing Dependent

Table 1. TSS Reduction of Selected BMPs (Barrett, 2005)

The water quality volume was calculated using equation 3-4 by multiplying the rainfall depth from Table 2 by the runoff coefficient from Figure 4 and by the contributing drainage area (7.15 acres).

Equation 3-4 WQV= Rainfall depth x Runoff Coefficient x Area

Table 2. Relationship between Fraction of Annual Rainfall and Rainfall Depth (in) (Barrett, 2005)

F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth
1.00	4.00	0.80	1.08	0.60	0.58	0.40	0.29
0.99	3.66	0.79	1.04	0.59	0.56	0.39	0.28
0.98	3.33	0.78	1.00	0.58	0.54	0.38	0.27
0.97	3.00	0.77	0.97	0.57	0.52	0.37	0.25
0.96	2.80	0.76	0.94	0.56	0.50	0.36	0.24
0.95	2.60	0.75	0.92	0.55	0.49	0.35	0.23
0.94	2.40	0.74	0.89	0.54	0.47	0.34	0.23
0.93	2.20	0.73	0.86	0.53	0.46	0.33	0.22
0.92	2.00	0.72	0.83	0.52	0.45	0.32	0.21
0.91	1.80	0.71	0.80	0.51	0.44	0.31	0.20
0.90	1.70	0.70	0.78	0.50	0.42	0.30	0.19
0.89	1.60	0.69	0.75	0.49	0.41	0.29	0.18
0.88	1.50	0.68	0.73	0.48	0.40	0.28	0.18
0.87	1.44	0.67	0.71	0.47	0.38	0.27	0.17
0.86	1.38	0.66	0.69	0.46	0.37	0.26	0.16
0.85	1.32	0.65	0.67	0.45	0.36	0.25	0.15
0.84	1.26	0.64	0.66	0.44	0.34		
0.83	1.20	0.63	0.64	0.43	0.33		
0.82	1.16	0.62	0.62	0.42	0.32		
0.81	1.12	0.61	0.60	0.41	0.31		
0.80	1.08	0.60	0.58	0.40	0.29		

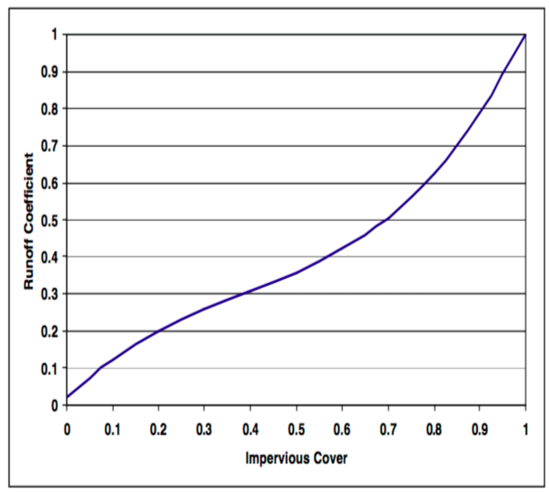


Figure 4. Relationship between Runoff Coefficient and Impervious Cover

The water quality volume needed to be increased by a factor of 20% to account for reductions in storage due to deposition of soils that can occur in maintenance activities (Barrett, 2005). In addition, a modification in the average annual rainfall was made due to studies relating to the changing climate in San Antonio. In San

Antonio specifically, the change in precipitation lacks evidence that relates to climate change but it is certain that precipitation will not be steady over time, it will decrease or increase (Schmandt, 2011). Since precipitation has increased over five percent over the last 50 years in the United States it is expected that precipitation will increase by 10 percent in the next 100 years in Texas (Karl, et. al., 2009).

Footprint Area and Equivalent Depth

The next step in the design requires the depths of the media as recommended in the LID Technical Guidance Manual to obtain the required footprint. A temporary ponding depth of 9 inches was used (Dorman, et. al., 2013). Also, soil media depth of 48 inches was used with a media porosity of 0.35 (Dorman, et. al., 2013). The depth of gravel used was 8 inches since the underdrain pipe diameter should have a minimum of 4 inches diameter; the porosity of the gravel will be 0.4 (Dorman, et. al., 2013). These values were used to get the equivalent depth of water stored in the bioretention and with that, the required bioretention footprint area following equations 3-5 and 3-6.

