UAB LIBRARIES
The University of Alabama at Birmingham

University of Alabama at Birmingham
UAB Digital Commons

All ETDs from UAB

UAB Theses & Dissertations

2012

Design of An Underground Storage Tank Involving Water Collection for Water Reuse to Irrigate the Campus Green Area of the UAB Campus

Zhuo Li
University of Alabama at Birmingham

Follow this and additional works at: https://digitalcommons.library.uab.edu/etd-collection

Recommended Citation

Li, Zhuo, "Design of An Underground Storage Tank Involving Water Collection for Water Reuse to Irrigate the Campus Green Area of the UAB Campus" (2012). *All ETDs from UAB*. 2279.
https://digitalcommons.library.uab.edu/etd-collection/2279

This content has been accepted for inclusion by an authorized administrator of the UAB Digital Commons, and is provided as a free open access item. All inquiries regarding this item or the UAB Digital Commons should be directed to the UAB Libraries Office of Scholarly Communication.

DESIGN OF AN UNDERGROUND STORAGE TANK INVOLVING WATER COLLECTION FOR WATER REUSE TO IRRIGATE THE CAMPUS GREEN AREA OF THE UAB CAMPUS

by

ZHUO LI

DR. ROBERT W. PETERS, COMMITTEE CHAIR
DR. JASON T. KIRBY
DR. VIRGINIA P. SISIOPIKU

A THESIS

Submitted to the Graduate Faculty of the University of Alabama at Birmingham,
in partial fulfillment of the requirements of the degree of Master of Science

BIRMINGHAM, ALABAMA

2012

DESIGN OF AN UNDERGROUND STORAGE TANK INVOLVING WATER COLLECTION FOR WATER REUSE TO IRRIGATE THE CAMPUS GREEN AREA OF THE UAB CAMPUS

ZHUO LI

DEPARTMENT OF CIVIL, CONSTRUCTION, AND

ENVIRONMENTAL ENGINEERING

ABSTRACT

The water supply of the UAB Campus Recreation Center is based on a natural underground water source, which is being using as swimming pool water. The underground water is continuously pumped from its foundation in order to avoid flooding the basement of the Recreation Center. As a result, in addition to the water usage of the Recreation Center, the additional water pumped underground could be utilized to irrigate the campus green area.

In this project, the methodology is specifically a case study for the UAB Campus Green area, and research was performed to analyze the feasibility of whether the pumped and drained underground water and roof runoff could irrigate the campus green area, focusing on the irrigation requirements of grass. This project primarily focused on the hydrological field, based on the fundamental equation of hydrology: $P - R - E - T - G = \Delta S$, where *P* is precipitation, *R* is runoff, *E* is evaporation, *T* is transpiration, *G* is groundwater flux, and ΔS is the change in storage. The possibility of whether the collected rainwater supplements the demand of grass land irrigation was determined.

To achieve this goal, a rainwater harvesting system was designed, and the use of Underground Storage Tanks (USTs) was assessed for their ability to store the collected rainfall water for further usage. This research performed a cost analysis, addressing the payback period, to explore the feasibility of implementing rainwater harvesting system at UAB. In addition, a sensitivity analysis addressing precipitation and evapotranspiration was performed to detect the impact on payback period and tank size. The sensitivity analysis indicated that there was little influence of changes to precipitation and evapotranspiration on the payback period.

Overall, the payback period was estimated to be 9.4 years which is little long for a project. Hence, several possible methods were recommended and discussed to reduce the payback period. Based on cost alone, it is not worthwhile to implement rainwater harvesting at UAB. However, as sustainability, environmental friendly option, it may be good for this application.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. Robert W. Peters for his valuable assistance and effort in my research in spite of his busy schedule. I especially want to thank Matt Winslett for his strong support and help in providing detailed water usage data, showing me the facilities, etc. I would also like to thank Dr. Jason T. Kirby and Dr. Virginia P. Sisiopiku for their valuable time and feedback as my thesis committee members. I also thank the Civil, Construction, and Environmental Engineering Department for resource support. Finally, I would like to thank my parents, uncle and family members for their constant financial support and encouragement. Without them, I wouldn’t have the opportunity to study in the United States, much less conduct this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMC	Antecedent Moisture Condition
BOD	Biochemical Oxygen Demand
DBAE	Department of Biology and Agriculture Engineering
ET	Evapotranspiration
GI	Galvanized Iron
NCSU	North Carolina State University
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
PVC	Polyvinyl Chloride
REC	Recreation Center
RHS	Rainwater Harvesting System
SWMM	Storm Water Management Model
TAMU	Texas A&M University
UAB	University of Alabama at Birmingham
UBOB	University Boulevard Office Building
UST	Underground Storage Tank

CHAPTER 1

INTRODUCTION

1.1 Water Conservation

Water conservation involves the reduction of water consumption and the recycling of water and wastewater for other uses, such as cleaning, flushing toilets, or irrigation. Water conservation is an important concept and aspect in sustainable design and development. Although the earth has vast quantities of water, fresh water accounts for only 2.5% of the total water resources (Shiklomanov and Gleick, 1993). The total volume of renewable freshwater in the global hydrologic cycle is many times more than is needed to sustain the current world population. However, only about 31% of the annual renewable water is accessible for human use due to the geographical and seasonal variation (Postel, 2000; Shiklomanov, 2000; Asano, *et al.*, 2007).

On a global scale, annual water use for irrigation exceeds 65% of the total human water use. Water usages for industry are approximately 20%, and those for municipal use are about 10% (Cosgrove and Rijsberman, 2000; Asano, *et al.*, 2007). Universally, the water resources in different regions and countries are expected to face unprecedented pressure in coming decades as a result of continuing population growth and uneven distribution of water and population (WHO, 2000; Asano, *et al.*, 2007). Due to the limited water available for human consumption, using rainwater is important and a good option to effectively achieve water conservation opportunities.

1.2 Significance of Water Conservation at the University of Alabama at Birmingham

The University of Alabama at Birmingham (UAB) has many facilities, including teaching buildings, laboratories, and sporting facilities. Moreover, there is a large, grassy area on the UAB campus (the campus green area) that needs a great amount of water for irrigation to maintain the vegetation. The water consumption at UAB in 2008-2009 and 2009-2010 was 697,920 ccf (522,080,416 gallons) and 659,271ccf (493,168,956 gallons), respectively (Winslett, 2011). With the amount of water usage, the corresponding water and sewer costs at UAB were $7,025,011 and $6,907,892 in 2008-2009 and 2009-2010, respectively (Winslett, 2011). With an increasing public awareness of dealing with sustainability, water conservation and reuse of water are receiving more attention than ever before. Water conservation can not only reduce the water cost at UAB but also achieve environmental benefits in protecting the natural water resources.

The UAB Facilities Management Department has taken steps to reduce the energy consumption in buildings. Through energy audits and conservation, the power consumption has been reduced dramatically and cost effectively. Similarly, the Facilities Management Department has taken steps in water conservation techniques. An underground storage tank (UST) was installed at the University Boulevard Office Building (UBOB) parking deck to collect the rainwater from the parking deck roof for the landscape irrigation near the UBOB. The runoff water is collected and drained through the pipe to the UST, as shown in Figure 1. Water exits into the UST through an inlet pipe with a spiral water channel that helps to filter sand and mud, as shown in Figure 2. Rainwater is pumped from the UST in order to water the shrubs next to the UBOB parking deck. Figure 3 shows the shrub area near the UBOB parking deck receiving irrigation. However, due to the pipe exposure in the open air, the system is closed in order to avoid the risk of freezing because the temperature in Birmingham area can be below 32^{o}F during the winter season.

Figure 1. Pipe Line in the UBOB Parking Deck.

Figure 2. Rainwater Inlet.

Figure 3. Shrubs near the UBOB Parking Deck.

1.3 Rainwater Collection Technology

The collection of rainwater runoff from building and household roofs is the most common method of harvesting rainwater (Gould and Nissen-Petersen, 1999). The rainwater harvesting has many advantages. First of all, rainwater harvesting can reduce the runoff volume from precipitation. Second, collected rainwater is a good water source for emergency use. Third, rainwater harvesting is sustainable and environmentally friendly. Finally, rainwater harvesting can conserve natural water resources. Considering climate conditions, collected rainwater can provide water supplements during drought periods or emergency events. Although harvesting rainwater can be expensive, it can be used from time to time. However, justification for installing such a system is usually based upon financial considerations.

CHAPTER 2

STUDY BACKGROUND

2.1 Objective and Scope of the Study

The objective of this study was to analytically investigate each term involved in the hydrologic cycle for the Campus Green area and the Campus Recreation Center at UAB. Determining land area and type, and analyzing historical data, the quantity of rainwater from roof runoff can be estimated as well as the amount of water required for irrigating the grassy area (Campus Green). To harvest the roof rainwater, a rainwater harvesting system (RHS) has been introduced for this project. Furthermore, a UST design combined with rainfall collection and natured underground water sources were performed to store the water for usage as irrigation based on the natural hydrology. Based on this information and the actual topography of the UAB Campus Green, the size, number and locations of USTs were identified. Finally, the economic issues of the project, including construction costs, were estimated and compared with current costs paid to Birmingham Water Works. The purpose of this study was to examine a way to reuse rainwater for water conservation opportunities on the UAB campus benefiting the environment.

2.2 Rainwater Harvesting Investigation at Texas A&M University

Property urbanization increases the impervious area of land, which leads to an increase of total runoff volume impacting the hydrologic cycle. It also influences the peak flow volume and concentration time, which affects the generation of high rates of runoff (Dietz, 2007). For the purpose of generating high runoff volume and using the collected rainwater for irrigating the local landscape, Saour (2009) performed a feasibility study for implementing a RHS on the west campus of Texas A&M University (TAMU). The study focused on the efficiency of a RHS to reduce irrigation costs and total campus runoff volume to White Creek.

A simple RHS was introduced, including an UST for a water collection facility at TAMU for future irrigation use. One hundred and thirteen buildings, with 60.5 acres of roof area, were selected for installation of a RHS to reduce runoff volume. Assuming 100% rainwater collection efficiency over an entire year, 60,850,000 gallons rainwater could be collected, thereby saving an estimated $406,000.00 per year at $2.44 per 1,000 gallons (City of College Station, 2008).

For estimating water demands for landscape area and rainwater collection, the estimate (Saour, 2009) was calculated using the following equations (Persyn, *et al.*, 2008):

$$\textit{SUPPLY (gallons)} = P(in) \times Area_R(ft^2) \times C \times 0.623$$

$$\textit{DEMAND (gallons)} = I(in) \times Area_I(ft^2) \times 0.623$$

where P = the amount of annual rainfall,

$Area_R$ = the catchment area,

$Area_I$ = irrigated area,

C = the runoff coefficient based on the rational method, which is based on the roofing material

0.623 = the conversion factor allowing the supply to be calculated in gallons with the listed units for each variable

I = the water amount needed for properly irrigating the landscape.

This estimation of water demand is not very accurate and only provides a rough estimate for the water supply and demand. There was no detailed explanation of how the water quantity for proper irrigation, parameter *I*, was determined. The water demand for irrigation should consider weather conditions, soil type, etc. Therefore, the cost saving on irrigation water cannot be estimated accurately due to insufficient details of exact water-needs data.

In designing the UST system, two scenarios were developed to compare their efficiency in conserving water. Both of the two scenarios studied by Saour (2009) were designed to collect all the annual rainwater. However, scenario one considered the 2-year peak flow, whereas scenario two was designed with a certain collection capacity for each storm. Scenario one was likely to achieve maximum rainwater collection with an obviously larger tank size and higher initial costs. The estimated payback periods for scenarios one and two were 20 years and 14 years, respectively. The cost and saving data for installing the rainwater harvesting system conducted by Saour (2009) are summarized in Table 1.

Table 1. RHS Water Conservation Savings and Cost of Saour’s Study (2009).

