1- Title: Investigating Rainwater Harvesting as a Stormwater Best Management Practice and as a Function of Irrigation Water Use.

2- Project Number: 2010TX364B

3- Principal Investigator:
Sa'd A. Shannak
PhD Graduate Student
Texas A&M University
The Water Degree Program
213 Teague, MS 3408
College Station, TX 77843-3408
979-862-2164, sshannok@tamu.edu

4- Former Co-Principal Investigator:
Bruce J Lesikar, PhD.
Texas AgriLife Extension Service
b-lesikar@tamu.edu

5- Abstract

Stormwater runoff has negative impacts on water resources, human health and environment. In this research the effectiveness of Rain Water Harvesting (RWH) systems is examined as a stormwater Best Management Practice (BMP). Time-based, evapotranspiration-based, and soil moisture-based irrigation scheduling methods in conjunction with RWH and a control site without RWH were simulated to determine the effect of RWH as a BMP on a single-family residence scale. The effects of each irrigation scheduling method on minimizing water runoff leaving the plots and potable water input for irrigation were compared. The scenario that reflects urban development was simulated and compared to other RWH-irrigation scheduling systems by a control treatment without a RWH component. Four soil types (Sand, Sandy Loam, Loamy Sand, Silty Clay) and four cistern sizes (208L, 416L, 624L, 833L) were evaluated in the urban development scenario.

To achieve the purpose of this study; a model was developed to simulate daily water balance for the three treatments. Irrigation volumes and water runoff were compared for four soil types and four cistern sizes. Comparisons between total volumes of water runoff were estimated by utilizing different soil types, while comparisons between total potable water used for irrigation were estimated by utilizing different irrigation scheduling methods.

This research showed that both Curve Number method and Mass-Balance method resulted in the greatest volumes of water runoff predicted for Silty Clay soil and the least volumes of water runoff predicted for Sand soil. Moreover, increasing cistern sizes resulted in reducing total water runoff and potable water used for irrigation, although not at a statistically significant level. Control treatment that does not utilize a cistern had the greatest volumes of predicted supplemental water among all soil types utilized, while Soil Moisture-based treatment on average had the least volume of predicted supplemental water.

6- Problem and Research Objectives

Problem

Though different policies requiring the use of RWH as a BMP are already in place, little research has addressed the effectiveness of implementing RWH system as a BMP. Therefore, investigating possible runoff reductions and effectiveness of RWH system on a household scale is an important research question and will potentially become increasingly so in the future. Moreover, the type of irrigation scheduling plays a significant role in determining the effectiveness of RWH as a stormwater BMP. For instance, most of the irrigation practices involved overwatering which in turn results in increasing water runoff and all the negative effects associated with it, such as: increasing pollution, decreasing groundwater recharge, increasing flash floods, and stream deterioration. As a result, this study involved three different management irrigation methods with RWH system and a control site without RWH. A comparison between each irrigation method was conducted based on reducing stormwater runoff and potable water input for irrigation. These irrigation methods include: time-based irrigation scheduling, evapotranspiration-based scheduling, and soil moisture-based scheduling.

A limited number of RWH as BMP studies have been conducted in the United States and no research has been done in Texas, or the Southeastern United States. Therefore, very little data exists on the environmental and economic incentives from implementing RWH system. The lack of research pertaining to the effectiveness of RWH system as a stormwater BMP creates a need to do this study. Furthermore, most of the available research that have mentioned RWH system as a BMP analyzed the effectiveness of the system based on the storage size and other climatic factors. None examined the impact of RWH system combined with different irrigation management methods or the runoff volume.

Objectives

The goal of this research is to study the effectiveness of a RWH system in terms of reducing total volume of runoff leaving lawn areas as well as total volume of potable water (supplemental water) used to meet irrigation requirements. This goal is attained by studying the following objectives:

1. Determine the effect of utilizing Curve Number method and Mass-Balance method in estimating total volume of water runoff.
2. Determine the effect of soil types (Sand, Sandy Loam, Loamy Sands, and Silty Clay) on the total volume of runoff and total volume of supplemental water.
3. Determine the effect of using several irrigation scheduling methods (Time-based, Soil moisture-based, ET-based and a control treatment that does not utilize a cistern) on the total volume of runoff and the total volume of supplemental water by utilizing: different cistern sizes (0L, 208L, 416L, 624L, 833L), depletion ratio of 50%, and soil depth of 15.2 cm.