Equation 3-5 Deq= (D surface)+(n media x D media)+(n gravel x D gravel)

where:

Deq= equivalent depth of water stored in representative cross section (ft)
D surface= average depth of temporary surface ponding (maximum 12 in)
n media= porosity of soil media
D media= depth of soil media
n gravel= porosity of gravel drainage layer
D gravel= depth of gravel drainage layer

Equation 3-6 A= WQV/Deq

where:

A= required bioretention footprint (ft^2)
WQV= water quality treatment volume (ft^3)
Deq= equivalent depth (ft)

Selection of Media and Flora

A bioretention basin should have a soil mixture adequate to filter all the pollutants necessary. First, soil should be free of stones, uniform mix, and free of other objects. The recommended sand is ASTM C-33 with a grain size of 0.02 to 0.04 inches. Clay content should be less than 5% and filtration media must have a minimum of 3 ft thickness if soil mixture is 50 to 60% sand, 20 to 30% compost, and 20 to 30% topsoil (Barrett, 2005). For a smaller soil media depth of 2 to 3 feet, then soil mixture should be 85 to 88% sand, 8 to 12% fines, and 2 to 5% plant delivered organic matter. The underdrain layer including the underdrain pipe should have ASTM No. 8 stone over a 1.5 feet envelope of ASTM No. 57 stone separated from the soil by 3 inches of washed sand (Dorman et. al., 2013). To make the basin more sustainable, crushed recycled glass can be used instead of sand; if this design is preferred, then more organic matter, from 20 to 30%, should be used. Additionally, only mature, low-nutrient compost should be used for all the designs (Center for Research, 2011).

Crushed recycled glass can be used instead of sand as media for the bioretention basin. The use of the crushed glass has several advantages over the use of sand, which include: 1) it is less expensive, 2) it is recycled so it is more environmentally friendly, and 3) it can be pulverized to meet the size the design specifies. The cost of crushed glass is 38% of the price of regular sand used for filtration and it can save money in maintenance since it gets clogged more slowly due to the shape of its particles (Rutledge, 2010). Additionally, recycled crushed glass filters have shown similar results in removal of particles than sand filters, which does not affect the design of the bioretention basin (Rutledge, 2010). If crushed glass is going to be used as media, then an extra mulch layer should be included in the design due to specifications (Barrett, 2005). Also, due to the fact that the crushed glass is a recycled material, the project could earn up to 2 credits for the Leadership in Energy and Environmental Design (LEED) certification (*USGBC*, 2016).

The plants used for the basin must be able to adapt to the San Antonio climate. Examples are Muhly grass, and Cedar Elm plant. These species are suitable for the LID features and can provide the specific characteristics needed to clean pollutants (Center for Research, 2011).

The irrigation of plants can be done using recycled water from the proposed buildings or from the already existing buildings. Therefore, the AC condensate water, reclaimed water, and blowdown water from a current building on campus were sampled and tested to determine if the water quality was suitable for the plants in order to reuse the water for irrigation. The water was analyzed for turbidity using a turbidity meter, pH using a pH probe and meter, conductivity using a conductivity meter, alkalinity and hardness following the titration method, copper, zinc, and sodium using the inductively coupled plasma mass spectrometry (ICP-MS), and phosphate measured spectrophotometrically.

Economic Analysis

An economic analysis was performed to select the most economical, efficient, and sustainable basin alternative. To achieve this, three basins were designed. The designs costs were calculated using sand and recycled crushed glass, and concrete or a geomembrane as liners. These scenarios give a better idea of the differences in cost regarding the material used. In addition, the maintenance cost was analyzed.