						Initial Cost ($)	
RHS	Area (sft)	Supply (gal)	Demand (gal)	Supply/Demand	Savings per year ($)	Scenario 1	Scenario 2
1	53,456	1,233,891	1,523,322	81%	$ 3,737.73	$ 174,351.00	$ 128,004.00
2	152,960	3,530,646	4,645,587	76%	$ 11,385.56	$ 476,541.00	$ 348,976.00
3	90,089	2,079,458	4,621,018	45%	$ 11,385.56	$ 276,357.00	$ 189,745.00
4	115,496	2,665,891	4,518,460	59%	$ 11,106.59	$ 354,138.00	$ 236,092.00
5	42,189	973,820	2,631,945	37%	$ 6,503.79	$ 130,722.00	$ 99,424.00
6	77,488	1,788,599	8,129,995	22%	$ 20,093.54	$ 236,092.00	$ 175,478.00
6b	30,818	711,343	3,556,717	20%	$ 8,863.97	$ 59,023.00	$ 76,054.00
7	67,929	1,567,952	3,646,400	43%	$ 8,938.48	$ 226,437.00	$ 152,228.00
8	32,388	747,592	3,559,960	21%	$ 8,842.71	$ 99,424.00	$ 76,054.00
9	180,758	4,172,290	11,920,829	35%	$ 29,229.50	$ 558,796.00	$ 381,727.00
10	24,811	572,700	1,101,347	52%	$ 2,681.61	$ 86,612.00	$ 59,023.00
11	69,090	1,594,741	3,543,869	45%	$ 8,591.77	$ 228,162.00	$ 152,108.00
12	35,772	825,690	3,058,111	27%	$ 7,460.62	$ 118,046.00	$ 76,054.00
13	21,392	493,769	1,410,768	35%	$ 3,438.33	$ 76,054.00	$ 49,712.00
14	16,187	373,626	1,624,461	23%	$ 3,935.96	$ 49,712.00	$ 38,027.00
15	41,029	947,035	4,509,691	21%	$ 11,105.27	$ 84,375.00	$ 99,424.00
16	29,566	682,457	4,014,452	17%	$ 10,050.19	$ 25,352.00	$ 25,352.00
17	185,633	4,284,816	7,934,844	54%	$ 19,357.57	$ 548,238.00	$ 394,539.00
18	31,858	735,359	1,838,397	40%	$ 4,542.21	$ 112,100.00	$ 71,699.00
19	39,526	912,352	950,367	96%	$ 2,313.91	$ 118,046.00	$ 87,739.00
20	40,857	943,074	1,473,554	64%	$ 3,623.28	$ 118,046.00	$ 87,739.00
21	33,559	774,610	3,622,045	21%	$ 8,837.79	$ 93,206.00	$ 78,293.00
22	15,944	368,017	1,143,992	32%	$ 2,791.34	$ 49,712.00	$ 38,027.00
23	20,054	462,894	2,180,682	21%	$ 5,320.86	$ 59,023.00	$ 49,712.00
24	81,067	1,871,205	5,195,755	36%	$ 12,677.64	$ 266,189.00	$ 177,069.00
25	122,795	2,834,363	5,212,417	54%	$ 12,718.30	$ 381,727.00	$ 263,681.00
26	58,233	1,344,150	1,821,931	74%	$ 4,445.51	$ 177,069.00	$ 118,046.00
27	11,212	258,806	758,689	34%	$ 1,851.20	$ 38,027.00	$ 27,589.00
28	10,175	234,861	1,010,131	23%	$ 2,464.72	$ 38,027.00	$ 27,589.00
29	21,431	494,680	575,741	86%	$ 1,404.81	$ 59,023.00	$ 49,712.00
30	26,609	614,195	1,045,360	59%	$ 2,550.68	$ 12,676.00	$ 12,676.00
31	83,246	1,921,501	4,977,891	39%	$ 12,146.05	$ 263,681.00	$ 236,092.00
32	20,792	479,934	775,782	62%	$ 1,892.91	$ 80,530.00	$ 50,704.00
33	34,827	803,892	2,120,564	38%	$ 5,174.18	$ 108,735.00	$ 76,054.00
34	11,788	272,088	711,184	38%	$ 1,735.29	$ 38,027.00	$ 27,589.00
35	101,488	2,342,573	7,151,609	33%	$ 17,449.93	$ 326,069.00	$ 156,073.00
36	55,447	1,279,830	3,460,641	37%	$ 8,443.96	$ 196,849.00	$ 133,471.00
37	11,788	272,088	711,184	38%	$ 7,554.05	$ 175,478.00	$ 116,319.00
38	55,676	1,285,128	5,065,333	25%	$ 12,359.41	$ 189,401.00	$ 90,968.00
39	101,921	2,352,555	10,726,221	22%	$ 26,171.98	$ 337,017.00	$ 238,360.00
40	52,325	1,207,771	3,492,948	35%	$ 8,522.79	$ 193,123.00	$ 118,046.00
41	209,436	4,834,233	14,668,418	33%	$ 35,790.94	$ 649,253.00	$ 447,408.00
42	117,004	2,700,704	6,802,351	40%	$ 16,597.74	$ 366,814.00	$ 248,768.00
Total	**2,636,114**	**60,847,180**	**163,444,963**		**$ 406,090.24**	**$ 8,256,280.00**	**$ 5,787,444.00**

Adapted from “Implementing Rainwater Harvesting System on the Texas A&M Campus for Irrigation Purpose: A Feasibility Study” by William H. Saour, 2009. Copyright 2009 by the Name of Copyright Holder. Adapted with Permission.

With the simulated rainwater harvesting system, Saour (2009) developed a hydraulic simulation using the Storm Water Management Model (SWMM) (U.S. EPA, 2004) with three precipitation events of 2-yr, 10-yr, and 100-yr 24-hr storms to compare the storm flow control effect with two conditions: no RHS and scenario one. The results showed that the rainwater harvesting system failed to achieve significant storm water control goals.

The research conducted by Saour (2009) on the west campus of TAMU is similar to the design for the underground storage tank involving rainwater collection on the UAB Campus Green. However, Saour's research was only a feasibility study and provided a general estimation on water supply, demand, initial cost and payback. As a result, the method used by Saour (2009) cannot be used as a referenced design procedure for the research at UAB. The application of RHS in this project is focused on a single large city block; the land type in the research area is pervious, so storm water control is not the main purpose of this project. Rather, the opportunity for water conservation using RHS for landscape irrigation is the desired goal.

2.3 The Peace College Study

Peace College performed a preliminary study of RHS implementation on its campus, which was based on the rainwater harvesting model of the Department of Biology and Agriculture Engineering (DBAE) at North Carolina State University. Due to the challenge of record drought in the city of Raleigh, it raised the awareness and willingness for rainwater harvesting implementation. This project primarily focused on the management of storm water runoff and water quality the improvement of the quality of water discharged from the Peace College campus nearly to the Neuse River.

In their research report (Knight, 2009), a 300,000 gallon underground storage: treatment facility would be utilized to collect rainwater from a RHS, and the captured rainwater would be used to irrigate the local landscape. This RHS would replace the domestic water supply of irrigation; in addition, the storage capacity would help achieve significant peak volume runoff reduction, nutrient removal and water quality enhancement. System controls and a monitoring system would be installed to manage water usage and monitor water quality improvement. In the RHS, a series of gauges was installed to monitor and record the rainwater captured and available water, and a flow meter was installed to monitor the water used for irrigation. In addition, a monitoring station was planned for installation upstream and downstream to monitor the performance of concerned pollutants removal.

2.3.1 Water Quality Monitoring Objectives

The RHS project was expected to reduce the runoff volume by 50% from the Peace College campus (Knight, 2009). By utilizing more than 50% of the rainwater of annual precipitation, approximately 3,000,000 gallons of water were to be utilized for irrigation and to help restore the natural hydrology in this area. Within the RHS, potential pollutants loading would be reduced, with nitrogen being of primary interest. By simulating the RHS model, potentially 60 pounds of nitrogen would be removed based on the annual base flow (Knight, 2009).

Rainwater harvesting system may also provide water-quality improvement for the receiving water stream. It is different from conventional Best Management Practices (BMPs), which are assigned a pollutant reduction percentage by directly measuring results from the process. RHS improves the water quality results from the combination of detention and further irrigation uses. Measuring influent and effluent pollutants loading is a better way to understand the effect of water quality improvement with RHS. For the future design, the measured goals and anticipated results for the Peace College Rainwater Harvest System. They were as follows (Knight, 2009):

Project Goal	**Measurable Result For Proposed Project**
Develop a low-impact development demonstration site.	Completed construction of a rainwater harvesting system, permeable pavement walkway, green roof, and bioretention areas.
Improve water quality of runoff leaving the campus.	Obtain water quality samples prior to construction and compare to those after construction to demonstrate improvement.
Recreate pre-development hydrology by reducing the volume of runoff leaving the campus and returning the captured water back to the landscape areas through irrigation.	Measure the quantity of precipitation for each event, as well as the volume of storm water runoff captured for each event within the cistern.
Educate visitors at the demonstration site low-impact development.	Observe visitors at the demonstration site and solicit feedback from those visitors, and measure participation in workshops and information sessions
Educate people throughout the community.	Measure participation in workshops and information sessions, as well as website traffic.

Adapted from “Peace College Rain Harvesting System” by Everette H. Knight, 2009. Copyright 2009 by the Name of Copyright Holder. Adapted with permission.

The preliminary study of a rainwater harvesting system based on the DBAE in the North Carolina State University is another RHS application study on a college campus. However, besides using rainwater for irrigation, the main purpose of that project was to control the runoff volume and improve the quality of the effluent water discharged to the connected drainage stream. The preliminary report discussed the effect of water quality improvement rather than focusing on the water conservation opportunity and water cost savings (Knight, 2009). Therefore, this research achieved different goals from the research being performed on the UAB Campus Green.

2.4 The Bangladesh Study

Although the groundwater in Bangladesh involves considerable quantities for domestic water supply, the high concentration of arsenic in water threatens public health in urban areas. The rainwater harvesting is a cost-effective technology to help solve this problem. Therefore, a feasibility study of rainwater harvesting to supply domestic water needs was performed for Sylhet city (Alam, *et al*., 2011) as a representative urban area in Bangladesh.

A total of 44 years of local precipitation data was collected to determine the mean amount of precipitation for each month. Analysis of the data determined that maximum rainfall occurred during from April to October. To analyze the potential rainwater collection from the precipitation, an experimental roof associated with a constructed storage tank was set up. In this research, the collected rainwater was monitored every 15 days for the feasibility of using water during drought periods. Water characteristics, such as suspended solids, dissolved solids, turbidity, hardness, biochemical oxygen demand

(BOD), lead, iron, and e. coli that form microorganisms were identified as parameters detrimental to water quality (Alam, *et al.*, 2011). To estimate the available rainwater, the equation (Ahmed and Rahman, 2000) $Y = (f \times A \times R) / 1{,}000\ \mathrm{m}^3$ was used,

where Y = the amount of water yielded per month

f = the catchment's efficiency or coefficient of available runoff

R = monthly rainfall (mm)

A = the catchment area in square meters.

By considering 25% of the rainwater loss by evaporation and washing the catchment area to get quality rainwater, the minimum catchment area with a runoff coefficient of 0.7 and 2.46 m annual rainfall depth was expressed in the following equation (Ahmed and Rahman, 2000): $A = 0.212\ q\ N$, where N is the number of people supplied with q liters per capita per day (lpcd). A family consisting of five people consuming 5 liters water capita/day was used as the basis in the study.

The research results indicated that the quantities of harvesting rainwater can fully fill family water demand (Alam, *et al.*, 2011). The monitoring of the water quality for a three-month period showed water quality parameters slightly changed during the storage period that the water quality met the domestic water supply standard. In addition, a brief cost analysis was performed to compare the water cost of rainwater harvesting with traditional and private water supply systems. Using the rainwater harvesting system for daily water supply was significantly lower in cost than a private water supply (approximately 1/3 the cost) (Alam, *et al.*, 2011).

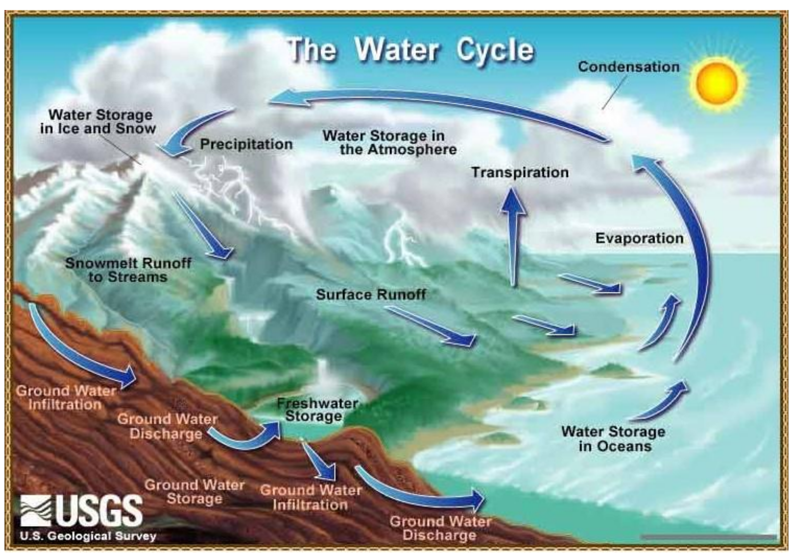
The feasibility study of rainwater harvesting implementation in Sylhet City, Bangladesh, involved an application study of the RHS for domestic water supply.

However, the research is different from the purpose of rainwater harvesting in UAB. The study of Alam *et al.* (2011) involves collection of rainwater to replace the public water supply for daily usage that was a high requirement for water quality. The rainwater collection project at UAB focuses on the possible quantity of rainwater that can be harvested, which does have requirements in water quantity. Therefore, the common points between these two research projects are rainwater harvesting, so the Alam *et al*.'s study (2011) can provide an idea for rainwater harvesting quantity estimation.

CHAPTER 3

HYDROLOGIC ANALYSIS

The hydrologic cycle is a concept in hydrology. It is a global, sun-driven process where water is transported from the ocean to the atmosphere to the land and goes back to the sea. Water is evaporated by the sun, incorporated into clouds as water vapor, falls to the land as precipitation, and finally finds its way to the atmosphere by a variety of hydrologic processes (Viessman and Lewis, 2003). The hydrological cycle can be expressed in terms of six major components: precipitation (P), runoff (R), transpiration (T), evaporation (E), groundwater flux (G), and the storage changes (ΔS). Figure 4 illustrates the layout of the hydrologic cycle.



Source: U.S. Geological Survey, 2012.

Figure 4. Hydrologic Cycle.

The hydrologic budget equation is expressed as:

$$P - R - E - T - G = \Delta S$$

This is the basis of hydrologic modeling, and various applications utilize this equation.