7- Materials and Methodology

A model was developed to simulate the daily water balance for four irrigation scheduling methods and to extent the results to other soil types and different storage capacities. This model was designed to simulate water balance data for a field area of the Urban Solutions Center of Texas A&M University system located in Dallas, TX. This center is located within the White Rock Creek watershed (Figure 1). Dallas –Fort Worth Metroplex is located North Central Texas at 32.78°N 96.78°W (Elev. 144m). The climate in the area is humid subtropical with hot summers. It is also characterized by a wide annual temperature range. Temperatures during the daytime of summer frequently exceed 100°F. The average length of warm season in this area is about 249 days. Precipitation ranges from 508 to more than 1270 millimeter (NOAA, 2010). Weather data for the period (April 2008- April 2010) for the Dallas Research Center were analyzed. The source of weather data was taken from a weather station on-site which is administrated by Biological and Agricultural Engineering Department of the Texas A&M University system (TexasET, 2010). The following estimated measurements based on weather data from the Dallas Research Center were considered:

o Volumes of water runoff leaving the roofs and the turfgrass irrigated area;
o Total irrigation demand;
o Volume of overflow from the cistern during storm events.
o Volume of rainwater captured and used for irrigation.
o Supplemental water used for irrigation.

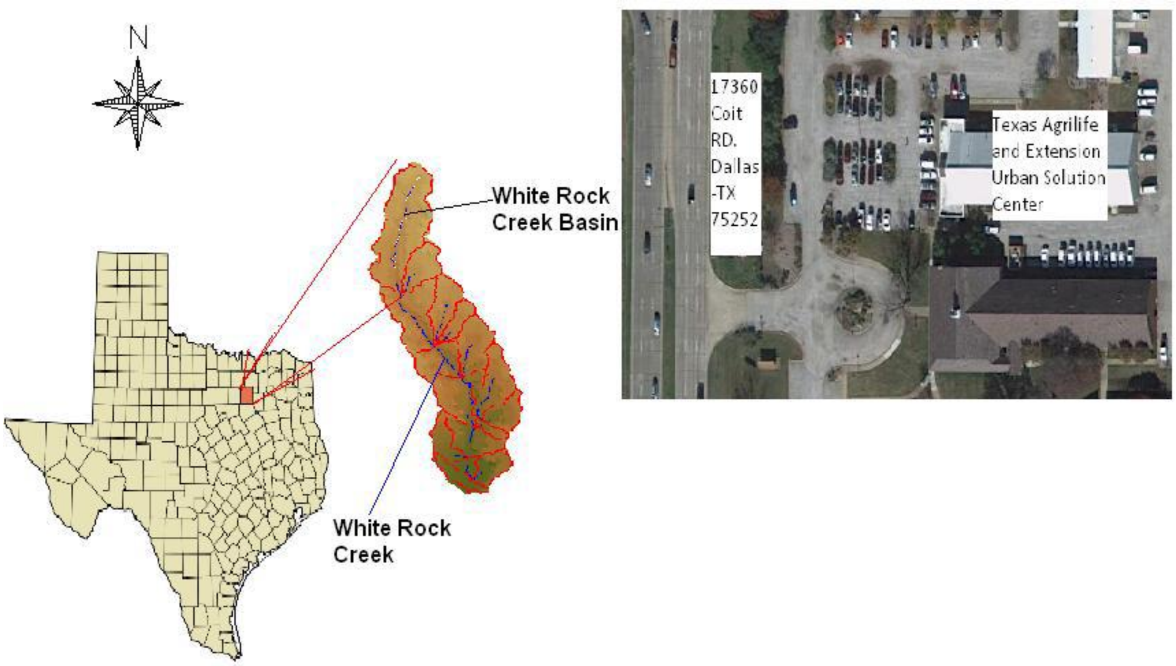


Figure 1. **Urban Solutions Center of Texas A&M University location.**

Several variables were considered as well in finding the previous measurements (Tables 1 and 2). First, four soil types were considered for this study; Sand, Sandy Loam, Loamy Sand, and Silty Clay. Second, four irrigation scheduling methods were considered; Time-based, Soil moisture-based, ET-based, and Time-based without a cistern. Third, five cistern sizes were studied; 0 L, 208 L, 416 L, 624 L, and 833 L which is equivalent to 0cm/ m^2 , 1.5cm /m^2 , 3.0 cm/ m^2 , 4.5cm/ m^2 , 6 cm/ m^2 respectively by considering 1 roof runoff coefficient. Fourth, three soil rooting depths were tested; 15.2 cm, 22.9 cm, and 30.5 cm. Fifth, four soil moisture allowable depletion ratios were studied; 40%, 50%, 60%, and 75%. The table below summarizes the considered variables:

Table1.Variables used in the simulation.

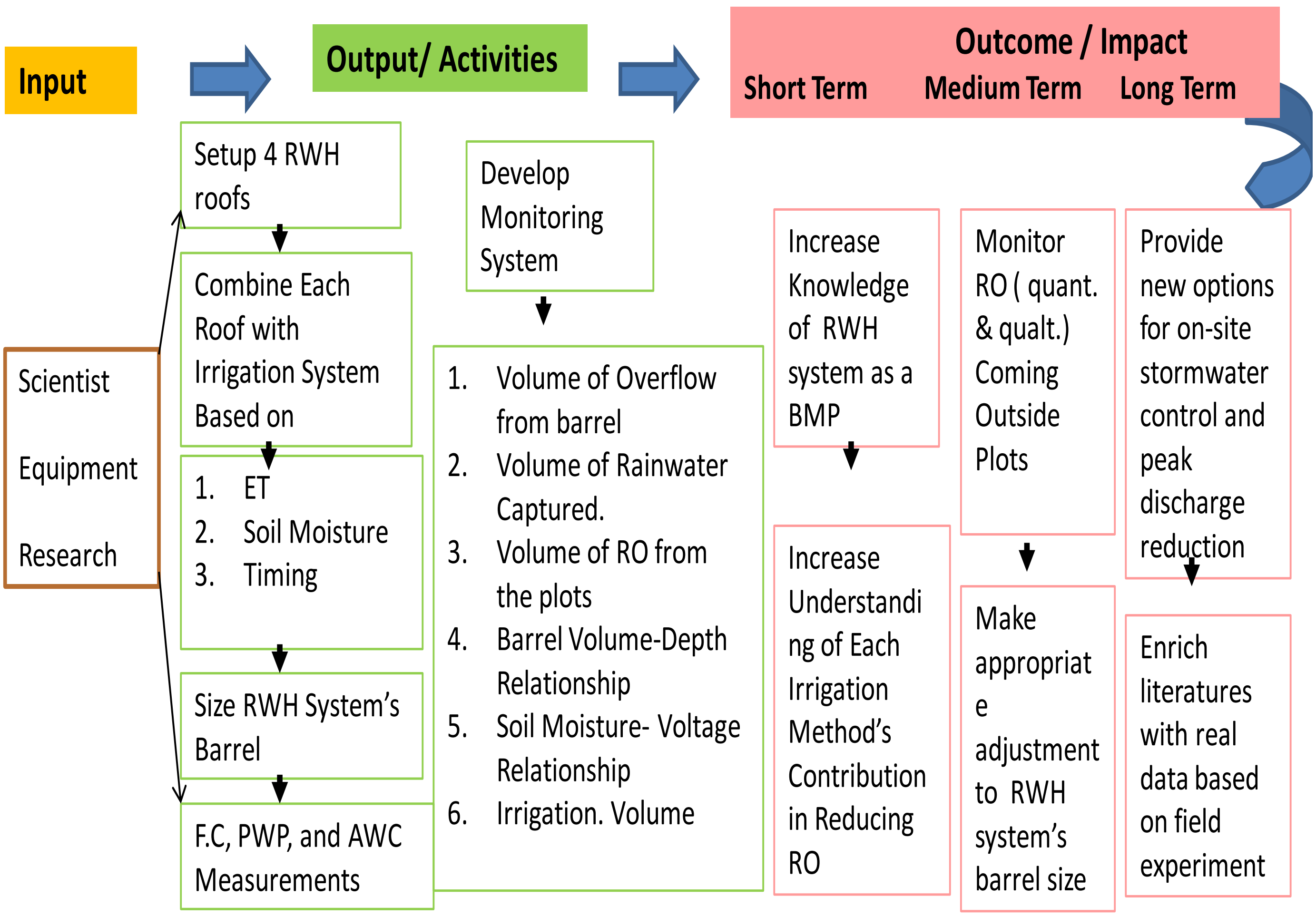
Soil type	Irrigation scheduling	Cistern size (L)	Depletion (%)	Soil depth(cm)
Sand	Time-based	0	40	15.2
Sandy Loam	Soil moisture-based	208	50	22.9
Loamy Sand	ET-based	416	60	30.5
Silty Clay	Time-based without cistern	624	75	
		833		