In accordance to the depth of the design, the approximate cost is broken down as follows:

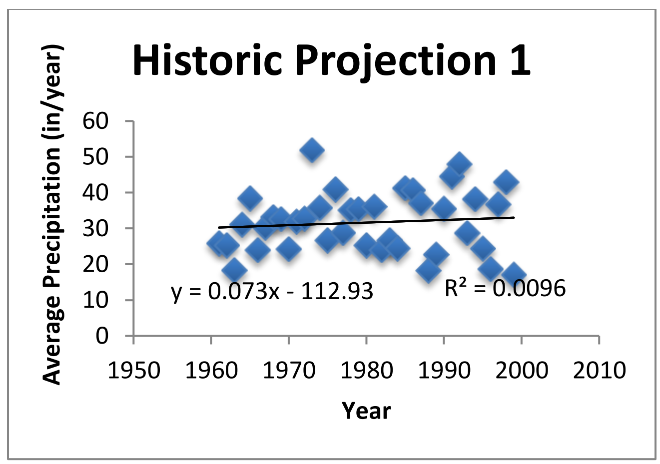
	Cost
Excavation with underdrains	$5/ft^2$
Soil or crushed glass	$5/ft^2$ or $2/ft^2$ respectively
Aggregate	$0.28/ft^2$
Pipe with underdrain	$3.6/ft^2$
Gutter	$18/ft^2$
Mulch	$0.32/ft^2$ or $0.42/ft^2$ (the latter is used when using crushed glass)
Concrete barrier or geomembrane liner	$12/ft^2$ or $0.45/ft^2$ respectively
Vegetation	$2/ft^2$

The maintenance cost to keep the basin working properly is of $1.91/ft^2$ every 2 years, $2.5/ft^2$ every 10 years, and of 10.11/ft^2 every 20 years. The quantities represent the cost depending on the depth needed for the design. The resulting footprint of 13,145.5 ft^2 is going to be used to estimate three different costs of the basin depending on the different characteristics used. Different materials result in different costs. The economic analysis was made based on the media used such as soil or crushed glass, concrete or geomembrane as a liner, and the different depths of mulch required depending on the crushed glass.

RESULTS AND DISCUSSION

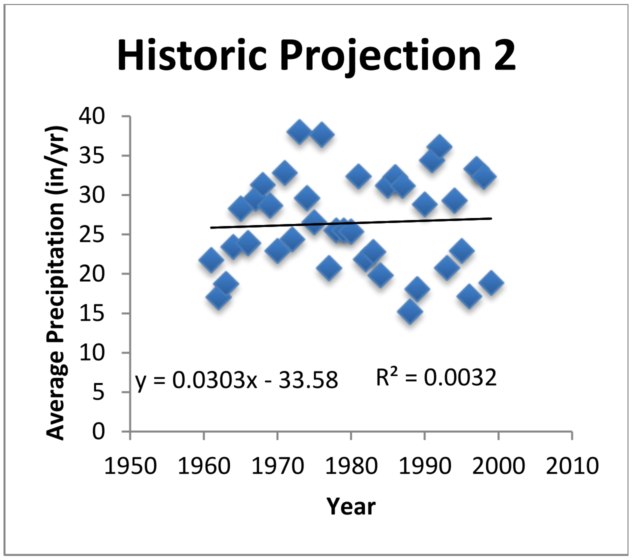
Average Precipitation Projections

The average precipitation from the projections is 33.64 in/yr for years 2081-2099, which is adopted in the basin's calculations. The average annual precipitation in Bexar County is of approximately 30 in/yr historically and an increase of 5% has been observed since 1950 (Barrett, 2005 and Karl, et. al., 2009). The 30 in/yr average compared to the 33.64 in/yr calculated for the future shows a percentage increase of 12.1% in average annual precipitation, which was within expectations since there was a 5% increase observed from 1950 to 2000 (5% increase for 50 years) (Karl, et. al., 2009). Figures 5 to 15 correspond to the results of the projections and its averages.