In this study, the irrigation water source involves the groundwater (G) and rainfall water (precipitation). The historical precipitation data was investigated to estimate the quantity of rainwater that could be obtained through the precipitation events by using the Natural Resource Conservation Service (NRCS) method to calculate the runoff (R) quantities in different land type. To estimate evaporation and transpiration, the water quantity lost from turf glass through this process can be determined as well as the amount of irrigation water. The water pumped from the natural underground source under the Campus Recreation Center involves the groundwater flow, and the change of the water pumped for the swimming pool represents the storage changes (ΔS). Therefore, the entire study is based on hydrologic cycle modeling to conduct research on the sustainable design and reuse of water.

3.1 Birmingham Area Climatology

Birmingham is located in a hilly area of north-central Alabama in the foothills of the Appalachian Mountains. There is a series of southwest to northeast valleys and ridges in the area. Although summers are long and hot, they are not generally excessively hot. On a typical mid-summer day, the temperature is nearly 70 degrees at dawn, approach 90^{o} at mid-day, and goes down below 90^{o} during the afternoon. July is normally the hottest month, with no high humidity added to the atmosphere, but there is little difference from mid-June to mid-August. January is normally the coldest month, but there is not much difference from mid-December to mid-February. Overall, winters are relatively mild. Even on cold days, it is unusual for the temperature to remain below freezing all day. Snowfall is erratic and usually melts quickly (Birmingham Weather Forecast Office, National Weather Service, 2011).

Birmingham has abundant rainfall that is fairly well distributed throughout the year. However, some of the wetter winter months, plus March and July, have twice the rainfall of October, the driest month. Summer rainfall is almost entirely from scattered afternoon and early evening thunderstorms. Serious droughts are generally rare and not severe. The stormiest time of the year with the greatest risk of severe thunderstorms and tornadoes is in spring, especially in March and April (Birmingham Weather Forecast Office, National Weather Service, 2011).

3.2 Site Description

The UAB Campus Green is a huge, open green space designed to be attractive, safe and used by the university community. The Campus Green area boundary runs with sidewalk near several facilities, including the Campus Recreation Center, Chemistry Building, Camp Hall, Heritage Hall, University Boulevard and 10th Avenue South. The Campus Green has been a part of UAB since 2008 as a part of the traditions in higher education. The plane figure of the Campus Green is indicated in Appendix A, which shows the layout of the green area and facilities (University of Alabama at Birmingham, 2011). The UAB Campus Green has over seven acres of green space and major sidewalks with pedestrian lighting, architectural landscape elements, and a number of trees. The

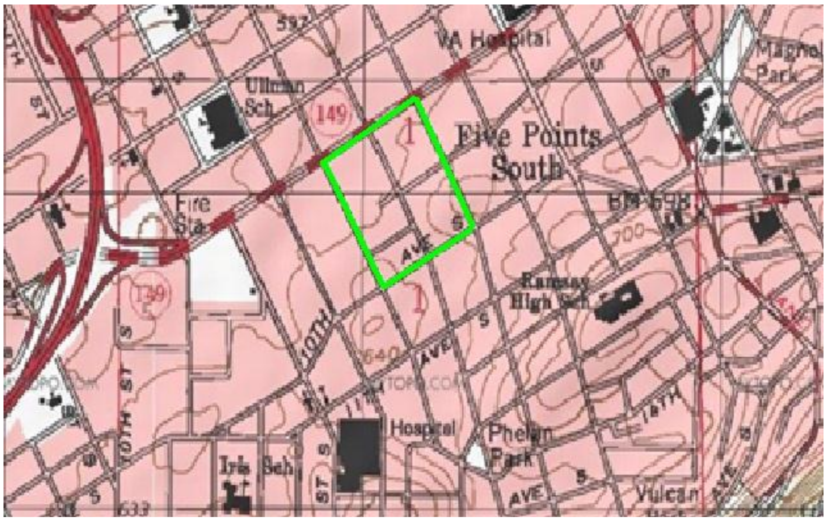
Campus Green is bordered by Blazer Hall, the Dining Commons, the Campus Recreation Center, and Heritage Hall, as shown in Figure 5.

Source: Google Maps, 2012.

Figure 5. Satellite View of UAB Campus Green.

The UAB campus green is located on a Birmingham city block, which boundary runs along with University Blvd., 10th Avenue South, 14th Street South and 16th Street South. The UAB Campus Green goes down with a general trend from the north to the south in elevation, and the southeast and southwest sides of the block have the highest elevation. The topography becomes slightly flat closest to University Blvd. The detailed topography map is shown in Figure 6 highlighted in green. Through the plane map of the

UAB Campus Green, almost the entire area is covered by grass or trees with the exception of pathway sidewalks and buildings.



Source: www.mytopo.com/ (2011).

Figure 6. Topographic Map.

An investigation has been done on Web Soil Survey; a brief description of the research area is listed in Table 2. From the table, the land type of this block is urban land and, the landform position is side sloped in three-dimensions.

Table 2. Map Unit Descriptions.

Map Unit Description

Printable Version

Report — Map Unit Description

Jefferson County, Alabama

44—Urban land

Map Unit Setting

Mean annual precipitation: 48 to 56 inches
Mean annual air temperature: 57 to 64 degrees F
Frost-free period: 180 to 210 days

Map Unit Composition

Urban land: 95 percent

Description of Urban Land

Setting

Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Convex
Across-slope shape: Linear

Interpretive groups

Land capability (nonirrigated): 8s

Source: Web Soil Survey. NRCS, 2011.

3.2.1 Historical Precipitation Data

On the National Oceanic and Atmospheric Administration (NOAA) website, three-year monthly historical precipitation data (from 2008 to 2010), for the Birmingham area, was investigated and are listed in Table 3, along with the overall mean monthly value. The precipitation data were analyzed to estimate the original amount of rainfall water. Moreover, a precipitation distribution graph in each year is illustrated in Figure 7. The precipitation quantity distribution in each month varies by each year and is not constant (see Figure 7), therefore, it is not simple to determine which month or season is dry within an individual year. However, it can be seen that September has the least precipitation within a year with the exception of 2009. In September, the precipitation quantity is extremely low (less than 0.5 inches in 2008 and 2010). It is the period in which droughts as most likely in Birmingham. In order to obtain more information, a graph is developed by using three year mean value and is presented in Figure 8.

Table 3. Historical Monthly Precipitation (in) Data in Birmingham, Alabama.

Month	**Year**			
	2008	**2009**	**2010**	**Mean**
January	4.47	6.28	4.01	4.92
February	4.66	5.07	3.14	4.29
March	4.59	6.82	6.91	6.11
April	5.24	2.12	5.3	4.22
May	7.98	6.26	8.82	7.69
June	3.97	3.03	3.29	3.43
July	5.05	7.59	1.13	4.59
August	7.9	4.49	4.79	5.73
September	0.4	10.69	0.43	3.84
October	1.94	7.88	3.7	4.51
November	2.49	5.33	4.82	4.21
December	6.4	6.1	1.37	4.62

Source: Birmingham Weather Forecast Office, 2011

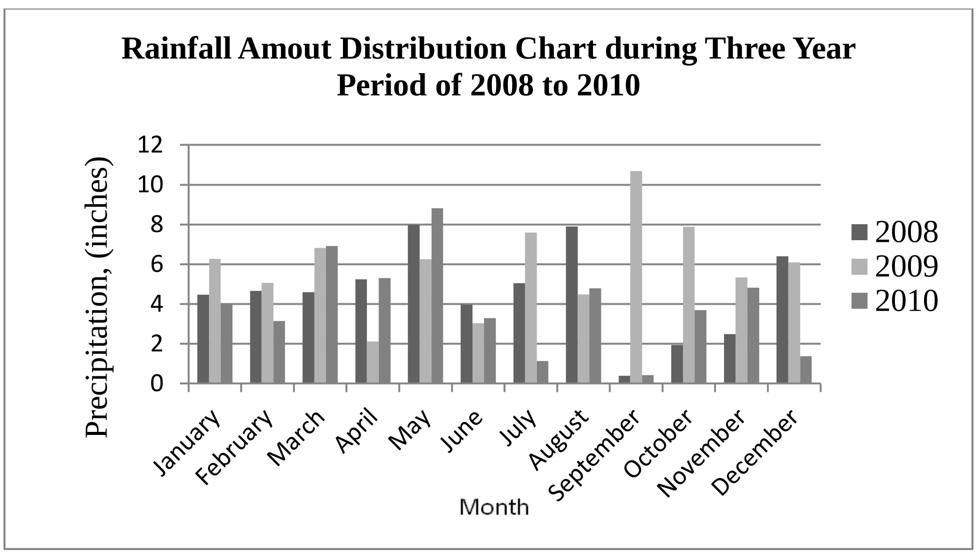


Figure 7. Rainfall Amount Distributions during Three-Year Period.

Based on the graph (Figure 8), besides September, October is another month with limited rainfall amounts, so the fall season in Birmingham is the most drought-prone period of the year. The summer has the hottest months with the most water evaporated so that the precipitation in June was reduced, resulting in less water available for irrigation. Based on the figure, it was shown that the precipitation is distributed unevenly during the year. Therefore, in the following calculation, the average precipitation was used with the research data because the mean value was most logical for a long estimation prospective, and implementing the rainwater harvesting is also for long-period application.

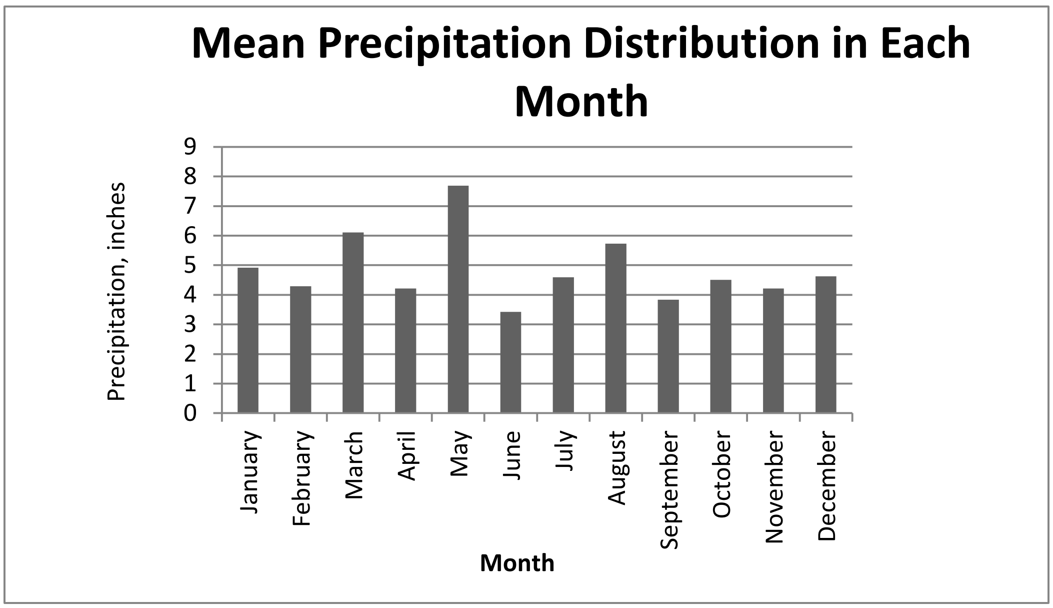


Figure 8. Average Precipitation Distributions in Each Month.

3.3 The Runoff Volume Calculation by NRCS Method

The calculation for estimating the depth of effective rainfall during a storm event should estimate the maximum possible retention *S*, dependent on the soil type and land use conditions in the area. The Natural Resource Conservation Service (NRCS) has performed considerable research to approximate *S* for various soil types and land use and has developed curve numbers as a function of soil type, land use, and hydrologic conditions of the drainage basin. The relationship between S and the curve number is expressed as Equation 3.1 (SCS, 1986):

$$S = \frac{1000}{CN} - 10 \tag{3.1}$$

With an assumption made in the development of NRCS method, $\frac{F}{S} = \frac{P_e}{P-I_a}$, the effective depth of precipitation (runoff depth) is presented as Equation 3.2 (SCS, 1986).

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{3.2}$$

where P_e= depth of effective precipitation (in, mm)

P = total precipitation total rainfall depth in storm (in, mm)

I_a = equivalent depth of initial abstraction (in, mm)

S = maximum possible retention (in, mm)

3.3.1 Soil Group

The NRCS has classified the soil in the United States into four major hydrologic groups: A, B, C and D. Group A has the highest infiltration rate, even if it is highly wetted. The typical soil A is well-drained sand and gravels. On the other hand, Group D has the lowest infiltration rate, and the soil is clayey, shallow soil over a nearly imperious area and soil with high water tables. Groups B and C is in the mid-range of the four groups. In the United States, the soil group information can be obtained from the NRCS soil survey within a projected area (SCS, 1986).

3.3.2 Curve Number

Since the NRCS has designed a curve number function, they provide a curve number table to engineers with coefficient range from 0 to 100. In order to achieve reasonably accurate estimations of runoff volume, the NRCS allows the curve number to depend on the antecedent moisture condition (AMC) with three conditions. The AMC-I, II and III conditions correspond to drier, normal, and wetter conditions, respectively. The AMC-I and III can be calculated from the AMC-II; the equations are listed as follows (SCS, 1986):

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \tag{3.3}$$

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \tag{3.4}$$

Appendix B lists the curve numbers that account for both cover conditions and soil type for normal antecedent moisture conditions (AMC-II).

3.3.3 Area Measurement with Various Land Uses

With the aforementioned information, the area of the UAB Campus Green requires the curve number for various land types and an area measurement for the estimation of the runoff. In chapter 1, the land type of the study area is urban land, and the land type is classified into three categorical groups based on Appendix B. They are commercial and business (roof area), streets and roads, and open space (grassy land).

In the area measurement procedure, the area was measured piece by piece. A tape meter was used for accurate measurement of small, accessible areas. The length and width were measured and then used to obtain the target area. For inaccessible areas, such as large grass lands and roofs, the Google map area calculator (Daft Logic, 2011) was used as a measurement tool with a counter-clockwise order beginning from the southwest to northwest. Some roof-area data were collected from the UAB Facilities Management Department and are listed in Table 4. However, it only incudes few buildings in the study area, so the other building roofs still needed to be measured, and area data of each building roof are listed in Table 5. The value of area estimated by the Google map area calculator depends on the order and locations of points selected for a certain area which formed a polygon and showed the area value. Considering the error of operation of area measurement, 5% sensitivity of measured area was performed in the measure results. Moreover, considering the accuracy of area measurement, the results in Table 5 are shown with three significant digits. After these steps, data for each area were added together for different land-type classifications.

Table 4. Roof Area Data Provided by the Facilities Management Division at UAB.

Building Name	**Roof Area, (ft^2)**
Blazer Hall	31,000 (Estimated by Google Area Calculator)
Blount Hall	28,000
Camp Hall	14,129
Denman Hall	6,194
Education Building	45,312
Hill University Center (HUC)	19,029
Hoehn Engineering Building	13,907
HUC Great Hall	7,006
Rast Hall	21,711
Ryals School of Public Health	18,738
Smolian International House	4,909
Sterne Library	59,100
9th Avenue Parking Deck	46,670

Table 5. Measured Roof Areas by Google Calculator around the UAB Campus Green.

Building	**Area, ft^2**
Camp Hall	14,000 ±700
Blazer Hall	31,000 ±1,500
Dining Facility	22,000 ±1,100
Recreation Center (REC)	89,000 ±4,500
Heritage Hall	23,000 ±1,200
Chemistry Building	22,000 ±1,100
Chemistry Annex	6,000 ±300

The final results of the area measurements with various land use are summarized in Table 6.

Table 6. Area Data for Various Land Use.

Land Type	Area	
	Square Feet	Acres
Street and Roads (Paved Area)	220,000 ±11,000	5.1 ±0.3
Open Space (Grass and Trees)	469,000 ±24,000	10.8 ±0.5
Total	689,000 ±35,000	15.9 ±0.8

3.3.4 Runoff Volume Calculation

Based on the above discussion, the estimation of effective runoff with the three-year average precipitation data of January was performed for the estimation of effective runoff volume from precipitation, the measured data was used without considering measurement errors.

The hydrologic group of soil in Jefferson County is B (SCS, 1982). Because of the soil moisture condition in Jefferson County, assuming soil wet condition is AMC Condition II, and the curve number can be directly obtained based on Appendix B.

Land Use	Area, acres	CN	Product, Area ×CN
Street and Roads (paved Area)	5.1	98	494.9
Open Space (grass and trees)	10.8	61	657.2
Total	15.9		1152.1

Thus, the composite CN was computed as:

$$CN = 1152.1 \div 15.9 = 72.5$$

The maximum possible retention for this basin at AMC-II is:

$$S = (1000 \div 72.5) - 10 = 3.8\, inches$$

The initial abstractions were estimated to be:

$$I_a = 0.2S = 0.2 \times 3.8\, inches = 0.76\, inches$$

Because P > I_a, the depth of runoff (effective precipitation) was estimated as:

$$P_e = \frac{[4.92 - 0.2(3.8)]^2}{(4.92 + 0.8(3.8)]} = 2.17\, inches$$

The total volume of runoff during the month of January is therefore estimated to be 2.17 inches. Similarly, the runoff depth of the other months is listed in Table 7.

Table 7. Estimated Runoff Volume for Each Month.

Month	Precipitation, (inches)	Effective Runoff, (inches)
January	4.92	2.17
February	4.29	1.70
March	6.11	3.13
April	4.22	1.65
May	7.69	4.47
June	3.43	1.10
July	4.59	1.92
August	5.73	2.81
September	3.84	1.38
October	4.51	1.86
November	4.21	1.64
December	4.62	1.95
Total	58.16	25.78

3.4 Evapotranspiration

In the case study, the total evaporation from the study area combined evaporation and transpiration. Therefore, the calculation was performed on the evapotranspiration, which is related to the determination of the need for irrigation water. In this chapter, the water requirements of the grass and trees, grown on an irrigation scheme, can be estimated. The influence of climate on grass water requirements is given by the reference crop evapotranspiration (ET_o). ET_o is usually expressed in millimeters per unit of time, e.g., mm/day, mm/month, or mm/season (Brouwer and Heibloem, 1986).

3.4.1 Estimation of Evapotranspiration

Evapotranspiration is an important component in the hydrologic budget of a vegetated area, but it is difficult to calculate because it depends on various phytological variables. Basically, there are several methods to determine *ET*; they are either (Viessman and Lewis, 2003):

1. “Theoretical, based on the physics of the process”;

2. “Analytical, based on the energy or water budget”;

3. Experimental, using evaporation pans.

There are no available measured data on pan evaporation or sufficient meteorological data, so a theoretical method to calculate the reference crop evapotranspiration had to be used. Many formulas had been developed for the estimation of evapotranspiration, and some of the equations are listed in Table 8, with an associated description of each provided.

Table 8. Potential Evapotranspiration Equations.

Equations	Description
Blaney and Criddle, 1950	does not include humidity prarameter
Modified Blaney-Criddle formula	modified From original Blaney-Criddle formula (SCS, USDA,1970)
FAO Blaney-Criddle formula (Doorenbos and Pruitt, 1975)	made compatible with crop coefficients developed with the modified Penman equation
Penman-Monteith equation (Allen *et al.*, 1998)	Penman’s equation was again modified in Food and Agriculture Organization of United Nations (FAO) 56 (Allen *et al.*, 1998) to be the Penman-Monteith equation
Penman-Monteith equation, standard equation of American Society of Civil Engineering (ASCE)	standard evapotranspiration equation of ASCE (Allen *et al.*, 2005)

Source: Sammis, *et al.*, 2011.

Among these equations, the Penman-Monteith equation used as the standard equation of ASCE is the most accurate to estimate evapotranspiration, and the Penman-Monteith equation modified by FAO is the second most accurate. However, these two equations need lots of parameters, such as net solar radiation, soil heat flux, actual vapor pressure, etc., which cannot be obtained in this study, so these two equations are not used. The FAO Blaney-Criddle formula is more accurate than the original and modified Blaney-Criddle formula and is simple for calculation. However, relative humidity, sunshine, and wind speed involved in this equation requires the minimum value that cannot be found for the Birmingham area. Hence, the FAO Blaney-Criddle formula was abandoned. Compared with the Blaney-Criddle formula (1950) and the one modified in 1970, it is simple to use and close in accuracy to estimate the reference evapotranspiration. The Blaney-Criddle formula has been used in an irrigation training manual of FAO as a simple and recommended equation, so it is selected as the method for estimation in this project.

The Blaney-Criddle method (Blaney and Criddle, 1950) uses mean monthly values, both for the temperature and the ET_o. The temperature refers to the mean daily temperature during the whole month. With the temperature, the Blaney-Criddle formula (Blaney and Criddle, 1950) is:

$$ET_o = p\,(0.46\,T_{mean} + 8) \tag{3.5}$$

where ET_o = Reference crop evapotranspiration (mm/day) as an average for a period of one month

T_{mean} = mean daily temperature (℃)

p = mean daily percentage of annual daytime hours

For the estimation of evapotranspiration, the mean daily temperature was replaced by monthly temperature, shown in Table 9, as the temperature parameter due to lack of daily temperature data. In this part, like usage of precipitation data, mean monthly temperature of three years from 2008 to 2010 was selected for estimation. To determine the value of *p*, Table 10 was used. To be able to determine the *p* value, it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator. The search results show that the latitude of Birmingham is 33 °31' 14" N, rounded to 33^o. In this calculation, the average monthly value for the three years was used for estimation as the precipitation. First, the mean value of January was estimated. Suppose the *p* value for the month January has to be determined for an area with latitude of 33^o north. From Table 10, the *p* value during January was estimated to be 0.234.

Table 9. Monthly Temperatures (^{o}F) Data in Birmingham, Alabama.

Month	**Year**				
	2008	**2009**	**2010**	**Mean, ^{o}F**	**Mean, ^{o}C**
January	43.1	44.7	38.9	42.23	5.69
February	49.2	48.1	39.9	45.73	7.63
March	56	57.5	51	54.83	12.69
April	63.5	62.3	65.2	63.67	17.59
May	70.3	71.1	73.4	71.6	22
June	79.1	79.3	81.7	80.03	26.69
July	81.6	78.5	84.6	81.57	27.54
August	79.7	78.6	84.7	81	27.22
September	75.3	74.7	78.1	76.03	24.46
October	63	61.8	65.2	63.33	17.41
November	51.2	53.6	55.7	53.5	11.94
December	49.1	44.2	40.1	44.47	6.93

Source: Birmingham Weather Forecast Office, 2011.

Table 10. Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes.

Latitude		60°	55°	50°	45°	40°	35°	30°	25°	20°	15°	10°	5°	0°
South	North													
Jul	Jan	0.15	0.17	0.19	0.2	0.22	0.23	0.24	0.24	0.25	0.26	0.26	0.27	0.27
Aug	Feb	0.2	0.21	0.23	0.23	0.24	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27
Sep	Mar	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Oct	Apr	0.32	0.32	0.31	0.30	0.30	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.27
Nov	May	0.38	0.36	0.34	0.34	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.27
Dec	Jun	0.41	0.39	0.36	0.35	0.34	0.32	0.32	0.31	0.30	0.29	0.29	0.28	0.27
Jan	Jul	0.40	0.38	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.27
Feb	Aug	0.34	0.33	0.32	0.32	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.28	0.27
Mar	Sep	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.27
Apr	Oct	0.22	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27	0.27
May	Nov	0.17	0.18	0.2	0.21	0.22	0.23	0.24	0.25	0.25	0.26	0.26	0.27	0.27
Jun	Dec	0.13	0.16	0.18	0.20	0.21	0.22	0.23	0.24	0.25	0.25	0.26	0.27	0.27

Source: Adapted from “Irrigation Water Management: Training Manual No. 3.” by C. Brouwer and M. Heibloem, 1986, *FAO.* “Introduction to Hydrology” (5th Edition) by Viessman, W., and Lewis, G. L., 2003, Pearson Education.

Based on Table 9, temperature of January is 5.69 ℃ and p has been estimated to be 0.234. Hence, ET_o in January is calculated as follows:

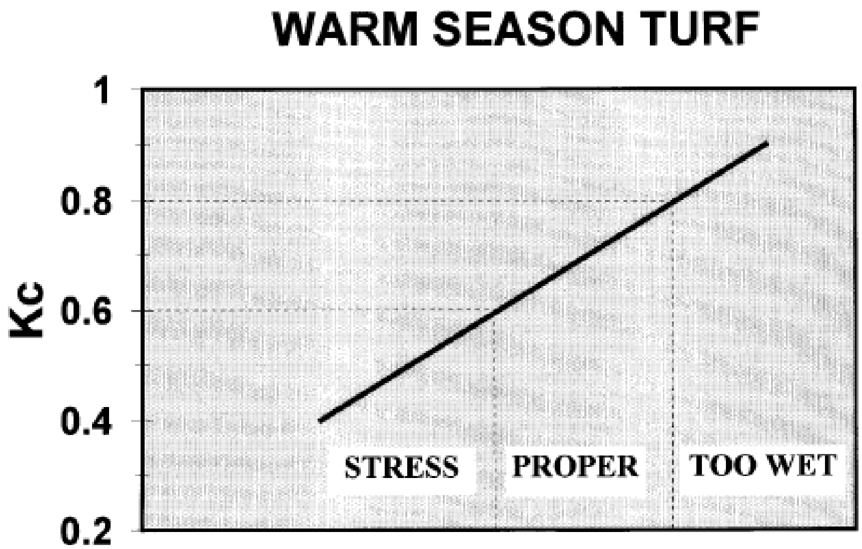
$$ET_o = 0.234\,(0.46 \times 5.69 + 8) = 0.234\,(2.62 + 8) = 0.234 \times 10.62$$

$$= 2.484\,mm/day$$

For January, $ET_o = 2.484\frac{mm}{day} \times 31 days = 77\ mm = 3.03\ iches$

The grass type is warm-season turf, which is suitable for growing in a warm climate. To calculate the ET value, the reference evapotranspiration needs to be multiplied by the crop coefficient, which can be obtained from Figure 9.The appropriate crop factor for warm season turf ranges from 0.6 to 0.8. “Use of a K_c below 0.6 will likely produce water stress; use of K_cs above 0.8 will likely produce wet and/or muddy conditions” (Arizona Cooperative Extension, 2000). For purpose of minimizing the irrigation requirement, the crop factor 0.6 was used for the estimation. Therefore, the ET value was calculated as follows, and the estimated evapotranspiration results are listed in Table 11.

$$ET = K_c \times ET_O = 3.03 inches \times 0.6 = 1.82\ inches$$



Adapted from "Turf Irrigation Management Series No.2: Converting Reference Evapotranspiration" by Arizona Cooperative Extension, 2009. Copyright 2000 by the Name of Copyright Holder. Adapted with Permission.