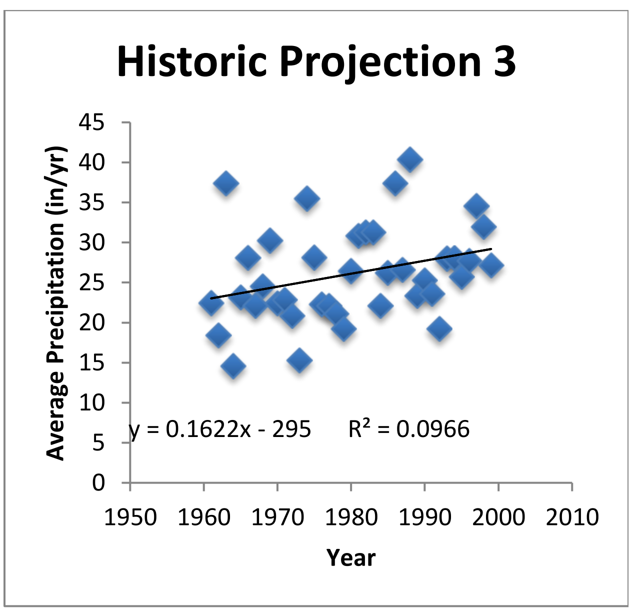
Average= 31.6 in/year

Figure 5. Historic Projection 1



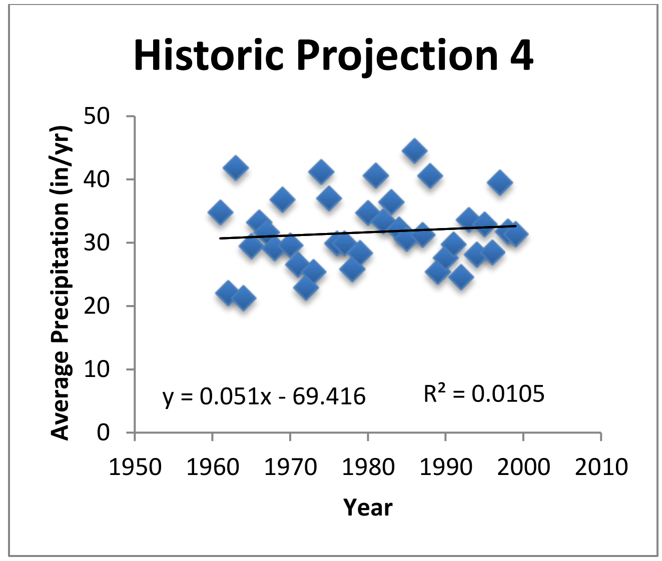
Average= 27.6 in/yr

Figure 6. Historic Projection 2



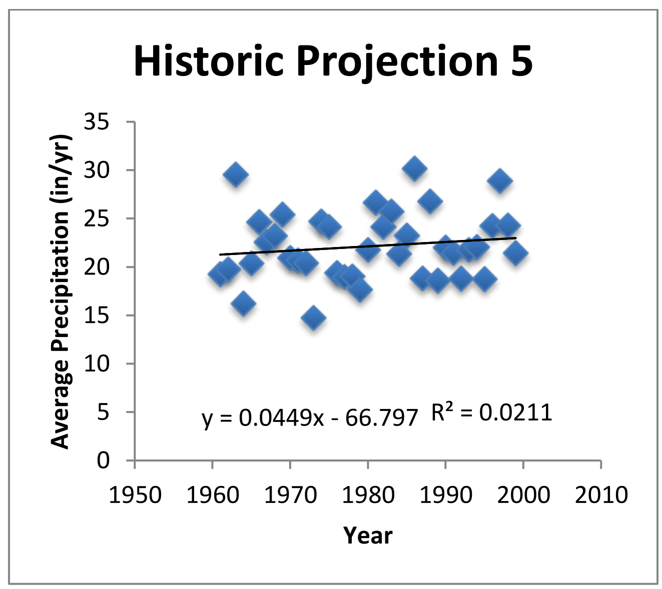
Average= 26.1 in/yr

Figure 7. Historic Projection 3



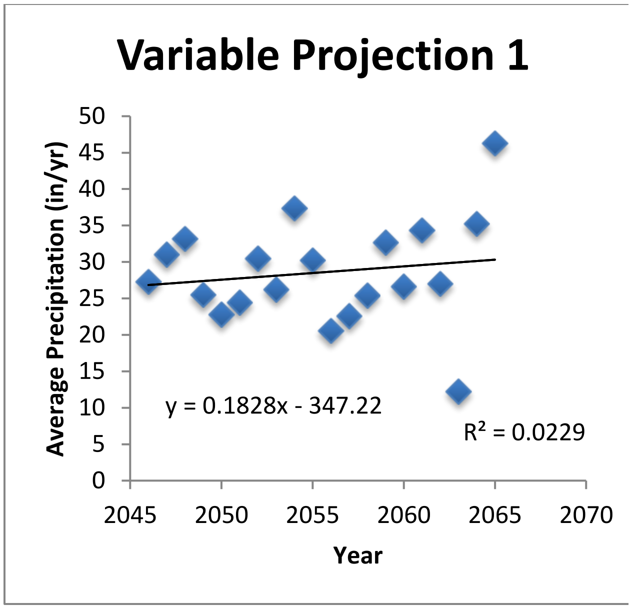
Average= 31.7 in/yr

Figure 8. Historic Projection 4



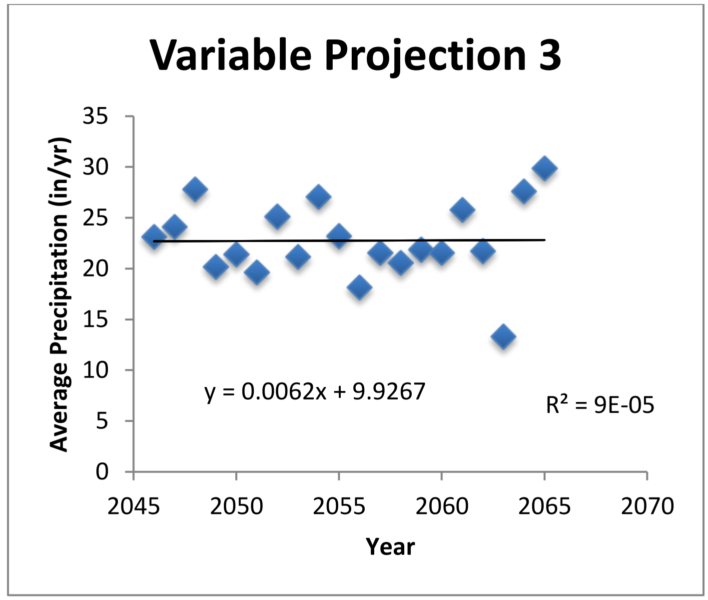
Average= 22.1 in/yr

Figure 9. Historic Projection 5



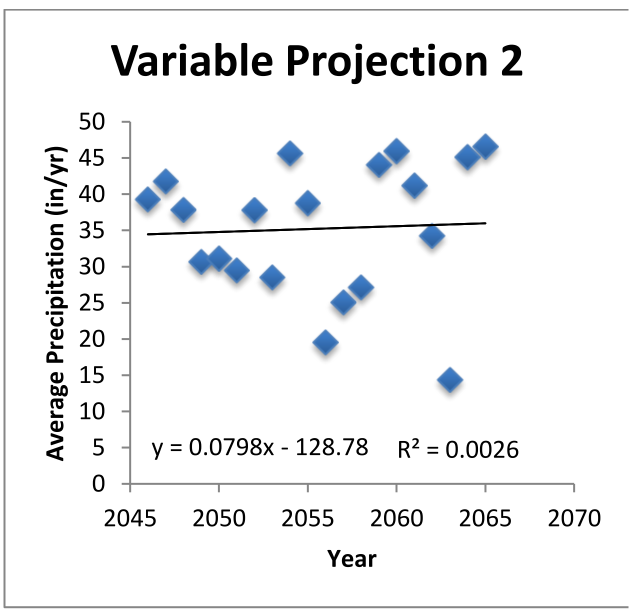
Average= 28.6 in/yr

Figure 10. Variable Projection 1



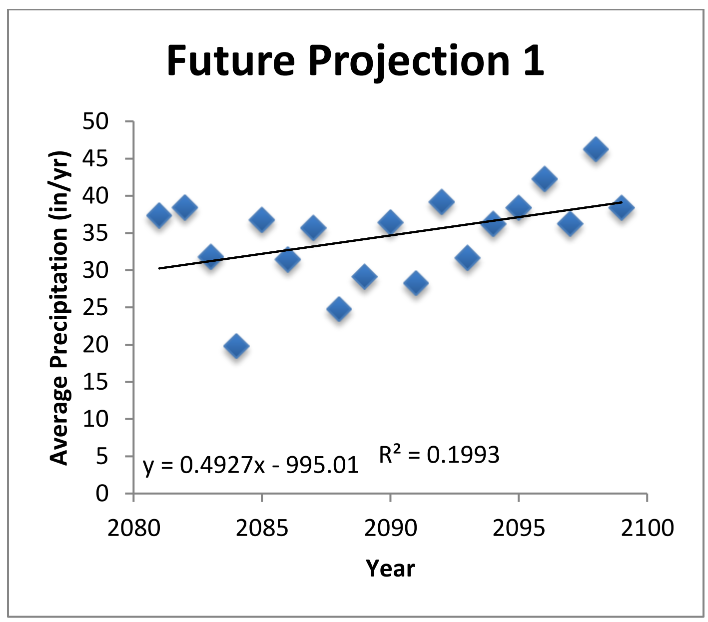