Figure 9. Warm Season Turf.

Table 11. Estimated Evapotranspiration Data by Blaney-Criddle Method.

Month	ET, inches/month
January	1.82
February	1.88
March	2.74
April	3.34
May	4.15
June	4.68
July	4.78
August	4.55
September	3.82
October	3.00
November	2.24
December	1.84

In addition to the evapotranspiration from land surface, the water will also have evapotranspiration effects when the rainwater is stored in the underground storage tank. However, the water will be evaporated as water vapor with little escape or penetration out of tank. Hence, this part of evapotranspiration was not considered in the estimation.

3.5 Irrigation Water Needs

In this case study, the water requirements are supplied by rainfall and the remaining part by irrigation. The irrigation water requirement is the difference between the crop water requirements (ET) and that part of the rainfall that is effectively used by the plants (Pe): IN = ET_{crop} – Pe (Brouwer and Heibloem, 1986).

Hence, the water needs for January$= ET - P_e = 1.82 - 2.17 = -0.35\ inches$

Here, the negative value indicates that no additional water is needed to irrigate the UAB Campus Green area during on the month of January. To estimate the total amount of irrigation water needed, the irrigation efficiency has to be applied in the estimation. The irrigation efficiency must be estimated because the total water applied can not be measured. The systems which are well-designed and operated can have efficiency ranges from 80% to 90% (University of California Cooperative Extension and California Department of Water Resources, 2000). For this project, the rainwater harvesting system was assumed to be well designed with 90% efficiency. Hence, the total irrigation water needed for the month of January is calculated as follows:

Total irrigation water needs for January= $\frac{-0.35\ inches}{90\%} = -0.39\ inches$

Using this same method, the results are listed in Table 12

Table 12. Irrigation Water Needs in Each Month with Solely Considering *ET*.

Month	Irrigation Water Needs, (inches)	Irrigation Water Needs, (gallons)
January	-0.39	-115,097
February	0.20	58,516
March	-0.43	-125,276
April	1.88	549,695
May	-0.36	-104,946
June	3.98	1,163,142
July	3.18	928,869
August	1.93	564,376
September	2.71	793,541
October	1.27	370,546
November	0.67	193,694
December	-0.12	-34,987

Note: The negative value indicates no additional water needed for irrigation beside natural precipitation

This calculated water need assumed the grassy land included all grass around sidewalks and lawns near buildings.

3.6 Groundwater Flow

Since the meter device has been installed to track the groundwater flow quantity involving the water pumped from the UAB Recreation Center to avoid flooding the recreation center's basement, this amount of water could be used as irrigation water. An investigation was performed on this quantity of water, and Figure 10 shows the metering device. This water metering was installed in the aquatic center.

The flow was approximately 2.87 million gallons, which was measured for a nearly three-year period. Considering the time period, an assumption was made that the groundwater flow is approximately 1.0 million gallons per year. There is a control system detecting the groundwater level and that pumps out the groundwater automatically. Due to the lack of pumped groundwater quantity and frequency, an assumption was made that the same amount of groundwater was pumped each month during the year, approximately 85,000 gallons per month.

Figure 10. Meter Device in the UAB Campus Recreation Center.

3.7 Water Storage

There are no existing water retention facilities on the UAB Campus Green, such as retention pond or crest weirs. However, the aquatic center of the Recreation Center could be considered as a storage facility, so the water quantity change in it involves changes in water storage. An investigation performed for the aquatic center of the Recreation Center showed that the pool contains 153,264 gallons of water and the spa contains 8,934 gallons (Winslett, 2011). However, there is no information regarding the frequency of the pool water of being refilled and recharged. The pool has automatic leveling systems that add water to both the pool and spa if they drop below set levels. Although the water quantity of pool and spa is large, it cannot be an irrigation water source due to the content of chlorine, which harms the grass. Therefore, only groundwater ties into this project as a potential irrigation water source.

CHAPTER 4

RAINWATER HARVESTING SYSTEM DESIGN

Development of a rainwater harvesting system is an integral part of this study. Rainwater harvesting is a term that describes the small-scale collection, storage and use of rainwater runoff for both domestic and agricultural purposes. If the rainwater collection can be fully developed, it will provide both environmental and sustainable benefits as a water supplement in wide and various applications.

4.1 Design of the USTs

With irrigation water requirement, a large amount of water is needed for irrigation during the summer, so large roof areas are required to capture rainwater. Considering the buildings near the UAB Campus Green, all building are suitable for rainwater collection because they are flat and are generally in good condition. These buildings can have RHS systems installed, and the usage of groundwater and captured rainwater can be stored in USTs, for further irrigation usage. With the selected buildings, the water collected from the rainfall was estimated as follows:

$$gallon\ colleted = \frac{Rianfall\ (inches)}{12} \times catchment\ surface(\ square\ feet)$$
$$\times\ 7.48 \times percentage\ collection\ effiency$$

where the 7.48 is a conversion factor for water quantity from cubic feet to gal

Rainwater harvesting depends on the material used, its design and construction. In practice, some rainwater losses are associated with first-flush, evaporation, splash-out overshoot from the gutters in hard rains and possibly leaks. Therefore, these factors are considered in the water supply estimation. Most installers usually assume an efficiency of 75% to 90% (Texas Water Development Board, 2005). With this assumption that the RHS is well designed, the collection efficiency can be assumed to be 90%. If the efficiency is assumed to be 75%, the quantity of harvested rainwater will likely not achieve the irrigation purpose.

The roof area of all buildings round the Campus Green is 207,398 ft^2 based on the area measurements. Table 13 presents the potential captured rainwater and water demand in each month.

Table 13. Potential Rainwater Collection Quantity and Irrigation Water Needs in each Month.

Month	Rain, (inches)	Collectable Rainwater, (gallons)
January	4.92	569,382
February	4.29	496,473
March	6.11	706,713
April	4.22	488,373
May	7.69	889,563
June	3.43	396,947
July	4.59	531,192
August	5.73	662,736
September	3.84	444,396
October	4.51	521,548
November	4.21	487,601
December	4.62	535,050

4.2 Irrigation Scheme

In addition to rainwater, groundwater is also a landscape-irrigation water source. The water pumped from groundwater is approximately 85,000 gallons per month from the previous chapter. With the aforementioned description, based on this data, the months of October to March and May require no additional or very little water for irrigation, but water is still needed to irrigate green areas for maintenance due to uneven precipitation distribution. For those months, irrigation water requirements are assumed to be at least approximately 30,000 gallons for turf maintenance and replacing the aforementioned negative value. Detailed irrigation water needs for each month and quantity shown in Table 14. The groundwater can provide this quantity. The RHS system can be used to collect water for extreme weather condition or be closed during that period. For the reminding months, the irrigation water will be provided by combining all the water sources.

Table 14. Irrigation Water Requirement and Water Sources.

Month	Rain, (inches)	Irrigation Water need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	4.92	30,000	569,382	85,000
February	4.29	58,516	496,473	85,000
March	6.11	30,000	706,713	85,000
April	4.22	549,695	488,373	85,000
May	7.69	30,000	889,563	85,000
June	3.43	1,163,142	396,947	85,000
July	4.59	928,869	531,192	85,000
August	5.73	564,376	662,736	85,000
September	3.84	793,541	444,396	85,000
October	4.51	370,546	521,548	85,000
November	4.21	193,694	487,601	85,000
December	4.62	30,000	535,050	85,000

The underground storage tank size is a very important component in a RHS. To decide the tank size, the water balance method was used. The water needs to be stored in tank for a month can be determined that the collected water quantity subtracts irrigation water needs. In next month, the water quantity is calculated by the same method, and plus the water stored in previous month. Based on this method, the value of water stored in tank can be negative, so proper tank size will be the largest absolute value remaining in the tank. According to the method, most months can achieve the irrigation goal with a small tank size except the months of June, July and September. For June and July, the irrigation water needs are approximately 2,100,000 gallons, whereas water sources can only provide about 53% of the amount, approximately 1,100,000 gallons. In order to supply this quantity, based on the water balance method, the tank should store about 1,000,000 gallons before the month of June and July, and this number will be the proper tank size. However, installing such large tank will not be cost-effective, because the cost will be much larger for the tank than the saving water costs, resulting in a bad payback. Therefore, the tank size will be determined by how much more water can be supplied to fit irrigation during the month of June and July, because water supply and demand of the other months can be satisfied by the water sources. Based on this method, the more water stored before June, the greater the percent the water sources that can satisfy the irrigation target. Since irrigation water needs cannot be achieved during the summer, the tank can be smaller in order to be cost-effective. Although the use of a small tank can achieve a better payback period, it cannot be too small to be functional for water storage, because the water balance method cannot reflect water-quantity changes during the month.

In order to design a proper tank size, the information of the UST system at UBOB is considered. The roof area at UBOB is only one quarter of the area involved in this project, so appropriate tank size will be quadrupled, to 40,000 gallons. Moreover, the UST in this project will store groundwater that needs to be enlarged by 20% considering the percentage of the total groundwater quantity. For practical applications, the tank size was assumed to increase another 20% due to holding capacity considerations. With these assumptions, the harvesting system is designed to collect 0.5 inch of precipitation from the entire building roofs within the city block; approximately a 60,000 gallon tank is necessary to store the water for irrigation purposes or further use. With this tank size, irrigation water needs for the months of June, July and September would to be reduced. The water quantity for the month of June will be decreased to the amount equal to the maximum the water source can supply. Therefore, additional water needs to be supplied to handle the demand for water, and the additional needs could be supplied by the

Birmingham Water Works Board. Therefore, this amount of water was subtracted from the month of June, as shown in Table 15.

Table 15. Water from Rainwater, Groundwater and Water Used for Irrigation.

Month	Rain, inches	Water from Rain, gallons	Water for Irrigation, gallons	Water from Groundwater, gallons	Balance, gallons
January	4.92	0	30,000	30,000	0
February	4.29	0	58,512	58,512	0
March	6.11	0	30,000	30,000	0
April	4.22	488,373	549,363	70,990	10,000
May	7.69	0	30,000	80,000	60,000
June	3.43	396,947	541,947	85,000	0
July	4.59	531,192	616,192	85,000	0
August	5.73	565,617	565,617	60,000	60,000
September	3.84	444,396	589,396	85,000	0
October	4.51	340,576	370,576	30,000	0
November	4.21	165,040	195,040	30,000	0
December	4.62	0	30,000	30,000	0
Total		2,932,141	3,606,643	674,502	

As shown in Table 15, the water supply amount that subtracts the irrigation water needs is the amount that needs to be stored in tanks. From the results shown in Table 15, the highest balance value is 60,000 gallons for the designed storage tank size. The shown data employ pumped groundwater, water balance in storage tanks, and rainwater harvesting. However, the total amount of water that can be saved by the rain water harvesting system will be the same. Based on this design, the rainwater harvesting system can satisfy approximately 77.6% of total irrigation water needs. To make a more economic design, smaller tanks will be better than larger tanks, because the smaller tanks sizes are more cost-effective and easier to install. Based on the condition of the UAB Campus Green, smaller tanks are easier to install at the study site due to space limitations.

In this part, two scenarios, a centralized and a decentralized system, are possible in designing a rainwater harvesting system on the UAB Campus Green. For a decentralized system, a few larger tanks are used and located in the lower altitude area, the Campus Recreation Center and Heritage Hall. In contrast, the centralized system collects rainwater with many small tanks that are located in each building.

For the decentralized system, two 30,000-gallon tanks can be used for water storage. The two tanks can be installed at the UAB Recreation Center and Heritage Hall. From the plane map of UAB (see Appendix A), the buildings are divided into two sites by the green area based on the aforementioned information. The rainwater harvesting system at UAB Campus Green will include roof catchment conveyance, first flushing, filtration, pump, irrigation system, etc. The RHS with the USTs on the UAB Campus Green is shown in Figure 11.

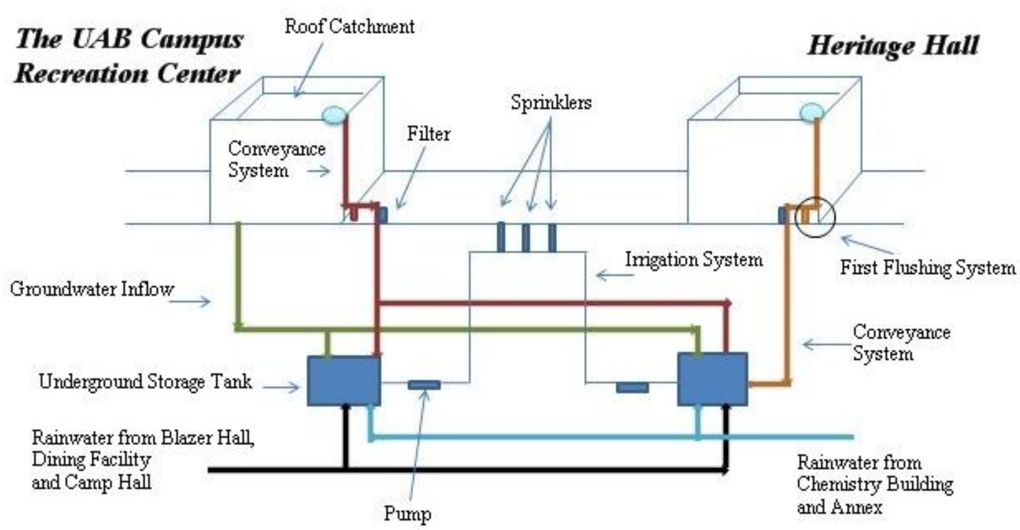


Figure 11. RHS with Underground Storage Tanks at the UAB Campus Recreation Center and Heritage Hall on UAB Campus Green.

In this RHS, the two tanks have separate rainwater collection, storage and distribution systems. However, the roof area of the UAB Campus Recreation Center is significantly larger than that of Heritage Hall, which means more water will be collected from the REC Center roof. Hence, rainwater overflow from the tank at the Recreation Center will be transmitted as overflow to the other storage tank at Heritage Hall to be stored. In addition, the two tanks contain groundwater and pool-water discharge for irrigation. In this way, the water sources are used fully by the RHS. The rainwater harvesting system for other buildings will use the same collection, conveyance, and filtration systems as shown in the figure. The rainwater harvested from the Dining Facility, Blazer Hall and Camp Hall will be transmitted in one pipeline, finally exiting into the two tanks. Similarly, rainwater harvested from the Chemistry Building and Chemistry Annex will be transmitted in one pipeline, finally exiting into the two tanks.

For the centralized system, many smaller tanks will be installed in the UAB Campus Green area closest to each building. The components of a RHS are the same as those designed in the decentralized system. The diagram of the rainwater harvesting system is also similar, with scenario one being that every two opposite storage tanks in a row are grouped together. Considering the difference in roof area, the rainwater from large roof area is also transmitted to other closer tanks by off-loading pipelines.

Comparing the two scenarios, scenario one is relatively simple, the rainwater can be transmitted to the tank by gravity and then distributed for irrigation by a high-power pump. Scenario two is a little complicated for design, and rainwater can also be transmitted by gravity if the buried depth is sufficient, so that a large pump or several pumps have to be used for transmission. However, dividing a large tank into several small tanks for water storage will cost more than using this large tank. Similarly, a few larger pumps also are more cost-effective than many smaller pumps. Based on the condition of the UAB Campus Green, scenario one is better for installation of underground tanks because of the large open area.

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, the cost analysis of installing USTs is performed to explore the financial feasibility. Due to the precipitation quantities, sensitivity analyses were also performed to explore the impact on the tank size, payback period, and percentage of the irrigation requirement that can be achieved.

5.1 Cost Analysis of the UST

The tank used in this research is constructed of fiberglass produced by Draco, Inc. A tank price quote was obtained from the website of Draco, Inc. With this quotation, the shipping price of different size tanks is listed in Table 16 (Eisenman, 2011).

Table 16. Draco, Inc. Underground Water Tanks.

Draco, Inc. Underground Water Tanks with Purpose of Landscape Irrigation		
Size of Tanks (gal)	Diameters of Tank (ft)	Shipping Price of Tank to Montgomery, AL , ($)
10,000	10	15,750
20,000	10	26,537.50
30,000	12	37,908.20
40,000	12	53,004.80
50,000	12	62,079.80

Source: www.darcoinc.com/ (Darco Inc., 2011).

The accessories included in the preliminary quote for a 30,000 gallons tank include:

- 30,000 gallon fiberglass underground water storage tank;
- 12’ diameter × 48’5” long;
- 24” diameter manway collar;
- Commercial rainwater capture system package;
- Anchor straps, SS cable kits and lugs for tank package; and
- Pipe stub with flexible pipeline coupler-8 inches.

Beside the cost of the tank, $8,000 is assumed for the accessories (Eisenman, 2011). Beside the accessories, the cost of installing a RHS depends on several components (Eisenman, 2011):

- Inspection, acceptance and offloading;
- Installation material and labor;
- Unspecified pipe, vale, and fittings;
- Unspecified pump, control, and level sensors;
- Concrete deadman anchors or concrete slab anchor—to prevent the tank floating up during flooding;
- Unspecified anchor straps and cable; and
- Site specific engineering.

In addition to these costs, maintenance is another small cost of this project. For a design rainwater harvesting system, the operation can be done automatically, and maintenance comes from the catchment, underground storage tank, filters, etc. For appropriately designed rainwater harvesting systems, the maintenance requirements are very small (LaBranche, *et al.*, 2007). In the hydrologic analysis chapter, the rainwater harvesting system has been assumed to be well-designed, so the cost of maintenance in this project is small and ignored in the total cost estimations.

It is difficult to determine the exact cost of each component due to a lack of data. However, the UAB Facilities Management Division has previously installed a RHS at the UBOB facility; the cost of that project can be considered as a reference. The total cost of that project was approximately $100,000 with a 10,000 gallon tank (Winslett, 2011). Based on tank prices introduced by Darco, Inc., an assumption was made, by subtracting the tank and accessories costs that the cost would be approximately $80,000. Within this design, costs of some components can be counted once, such as site specific engineering. In this project, two 30,000 gallon tanks were used due to less cost than a 60,000 gallon tank. Therefore, the total cost of the USTs on the UAB Campus green is estimated as follows:

$$\text{Total cost of RHS} = (\$37{,}908.20 \times 2) + \$80{,}000 = \$155{,}816$$

5.1.1 Water Charge

With the required calculated water quantity, water costs can be estimated. The cost for irrigation is broken up into two stages of consumption: 15 CCF cost $2.28/CCF, while any usage over 15 CCF costs $3.48/CCF (Birmingham Water Works Board, 2011). Hence, the water cost for each month is estimated in Table 17.

Table 17. Water Charge of Irrigation on Each Month.

Month	Water Needs, (gallons)	Water Cost, ($)
January	30,000	121.6
February	58,512	254.2
March	30,000	121.6
April	549,363	2,537.9
May	30,000	121.6
June	541,947	2,503.4
July	616,192	2,848.8
August	565,617	2,613.5
September	589,396	2,724.1
October	370,576	1,706.1
November	195,040	889.4
December	30,000	121.6
Total	3,606,643	16,563.6

5.1.2 Payback Period

With the USTs cost data and annual water charge, the payback period is estimated as follows:

$$\text{The Payback Period} = \frac{\text{UST Cost}}{\text{Water charge per year}} = \frac{\$155{,}816}{\$16{,}563.6} = 9.4 \text{ years}$$

From the financial aspect, this project has a somewhat long payback period, which means it is not worthwhile to build a rainwater harvesting system. However, payback period results involved in the study at Texas A&M University shows 14 and 20 years in two different scenarios (Saour, 2009). Results performed briefly by the UAB Facilities Management Department shows three different payback periods, 9.9, 26.2 and 35.6 years in three different scenarios, respectively. Compared with these two results, the estimated payback period is consistent with the results, 9.9 years, performed by UAB Facilities Management Department. The possible reason the payback period in this project is relatively less than other payback periods values is due to the costs estimation, which might be less the actual project costs. If the increase cost estimation, the payback period in this study would still be consistent with these two researches. Hence, the result in this report is still reasonable and consistent with their research, and shows an even better plan for installation of rainwater harvesting system.

5.2 Sensitivity Analysis

From the historical precipitation data, it shows that precipitation quantity changes from month to month and year to year. The rainfall quantity in September was commonly low but it increased significantly in 2009. Moreover, the runoff quantity will be influenced by the precipitation, so it was necessary to conduct a sensitivity analysis study concerning the runoff. Evapotranspiration also changes year by year so another sensitivity analysis study was performed based on the ET values. Therefore, due to the variables, a sensitivity analysis study was performed to study the impact of these factors on the tanking size and related payback years. In this chapter, variations of 5%, 10% and 25% were determined as the variables for the sensitivity analysis studies addressing precipitation and evapotranspiration. Within this study, first, the ET value was held constant, and the impact with changes of precipitation was explored. Then, the precipitation was held constant while the ET value was varied to determine the influence of changes in ET. Moreover, the interaction of ET and precipitation were performed with variations of 5%, 10%, and 25%. In the interactions study, these elements increased or decreased at the same time so the results could be analyzed. For the irrigation water needs, if it remains negative, it will be still indicated by 30,000 gallons of water for grass maintenance. Moreover, using the water balance method, with the change of rainfall and evapotranspiration, the irrigation water needs can be satisfied for every month by a smaller tank size, the tank size can be decreased, and the payback period will be calculated by estimated cost of the modified tank size. Otherwise, the tank size will remain the same equal to the tank size determined using the average values.

5.2.1 Sensitivity Study of Precipitation

Since the tank size is determined by the quantity of irrigation water needs, the same procedure was used to calculate irrigation water needs and develop irrigation schemes. The detailed results of 5% sensitivity are listed in Tables 18 and 19.

Table 18. Sensitivity Study with 5% Decrease in Precipitation.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	540,913	85,000
February	108,939	471,650	85,000
March	30,000	671,377	85,000
April	598,930	463,954	85,000
May	30,000	845,085	85,000
June	1,199,137	377,100	85,000
July	984,394	504,632	85,000
August	639,375	629,599	85,000
September	836,368	422,176	85,000
October	424,651	495,471	85,000
November	242,816	463,221	85,000
December	30,000	508,297	85,000
Total	5,154,610	6,393,475	1,020,000

Note: Here the 30,000 gallons used for turf maintenance replaces the negative value mentioned in previous chapter

Table 19. Sensitivity Study with 5% Increase in Precipitation.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	30,000	598,314	85,000
February	30,000	520,776	85,000
March	30,000	741,817	85,000
April	499,607	512,675	85,000
May	30,000	933,926	85,000
June	1,126,455	416,621	85,000
July	872,106	557,809	85,000
August	489,037	695,526	85,000
September	750,114	466,384	85,000
October	315,825	547,394	85,000
November	144,441	511,518	85,000
December	30,000	561,281	85,000
Total	4,347,585	7,402,971	1,020,000

With the decrease and increase of precipitation, the effective runoff decreased and increased, influencing the irrigation water quantity. For 5% changes in precipitation, irrigation water needs still exceed the irrigation target during the summer for the month of June, July, and September. Tank size could be enlarged but the payback period will be longer. Since the tank size stays the same, the payback period will increase and decrease with increases and decreases in precipitation. The relationship between precipitation and payback period is an inverse ratio.

Similarly, the detailed results of 10% sensitivity analysis are listed in Tables 20 and 21.

Table 20. Sensitivity Study with 10% Decrease in Precipitation.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	30,000	512,444	85,000
February	158,161	446,826	85,000
March	36,518	636,042	85,000
April	646,972	439,535	85,000
May	111,144	800,607	85,000
June	1,234,025	357,253	85,000
July	1,038,697	478,073	85,000
August	713,111	596,463	85,000
September	878,036	399,956	85,000
October	477,540	469,393	85,000
November	290,745	438,841	85,000
December	75,976	481,545	85,000
Total	5,690,925	6,056,978	1,020,000

Table 21. Sensitivity Study with 10% Increase in Precipitation.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	30,000	626,320	85,000
February	30,000	546,121	85,000
March	30,000	777,384	85,000
April	448,034	537,210	85,000
May	30,000	978,520	85,000
June	1,088,169	436,642	85,000
July	814,572	584,311	85,000
August	411,053	729,010	85,000
September	704,782	488,835	85,000
October	259,099	573,703	85,000
November	92,260	536,361	85,000
December	30,000	588,554	85,000
Total	3,967,969	7,402,971	85,000

Based on Table 21, similar to the 5% change in precipitation, the water supply cannot satisfy water demand during the summer even with a 10% increase in precipitation. With an increased percentage of precipitation, the difference between the water supply and demand during summer are far less but still not balanced, so the tank size remains the same. The payback period changed following the relationship with precipitation. Hence, there is an impact on tank size but with an increased payback period. Detailed results of the 25% sensitivity analysis are listed in Tables 22 and 23.

Table 22. Sensitivity Study with 25 % Decrease in Precipitation.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	176,961	427,037	85,000
February	297,394	372,355	85,000
March	268,176	530,035	85,000
April	782,711	366,279	85,000
May	424,220	667,172	85,000
June	1,331,042	297,710	85,000
July	1,192,984	398,394	85,000
August	925,256	497,052	85,000
September	994,969	333,297	85,000
October	627,632	391,161	85,000
November	426,152	365,701	85,000
December	231,942	401,287	85,000
Total	7,679,439	5,047,480	1,020,000

Table 23. Sensitivity Study with 25% Increase in Precipitation.

Month	Irrigation water need, (gallons)	Collectable Rainwater, (gallons)	Maximum groundwater , (gallons)
January	30,000	711,728	85,000
February	30,000	620,592	85,000
March	30,000	883,391	85,000
April	288,783	610,466	85,000
May	30,000	1,111,954	85,000
June	969,298	496,184	85,000
July	636,281	663,990	85,000
August	174,154	828,420	85,000
September	565,019	555,495	85,000
October	85,100	651,935	85,000
November	30,000	609,501	85,000
December	30,000	668,812	85,000
Total	2,898,635	8,412,468	1,020,000

Based on the data of 25% increase of precipitation, the irrigation requirements can be achieved, with exception of the month of June. Therefore, tank size will remain at 60,000 gallons, but the payback period will increase due to a smaller amount of water.

5.2.2 Sensitivity study of Evapotranspiration

Unlike the change in precipitation, the payback period and ET have a relationship involving a direct ratio. The greater the ET, the less the pay payback period will be. Since the sensitivity study of ET is pretty much the same situations, with precipitation in each percentage, it was necessary to examine the impact on tank size and payback period for each particular ET percentage. The analysis was performed by considering the entire sensitivity study of evapotranspiration. Tables 24 to 29 list detailed changes in irrigation supply and demand using 5%, 10 % and 25% changes of ET.