Average= 22.7 in/yr

Figure 12. Variable Projection 3



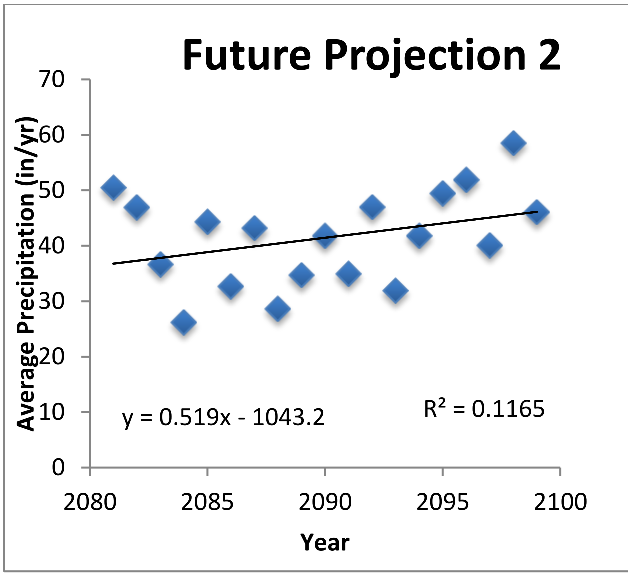
Average= 35.2 in/yr

Figure 11. Variable Projection 2



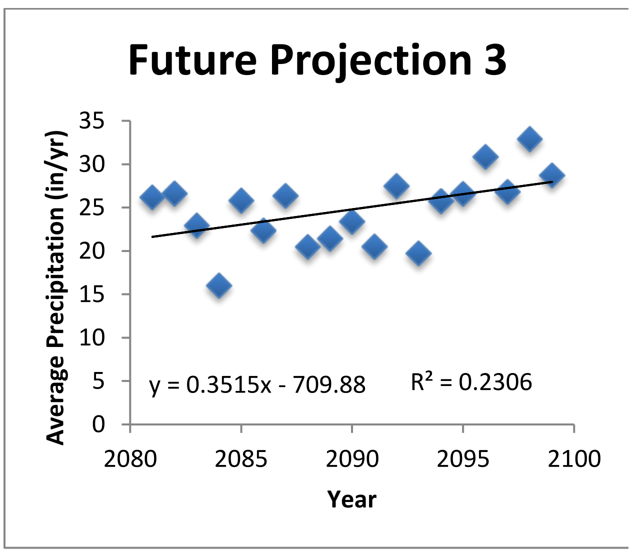
Average= 34.7 in/yr

Figure 13. Future Projection 1



Average= 41.4 in/yr

Figure 14. Future Projection 2



Average= 24.8 in/yr

Figure 15. Future Projection 3

Contributing Drainage Area

The drainage area was obtained by utilizing two different Texas Natural Resources Information System (TNRIS) contours and the Google Earth measuring program. The drainage area contributing runoff considered for the measurement was only that of the new proposed area and it includes the pervious and impervious areas. The total area of the whole development was measured to be 7.15 acres. The buildings were assumed to have 1 acre of area, based on measurements done to the already existing AET building on UTSA, thus the 5 buildings of the proposed development will account for 5 acres of impervious area. Moreover, 1 acre more of impervious area was assumed to account for pathways, sidewalks and any other construction surrounding the buildings. Subsequently, the pervious area that included the vegetation that the development will have was 1.15 acres.