Table 24. Sensitivity Study with 5% Decrease in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	30,000	569,382	85,000
February	30,000	496,473	85,000
March	30,000	706,713	85,000
April	495,077	488,373	85,000
May	30,000	889,563	85,000
June	1,087,674	396,947	85,000
July	852,001	531,192	85,000
August	491,664	662,736	85,000
September	731,076	444,396	85,000
October	321,816	521,548	85,000
November	158,633	487,601	85,000
December	30,000	535,050	85,000
Total	4,287,941	6,729,974	1,020,000

Table 25. Sensitivity Study with 5% Increase in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater , (gallons)
January	30,000	569,382	85,000
February	89,068	496,473	85,000
March	30,000	706,713	85,000
April	603,649	488,373	85,000
May	30,000	889563	85,000
June	1,239,805	396,947	85,000
July	1,007,383	531,192	85,000
August	639,569	662,736	85,000
September	855,251	444,396	85,000
October	419,336	521,548	85,000
November	231,448	487,601	85,000
December	30,000	535,050	85,000
Total	5,205,509	6,729,974	1,020,000

Table 26. Sensitivity Study with 10% Decrease in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	569,382	85,000
February	30,000	496,473	85,000
March	30,000	706,713	85,000
April	440,791	488,373	85,000
May	30,000	889,563	85,000
June	1,011,608	396,947	85,000
July	774,310	531,192	85,000
August	417,711	662,736	85,000
September	668,988	444,396	85,000
October	273,056	521,548	85,000
November	122,225	487,601	85,000
December	30,000	535,050	85,000
Total	3,858,689	6,729,974	1,020,000

Table 27. Sensitivity Study with 10% Increase in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	569,382	85,000
February	119,625	496,473	85,000
March	30,000	706,713	85,000
April	657,936	488,373	85,000
May	30,881	889,563	85,000
June	1,315,871	396,947	85,000
July	1,085,074	531,192	85,000
August	713,522	662,736	85,000
September	917,339	444,396	85,000
October	468,096	521,548	85,000
November	267,855	487,601	85,000
December	30,000	535,050	85,000
Total	5,666,199	6,729,974	1,020,000

Table 28. Sensitivity Study with 25% Decrease in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	569,382	85,000
February	30,000	496,473	85,000
March	30,000	706,713	85,000
April	277,932	488,373	85,000
May	30,000	889,563	85,000
June	783,411	396,947	85,000
July	541,237	531,192	85,000
August	195,853	662,736	85,000
September	482,724	444,396	85,000
October	126,776	521,548	85,000
November	30,000	487,601	85,000
December	30,000	535,050	85,000
Total	2,587,933	6,729,974	1,020,000

Table 29. Sensitivity Study with 25% Increase in ET.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	34,132	569,382	85,000
February	211,294	496,473	85,000
March	95,895	706,713	85,000
April	820,794	488,373	85,000
May	233,236	889,563	85,000
June	1,544,068	396,947	85,000
July	1,318,147	531192	85,000
August	935,380	662,736	85,000
September	1,103,602	444,396	85,000
October	614,377	521,548	85,000
November	377,078	487,601	85,000
December	113,773	535,050	85,000
Total	7,401,776	6,729,974	1,020,000

Based on the irrigation water needs and potential water sources with changes of ET, the tank size can be reduced with a 25% decrease in evapotranspiration like the 25% increase of precipitation based on the water balance method. June and July are still the months that need the most water for irrigation. Like the 25% decrease in precipitation, with a 25% increase of ET, the irrigation water demand on the month of August and September exceeds the water supply quantity, so that water demand quantity needs to be reduced in order to satisfy the designed irrigation capacity. The payback period increases or decreases with the increase or decrease of evapotranspiration.

5.2.3 Sensitivity Study of Interaction of Precipitation and Evapotranspiration

After analyzing the impact using the change in precipitation or evapotranspiration separately, researchers should explore the impact the interaction of ET and precipitation needs. In this analysis, these two factors increase or decrease at the same time. The exact data of irrigation water needs and collected rainwater from roof are listed in Tables 30 to 35.

Table 30. Sensitivity Study with 5% Decrease in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	540,913	85,000
February	78,383	471,650	85,000
March	30,000	671,377	85,000
April	544,644	463,954	85,000
May	30,000	845,085	85,000
June	1,123,071	377,100	85,000
July	906,703	504,632	85,000
August	565,423	629,599	85,000
September	774,280	422,176	85,000
October	375,891	495,471	85,000
November	206,409	463,221	85,000
December	30,000	508,297	85,000
Total	4,694,804	6,393,475	1,020,000

Table 31. Sensitivity Study with 5% Increase in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	597,851	85,000
February	37,553	521,297	85,000
March	30,000	742,048	85,000
April	553,652	512,791	85,000
May	30,000	934,041	85,000
June	1,202,193	416,795	85,000
July	949,921	557,752	85,000
August	562,187	695,873	85,000
September	811,739	466,616	85,000
October	364,091	547,625	85,000
November	179,886	511,981	85,000
December	30,000	561,802	85,000
Total	4,781,222	7,066,472	1,020,000

Table 32. Sensitivity Study with 10% Decrease in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Rainwater Collection, (gallons)	Maximum Groundwater, (gallons)
January	30,000	512,444	85,000
February	97,049	446,826	85,000
March	30,000	636,042	85,000
April	538,399	439,535	85,000
May	30,000	800,607	85,000
June	1,081,894	357,253	85,000
July	883,315	478073	85,000
August	565,205	596,463	85,000
September	753,861	399,956	85,000
October	380,020	469,393	85,000
November	217,930	438,841	85,000
December	30,000	481,545	85,000
Total	4,637,673	6,056,978	1,020,000

Table 33. Sensitivity Study with 10% Increase in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	626,320	85,000
February	30,000	546,121	85,000
March	30,000	777,384	85,000
April	556,606	537,210	85,000
May	30,000	978,520	85,000
June	1,240,300	436,642	85,000
July	969,954	584,311	85,000
August	558,958	729,010	85,000
September	828,958	488,835	85,000
October	356,620	573,703	85,000
November	165,075	536,361	85,000
December	30,000	588,554	85,000
Total	4,826,471	7,402,971	1,020,000

Table 34. Sensitivity Study with 25% Decrease in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	427,037	85,000
February	144,612	372,355	85,000
March	45,505	530,035	85,000
April	511,280	366,279	85,000
May	86,963	667,172	85,000
June	950,714	297,710	85,000
July	804,529	398,394	85,000
August	555,493	497,052	85,000
September	684,530	333,297	85,000
October	383,832	391,161	85,000
November	244,115	365,701	85,000
December	82,412	401,287	85,000
Total	4,523,985	5,047,480	1,020,000

Table 35. Sensitivity Study with 25% Increase in Precipitation and Evapotranspiration.

Month	Irrigation Water Need, (gallons)	Collectable Rainwater, (gallons)	Maximum Groundwater, (gallons)
January	30,000	711,728	85,000
February	30,000	620,592	85,000
March	30,000	883,391	85,000
April	560,214	610,466	85,000
May	30,000	1,111,954	85,000
June	1,349,627	496,184	85,000
July	1,024,736	663,990	85,000
August	543,918	828,420	85,000
September	875,458	555,495	85,000
October	328,901	651,935	85,000
November	115,389	609,501	85,000
December	30,000	668,812	85,000
Total	4,948,243	8,412,468	1,020,000

Actually, the sensitivity study with the interaction of precipitation and evapotranspiration indicates a similar situation and results with the sensitivity analysis of precipitation. With the above sensitivity analysis results, the tank size cannot be either increased to fully meet the quantity requirements of irrigation or decreased due to the decline of irrigation water quantity. Therefore, the tank will remain as the design value. The payback period, however, changes slightly with a variation in water quantity.

5.2.4 *Sensitivity Analysis Results*

Summarizing the sensitivity results using the water balance method on the calculation of average value, Table 36 summarizes the results impacting on tank size.

Table 36. Sensitivity Study Results of Impact on Tank Size.

Sensitivity	Impact on Size
5 % decrease in precipitation	NO
5 % increase in precipitation	NO
10 % decrease in precipitation	NO
10 % increase in precipitation	NO
25 % decrease in precipitation	NO
25 % increase in precipitation	NO
5 % decrease in evapotranspiration	NO
5 % increase in evapotranspiration	NO
10 % decrease in evapotranspiration	NO
10 % increase in evapotranspiration	NO
25 % decrease in evapotranspiration	NO
25 % increase in evapotranspiration	NO
±5 % change in precipitation and evapotranspiration	NO
±10 % change in precipitation and evapotranspiration	NO
±25 % change in precipitation and evapotranspiration	NO

Similarly, Tables 37, 38 and 39 show the impact on the payback period with the change of precipitation, evapotranspiration, and interaction of precipitation and evapotranspiration, respectively.

Table 37. Results of Precipitation Impact in Payback Year Percentage of Irrigation.

	Annual Saved Water Cost, ($)	Payback, yr	Change in payback year, (%)	Percentage of Achievement Total Irrigation Needs, (%)
5% Decrease	17,485.1	8.9	-5.2	74
5% Increase	15,670.7	9.9	+5.8	78.5
10% Decrease	18,748.9	8.3	-11.6	71.6
10% Increase	14,882.1	10.5	+11.4	81.8
25% Decrease	21,830.5	7.1	-24.1	61.7
25% Increase	11,743.1	13.3	+41.2	88.7

Note: the + indicates the percentage of increase of payback period and - indicates the percentage of increase of payback period

Table 38. Results of ET Impact in Payback Year and Percentage of Irrigation.

	Saved Water Cost,($)	Payback Period,(yr)	Change in Payback year, (%)	Percentage of Achievement Total Irrigation Needs, (%)
5% Decrease	15,438.1	10.1	+7.4	78.5
5% Increase	17,698.6	8.8	-6.3	74.0
10% Decrease	14,445.2	10.8	+14.8	79.4
10% Increase	18,723.4	8.3	-11.5	71.8
25% Decrease	10,700.7	14.6	+54.9	90.7
25% Increase	21,839.2	7.1	-24.1	64.0

Table 39. Results of ET and Precipitation in Payback Year Percentage of Irrigation.

	Saved Water Cost, ($)	Payback Period, (yr)	Change in Payback year, (%)	Percentage of Achievement Total Irrigation Needs, (%)
5% Decrease	16391.5	9.5	+1.1	76
5% Increase	16688.6	9.3	-0.7	76
10% Decrease	16201.8	9.6	+2.3	76.1
10% Increase	16867.8	9.2	-1.7	76.1
25% Decrease	15858.9	9.8	+4.5	76.4
25% Increase	17412.4	8.9	-4.8	76.6

5.3 Discussion

From the results, the tank size does not change with the sensitivity study except for a 25 % decrease in evapotranspiration and a 25% increase in precipitation. Comparing the precipitation and evapotranspiration impacts of percentage change on payback period for each corresponding sensitivity changes, the evapotranspiration has more influence on both tank size and payback period than does precipitation. The reason is that the changes in ET directly affect irrigation water needs, whereas the precipitation influence needs to be calculated that affects irrigation water needs. The relationship between precipitation and runoff is another ratio, so ET has more of an impact on tank size and payback period.

Based on an analysis of the interaction of precipitation and evapotranspiration, the tank size cannot be significantly reduced or increased to meet irrigation-water needs. Therefore, the tank size based on the average value is suitable with a 25% variation of precipitation and evapotranspiration. Considering changes in payback period data, the average payback year is still approximately 9.4 years. Hence, the sensitivity studies demonstrate that there is little impact on the design tank size and little impact on payback period with the changes of precipitation and evapotranspiration.

Although the collected water source cannot fully meet the irrigation water requirement, the design rainwater harvesting system can generally satisfy approximately 78% of total irrigation needs. When precipitation increases or evapotranspiration decreases significantly, the irrigation water needs can be approximately 90% supplied by the designed rainwater harvesting system. The actual irrigation needs may differ from the estimation; e.g., the month of May probably needs much more water for irrigation.

However, this project provides a general feasibility analysis of installing a rainwater harvesting system.

Since the irrigation cannot be fully satisfied and payback period is little long, more analysis should be done to explore a better plan and payback period to implement a rainwater harvesting system. To achieve a better payback period, the irrigation water needs may be reduced to 60% or 50% of the total by designing smaller tanks as assuming the tank size can meet requirement of water storage. With this assumption, the estimated payback period is listed in Table 40. According to the table, only when the tank sizes are 20,000 and 30,000 gallons for 60% of total irrigation water needs, the payback period is better than the sample design. The problem with this scenario is that the tank size probably cannot be fully functional for water storage.

Table 40. Payback Period with Different Tank Size and Percent of Irrigation Requirement.

Tank size, (gallons)	50% of Total Irrigation Water Needs	60% of Total Irrigation Water Needs
20,000	9.7 years	8.1 years
30,000	10.8 years	9.0 years
40,000	12.2 years	10.1 years

Based on the water balance method, the tank size can be fairly small but the tank should be at least 40,000 gallons in order to be functional for water storage. Moreover, the estimation showed that lower irrigation requirements and smaller tank will have a worse or the same for the payback period. The reason is that the tank cost is a small part of the total costs and the percentage of water savings has more influence on the payback period. Hence, a better option is to reduce the design tank size and have the maximum irrigation requirement by the design tank size. Instead of a 60,000 gallon tank, the cost of designing three other tank sizes, 40,000, 50,000 and 70,000 gallons, is estimated, and the results are shown in Table 41, based on the same estimation method.