Footprint Area, Water Quality Volume, and Equivalent Depth

The footprint area is the last step in the calculations and it is obtained after applying equations 3-1 through 3-6. First, the required TSS removal was obtained with a value of 5,490 lb by using the projected average precipitation (Section 4.1). Then, the calculation of the load removed by the BMP resulted in 6,234 lb. Third, the fraction of the rainfall treated, which is of 0.88 was used to obtain the rainfall depth that resulted in 1.5 in. The runoff coefficient used was of 0.68 and the water quality volume resulted in 26,476 ft^3 for the contributing drainage area calculated for the site. Then, the result of the equivalent depth of water stored was of 29 in by using a temporary ponding depth of 9 in, soil media depth of 48 inches with a media porosity of 0.35, a depth of gravel of 8 in, since the underdrain pipe diameter should have a minimum of 4 in diameter, with porosity of gravel of 0.4. Finally, the footprint area, after being increased by 20% to account for reductions in storage due to deposition of soils that can occur in maintenance activities, was 13,146 ft^2. An Excel file was used to aid in the calculations and it is included in Appendix A.

The results obtained were expected since the closest existing basin to the new development on UTSA was 14,648 ft^2, which was similar in size. The basin could be easily implemented in the new development because it can be accommodated into the terrain. Additionally, the shape of the basin will not affect its function so it could be shaped as needed to fit the lowest corner (Barrett, 2005).

Economic Analysis, Media, and Flora

With the calculated footprint area, an economic analysis was obtained. The economic analysis includes the media and flora used and it is based on the size and media of the basin. The bioretention basin economic analysis was conducted for three scenarios: 1) using soil, concrete as a liner, and regular depth of mulch; 2) using crushed glass, concrete as a liner, and the extra mulch necessary for the glass; and 3) using crushed glass, a geomembrane liner, and extra depth of mulch. The results show that the less expensive option is the number 3. When using soil, concrete as a liner, and regular depth of mulch, the total approximate cost of the basin is $607,321. If crushed glass is going to be used, concrete as a liner, and the mulch required when using glass, the cost is $569,199. The most economical option will be when using crushed glass, a geomembrane liner barrier, and the mulch required when using glass, and that gives a cost of $417,369. Table 3 shows these comparisons.

Table 3. Economic Analysis

	Scenario 1	Scenario 2	Scenario 3
Media:	Soil	Crushed Glass	Crushed Glass
Liner Material:	Concrete	Concrete	Filter Liner
Mulch Depth:	Regular	Extra Mulch	Extra Mulch
Cost ($):	607,321	569,199	417,369

The maintenance cost is related to the footprint area, which is the same for all scenarios. The maintenance cost was $1.91/ft^2$ every 2 years, $2.5/ft^2$ every 10 years, and of $10.11/ft^2$ every 20 years. The footprint of 13,145 ft^2 was used, then the estimate cost of maintenance for this basin for 40 years will be of $899,413 without considering the interest rate. Although the recycled crushed glass has shown to be cost effective regarding maintenance, the total cost is calculated by using the sand maintenance cost so actual cost may be less (Dorman, et. al., 2013). The average cost of Muhly grass and Cedar Elm plants were used. Excel was used to make the economic analysis calculations and the table with the results is included in Appendix A.

Muhly grass and Cedar Elm plants adapt to the San Antonio climate, which make them suitable for the LID features and can provide the specific characteristics needed to clean pollutants (Center for Research, 2011). It is expected that these plants will help with the removal of TSS, phosphorus, nitrogen, and fecal coliform. In the case of the Cedar Elm, its large size and roots help achieve a better pollutant removal since bigger vegetation has proved to have better removal outcomes than smaller plants (Dorman, et. al., 2013). Additionally, the Muhly grass is also considered an ornamental plant, which provides aesthetic benefits in the design (Center for Research, 2011 and Dorman, et. al., 2013). The plants will require little to no irrigation and recycled water could be used as a supplement to irrigate them when necessary. The water quality experiments for the AC condensate water from the AET building at UTSA showed that the water was suitable for irrigation. The results are presented in Table 4 showing concentration values for AC condensate water, reclaimed water, blowdown water, and the optimal concentration values for irrigation.

The optimum concentrations are 5.5 to 8.5 for pH, 0 to 700 microsiemens/cm for conductivity, 0 to 125 mg/L CaCO3 for alkalinity, hardness does not affect the plants directly, copper is not recommended above 0.5 mg/L but it will not necessary have impacts on the plants, zinc is not present in the concentrations, from 0 to 120 mg/L for sodium, and from 0 to 15 mg/L for phosphorous (Yiasoumi, et. al., 2011, Natural Resource Management Ministerial Council, n.d., Hopkins, 2007, and Douglas, n.d.). The concentrations obtained in the lab for AC condensate water are between the optimal values for irrigation with the exception of copper. Copper is believed to be present due to copper in the pipes and not related to the water concentrations directly.