Table 41. Payback Period and Achievable Irrigation Percentage of Various Tank Size.

Tank Size, gallons	Payback Period, yr	Percentage of Achievement Total Irrigation Needs, (%)
40,000	8.1	75.4
50,000	8.6	75.6
70,000	10.0	76.4

Results show that employing a 40,000 gallon tank will achieve the best payback period, and these tanks can achieve almost the same percentage of irrigation requirements. However, there is no big difference on payback periods between 40,000, 50,000 and 60,000 gallon tanks. Although the smaller tanks are good for the payback period, they might not be functional for water storage, and the payback period will be more than the theoretical estimation. Hence, regarding water storage, a 60,000 gallon tank may be still a good choice.

Since the payback period is under 10 years, another way to reduce the payback period is to find a local manufacturer to make steel or concrete tanks to replace fiberglass tanks from other states. However, due to a low percent of tank costs in the total costs, this method improves the payback period. Because of a lack of cost information of these types of tanks, an assumption is made that these tanks can save 50% more than fiberglass tanks. With this assumption, the payback period is about 7.2 years.

Beside irrigation, the rainwater has potential use for toilet flushing and cleaning water in the month when the irrigation water requirement can be easily satisfied. This possible use of toilet water was not performed due to the unstable water supply, whereas the rainwater is a good, possible source for cleaning water. If the collected rainwater and groundwater can be used fully, the payback period can be reduced to less than 5 years.

In chapter 3, swimming pool water was not used for irrigation due to its high density of chlorine and the unknown frequency of water discharging. In order to improve the payback period, the pool water could be treated by an alternative method, such as ultraviolet radiation and ozonation. The concern of using an alternative method is the cost and health impact on humans. The ozone involved in the ozonation method is possible toxic, so it is not a good option for disinfection. In contrast, ultraviolet disinfection is applicable and relatively cost-effective, but some cost will be spent on the replacement of the disinfection system. If the pool water is discharged twice a year and fully utilized, the payback period can be reduced by 0.5 years.

These above options of reduction of payback period were summarized in Table 42.

Table 42. Options of Reduction of Payback Period.

Options to reduce payback period	Assumption	Reduction of Payback Period
Using concrete or steel tanks for storage	50% cost of fiberglass tank	reduced to 7.2 years
Rainwater usage for toilet flushing and cleaning water	all rainwater can be used	less than 5 years
The pool and spa water from REC center	treated by alternative method and good for irrigation usage	reduced 0.5 years

Moreover, a fountain could potentially be built on Campus Green for aesthetic purposes by using rainwater stored in tanks. Although the fountain also has an evapotranspiration effect, the water loss depends on the fountain area which will not much influence the irrigation function. With an aesthetic function, the RHS will not only be considered an investment project but it might be a landmark on the UAB campus.

Besides the cost, the concern of bacteria and algae in the system would need to be addressed. This concern is not a big issue for irrigation purposes but in the operation and maintenance of the system. If the storage facility is not maintained well, the bacteria and algae cause filter problems and a problem in monitoring the system. To solve this problem, an ultraviolet disinfection device can be utilized to control the growth of bacteria. Another option is chlorination with automatic self-dosing systems, and appropriate contact time is critical to kill bacteria (Texas Water Development Board, 2005). In addition, the storage facility should be carefully monitored and maintained.

Aside from the financial problem, the rainwater harvesting system benefits the environment. The system will reduce the precipitation runoff volume, which means a reduction of the volume of water running to the river. It will relieve the erosion of river banks, as well as the river water quality that will benefit the ecosystem in and along the river. Because of water conservation for irrigation, the amount of water used for irrigation may be treated for potable water. Since rainwater is reused, the energy used for wastewater treatment and water supply will also potentially reduced, which may lead to a reduction in air pollutant emissions.

CHAPTER 6

CONCLUSION

The UAB Facilities Management Department has successfully installed USTs at the University Boulevard Office Building (UBOB) and is considering extending the application of RHS on the UAB Campus Green as a part of their GO GREEN sustainable project. The design of underground water storage tanks involving rainwater harvesting on the UAB campus is a further study on water conservation at UAB and enables water to be saved for irrigation on the Green.

The data collected and investigated is relevant for the irrigation water needs estimation. In the project, each term involved in the hydrological cycle has been explained and calculated appropriately. The investigation at the UAB Campus Green, along with data from the Facilities Management Department aids in this research providing more accurate estimates. Even though the cost estimation of the RHS is relatively simple, the total cost is acceptable. According to the estimated three-year average value, the designed tank size is 60,000 gallons. By considering the financial aspects and the function of storing water, the payback period is about 9.4 years. In order to explore the impact on tank size and the payback period, and the changes of precipitation and evapotranspiration, a sensitivity analysis study was performed. With the sensitivity study, changes of 25% for precipitation and evapotranspiration have little effect on tank size and payback period. In general, the tank size and payback period remain nearly the same. The study demonstrated that the design of a RHS for the UAB Campus Green is reasonable.

Though the payback period is relatively long for projects, the fiberglass tank has a long lifespan that will be economic even for a long period application. After exploring possible method to improve payback period, the results showed more acceptable result, which is almost acceptable for installation on economic aspect. Moreover, the RHS not only benefits the environment by saving water resources but can achieve an aesthetic function with a fountain, as well as relief from impact on rainwater-receiving streams. In this project, a general concept and estimation were performed to examine the feasibility of such a system. If the system is planned, more specific, exhausting work should be performed. From the ecological angle and trend of water conservation, it is worthwhile to implement a RHS on the UAB Campus Green, and more RHS systems could be implemented on campus.

Although this research is specifically a case study on regarding the UAB Campus Green, the methods and principals are general and applicable to big or small implementation, such as another campus project or household, respectively.

REFERENCES

Ahmed, M. F., and Rahman, M. M. (2000). *Water Supply & Sanitation: Rural and Low Income Urban Communities.* Dhaka: ITN-Bangladesh, Centre for Water Supply and Waste Management.

Alam, R., Munna, G., Chowdhury, M. A., Sarkar, M. S., Ahmed, M; Rahman, M.T., Jesmin, F., and Toimoor, M. A. (2011). Feasibility Study of Rainwater Harvesting System in Sylhet City. *Environmental Monitoring and Assessment*, 184 (1):573-580.

Allen, R. G., Walter, Ivan A. (Editor), Elliott, Ronald L. (Editor), Howell, Terry A. (Editor), Itenfisu Daniel (Editor), Jensen, Marvin E. (Editor), and Snyder, Richard L. (Editor) (2005). *The ASCE Standardized Reference Evapotranspiration Equation.* Reston, VA: ASCE/The Irrigation Association/EWRI, 0-7844-0805-X.

Allen, R., Pereira, L., Raes, D., and Smith, M. (1998). Irrigation and Drainage Pape: No. 56 Crop Evapotranspiration (guidelines forcomputing crop water requirements). 1-281.

Arizona Cooperative Extension, College of Agriculture and Life Sciences, The University of Arizona. (December, 2000). *Turf Irrigation Management Series No.2: Converting Reference Evapotranspiration. AZ1195.* Tucson, AZ: Arizona Cooperative Extension. http://ag.arizona.edu/pubs/water/az1195.pdf

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R., and Tchobanoglous, G. (2007). Water Reuse: An Introduction. In *Water Reuse: Issues, Technologies, and Applications* (p. 15). New York, NY: McGraw-Hill.

Birmingham Water Works Board. (2011). *Birmingham Water Works Board-Residential Rates* . Retrieved August 2011, from http://www.birminghamwaterworks.com/index.php?option=com_content&task=section&id=109&Itemid=177

Birmingham Weather Forecast Office. (2011). *National Weather Service Climate*. Retrieved June 2011, from National Oceanic and Atmospheric Administration: http://www.nws.noaa.gov/climate/index.php?wfo=bmx

Blaney, H. F., and Criddle, W. D. (1950). *Determining Water Requirements in Irrigated Area from Climatological and Irrigation Data.* USDA, SCS-TP-96. 48p.

Brouwer, C., and Heibloem, M. (1986). *Irrigation Water Management: Training Manual No. 3.* Food and Agriculture Organization of the United Nations.

City of College Station. (2008). *City of College Station: Code of Ordinances/ Chapter 11-Utilities*. Retrieved from http://code.ci.college-station.tx.us/browse.aspx?dbid=1&startid=1

Cosgrove, W. J., and Rijsberman, F. J. (2000). *World Water Vision: Making Water Everybody's Business.* London, UK: EarthscanPublications.

Daft Logic. (2011). Retrieved July 2011, from Google Maps Area Calculator Tool: http://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm

Darco Inc. (2010). *Risk Free Quick Quote-Darco Underground Water Storage Tanks*. Retrieved August 2011, from Darco Inc. Web Site: http://www.darcoinc.com/free-quote.html

Dietz, M. E. (2007). *Low impact development practices: A review of current research.* Water Air and Soil Pollution 186 (1-4):351-363.

Doorenbos, J., and Pruitt, W. O. (1975). Guidelines for predicting crop water requirements. *Irrigation and drainage paper*, FAO, (24)-195.

Eisenman, S. (2011, September). Darco Inc., Bennett, CO. Personal Communication. (Z. Li, Interviewer)

EPA, U.S. (2004). *The Use of Best Management Practices (BMPs) in Urban Watersheds.* EPA/600/R-04/184.

Google Maps. (2012). *University of Alabama at Birmingham-Google Maps*. Retrieved Febuary 2012, from Google Maps: http://maps.google.com/maps?hl=en&tab=wl

Gould, J., and Nissen-Petersen, E. (1999). *Rainwater Catchment Systems for Domestic Supply: Design, Construction and Implementation.* London: IT Publications.

Knight, E. H. (2009). *Peace College Rainwater Harvesting System.* Raleigh, NC.

LaBranche, A., Wack, H.O., Crawford, D., Crawford, E., Sojka, Nickolas J., DVM, and Brand, C. (August, 2007). *Virginia Rainwater Harvesting Manual 2007.* Salem, VA: The Cabell Brand Center.

MyTopo. (2011). *Free Online Topo Map*. Retrieved July 2011, from MyTopo: http://www.mytopo.com/maps/index.cfm

Persyn, R. A., Porter, D. O., and Silvy, V. A. (2008). *Rainwater harvesting.* 05-08.B-1653: Agrilife Extension, Texas A&M System.

Postel, S. (2000). Entering an Era of Water Scarcity: the Challenge Ahead. *Ecological Applications*, *10(4)*, p 941–948.

Sammis, T. W., Wang, J., and Miller, D. R. (2011). The Transition of the Blaney-Criddle Formula to the Penman-Monteith Equation in the Western United States. *Journal of Service Climatology*, 5(1): 1-11.

Saour, W. H. (2009). *Implementing Rainwater Harvesting System on Texas A&M Campus for a Purpose of Irrigating: A Feasibility Study (Senior Scholars Thesis).* College Station, TX.

Shiklomanov, I. A. (2000). Appraisal and Assessment of World Water Resources. *Water International, Volume 25, 1*, 11-32.

Shiklomanov, I., and Gleick, P. H. (Editor). (1993). Igor Shiklomanov's chapter *"World Fresh Water Resources"* in Peter H. Gleick (Editor), 1993, *Water in Crisis: A Guide to the World's Fresh Water Resources.* New York, NY: Oxford University Press.

Soil Conservation Service, Department of Agriculture, United States. (1970). Irrigation Water Requirements. Tech Release NO.21. 92.

Soil Conservation Service, Department of Agriculture, United States. (August, 1982). *Soil Survey of Jefferson County, Alabama.*

Soil Consrvation Survice (SCS). (1986). *Urban Hydrology for Small Watershed, TR-55.* Washington DC: National Resource Conservation Service.

Texas Water Development Board. (2005). *The Texas Manual on Rainwater Harvesting. Third Edition.* Austin, TX. http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf

U.S. Geological Survey. (2011). *The Water Cycle, U.S. Geological Survey Water Science School*. Retrieved Febuary 2012, from http://ga.water.usgs.gov/edu/watercycle.html

University of Alabama at Birmingham. (2011, July). *UAB-Campus Green*. Retrieved from University of Alabama at Birmingham: http://www.uab.edu/handbook/student-services/c-campus-green

University of California Cooperative Extension and California Department of Water Resources. (August, 2000). *A Guide to Estimating Irrigation Water Needs of Landscape Planting in California: The Landscape Coefficient Method and WUCOLS III.* Sacramento, California: California Department of Water Resources. http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf

Viessman, W., and Lewis, G. L. (2003). *Introduction to Hydrology, 5th Edition.* Upper Saddle River, NJ: Pearson Education.

Web Soil Survey, Natual Resores Conservation Service, Department of Agriculture, United States. (2011). *Web Soil Survey*. Retrieved June 2011, from Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

World Health Orgnization (WHO). (2000). *Global Water Supply and Sanitation Assessment 2000 Report.* Geneva, Switerland: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, World Heallth Orgnization.

Winslett, M. (2011, June). Facility Management Department, University of Alabama at Birmingham, Birmingham, AL. Personal Communication. (Z. Li, Interviewer)

APPENDIX A. PLANE FIGURE OF THE UAB CAMPUS GREEN.

Source: www.uab.edu/

APPENDIX B. RUNOFF CURVE NUMBER FOR URBAN AREAS.

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Source: SCS, 1986