Table 4. Water Quality Characteristics

	AC Condensate H2O	Reclaimed H2O	Blowdown H2O	Optimal Conditions
Turbidity (NTU)	2.51	0.65	2.5	Not a Concern
pH	5.75	5.72	8.05	5.5 to 8.5
Conductivity (microsiemens/cm)	9.65	11.71	2.23	0 to 700
Alkalinity (mg/L CaCO3)	2	4	111	0 to 125
Hardness due to Calcium (mg/L CaCo3)	225	250	1296*	Not a Concern
Total Hardness (mg/L CaCO3)	225	250	1684	Not a Concern
Copper (mg/L)	1.851	1.905	0.037	< 0.5
Zinc (mg/L)	0	0	0	Not a Concern
Sodium (mg/L)	0.627	0.108	76.52	0 to 120
Phosphorus (mg/L PO4)	0.38	0.56	2.75	0 to 15

CONCLUSIONS

The goal of this project was successfully achieved by obtaining the water quality volume treated by the BMP, the depth size, the footprint area, the adequate media and flora, and an economic analysis including 3 different scenarios. The drainage area and the future average precipitation were used to calculate the quality volume and the depth of the basin and the footprint area. The results for the average future precipitation were estimated and the results agree with other studies (Karl, et. al., 2009). The footprint area was obtained to be of similar size to a sand filter already existing on campus near the development and so the comparison showed that the project followed a correct approach. Additionally, the flora selected adapts to San Antonio climate and if irrigation is needed, water quality testing showed that recycled AC condensate water could be used for the plants. In this project, sand and crushed glass were proposed as media. The three economic analyses scenarios showed that when using crushed glass and a geomembrane as liner, the most economical option is attained.

This project can be used as a reference when designing bioretention filters in San Antonio or in other places. The methodology followed for the design of the basin can be used in different projects to achieve similar results. Included in the methodology, the precipitation changes and the drainage area calculation methods can be followed in a similar way for other places in the world to obtain specific results for diverse developments.

This project can be further developed by making experiments to obtain with more accuracy the pollutant removal of the bioretention basin using different media. The three economic analyses scenarios introduced in the thesis can be built in a smaller scale to obtain more accurate pollution removal loads for each one. Due to the fact that crushed glass as media was not very common, little information was available regarding its pollutant removal properties when using it in a BMP. Further experiments to scale can be used to determine if crushed glass is a better option in bioretention basins regarding pollution removal. Theory combined with practice can improve the results and by implementing bioretention basins, ecosystems could be conserved and human impact will be diminished.

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Appendix A

Results obtained following the methodology explained above and reference table:

LM (lb)=	5490
LR (lb)=	6234
F=	0.88
WQV (ft^3)=	26474
Deq (ft)=	2.4
A (ft^2)=	10955
A+20%(ft^2)=	13145

Table 5. Average Annual Rainfall by County

County	Average Annual Precipitation (inches)
Bexar	30
Comal	33
Hays	33
Kinney	22
Medina	28
Travis	32
Uvalde	25
Williamson	32

Bioretention Basin Economic Analysis:

	Dollar/ft^2	
Excavation with underdrains:	5	
Soil/crushed glass:	5	2
Aggregates:	0.28	
Pipe (underdrain):	3.6	
Gutter:	18	
Mulch:	0.32	0.42
Concrete barrier (liner)/filter fabric:	12	0.45
Vegetation:	2	

Mantainance (every 2 years):	1.9
Mantainance (every 10 years):	2.5
Replacement (every 20 years):	10.1

Approximate cost using soil, concrete as a liner, and regular depth of mulch ($):
607321

Approximate cost using crushed sand, concrete as a liner, and mulch required ($):
569199

Approximate cost using crushed sand, concrete as a liner, and mulch required ($):
417369

Mantainance every 2 years ($):
25108
Mantainance every 10 years ($):
32864
Replacement every 20 years ($):
132901

Mantainance every 40 years ($):
899413.1942