Table 2. Soil hydraulic properties considered as an input data in the simulation.

Parameter/ Soil Type	Sand	Sandy Loam	Loamy Sand	Silty Clay
Field capacity (%)	0.1	0.18	0.12	0.41
Permanent witling point (%)	0.04	0.08	0.05	0.28
Available water content (%)	0.06	0.10	0.07	0.14
Saturation (%)	0.45	0.46	0.47	0.54
Free drainage (%)	0.35	0.28	0.35	0.13
Roof runoff coefficient	0.95	0.95	0.95	0.95
Curve Number for lawns, good condition	55	71	65	80

The turfgrass which was used is a Crowne zoysia grass, this grass had been developed by Texas A&M University in cooperation with the United States Golf Association. The experimental name for this grass is (DALZ8512') and the scientific name is Zoysia japonica. This species is known for its tolerance to drought conditions and low water use, excellent cold hardiness, and rapid recuperative ability (Engelke et al., 1996).
A roof to lawn area ratio of 1:3 was used to reflect a typical residential area in the Dallas/Fort Worth Metroplex. Roof area considered in this study is 13.94 m^2 and a plot area of 20.9 m^2. Cistern sizes were developed based on a ratio of impervious surface area (rooftops) to total volume of rainfall and by assuming rainwater collection from half the roof. The total volume of runoff generated from rooftops is calculated by multiplying the Area of the roof, Roof Runoff Coefficient, and Rainfall depth. Therefore, the total volume of runoff from a roof during a 2.54 cm rainfall event was 0.35 m^3 (13.9 m2 0.0254 m) and a 1 roof runoff coefficient.

Research-Diagram



Assumptions

1. RWH system is sufficient in controlling small stormwater events.
2. Each irrigation method combining the RWH system has a different impact on the effectiveness of RWH system as a BMP.

8- Principle Findings

Figure 2 illustrates a graphical comparison between all irrigation scheduling methods and total supplemental water estimated. By utilizing 0L cistern, both Control and Time-based treatment ended with the same volume of predicted supplemental water and it was the least among the other treatment when utilizing all soil types. By utilizing all cistern sizes, Control treatment predicted the greatest volumes of supplemental water by considering: Loamy Sand, Sandy Loam and Silty Clay soil, while Soil Moisture-based treatment on average predicted the least volumes of supplemental water except when utilizing sand soil.

As it can be noticed from Figure 1; Control treatment that does not utilize a cistern had the greatest volume of predicted supplemental water as well among all cistern sizes utilized except when utilizing Sand soil, while Soil Moisture-based treatment on average had the least volume of predicted supplemental water. ET-based irrigation method comes in the second order in terms of least predicted supplemental water after the Soil Moisture-based treatment. Time-based treatment on average comes in the third order after both ET and Soil Moisture-based.

Figure 3 shows a comparison between all irrigation scheduling methods and total runoff estimated. As it can be noticed from this figure; Control treatment that does not utilize a cistern had the greatest volume of predicted runoff among all soil types and cistern sizes utilized, while Time-based treatment on average had the least volume of predicted runoff. ET-based irrigation method comes in the second order in term of least predicted runoff after the Time-based treatment. Soil Moisture-based treatment on average comes in the third order after both ET and Time-based.

By utilizing coarse soil texture such as sand among the four irrigation scheduling treatments, total volumes of water runoff estimated were the least, while utilizing fine soil texture such as silt clay estimates greatest volume of water runoff.

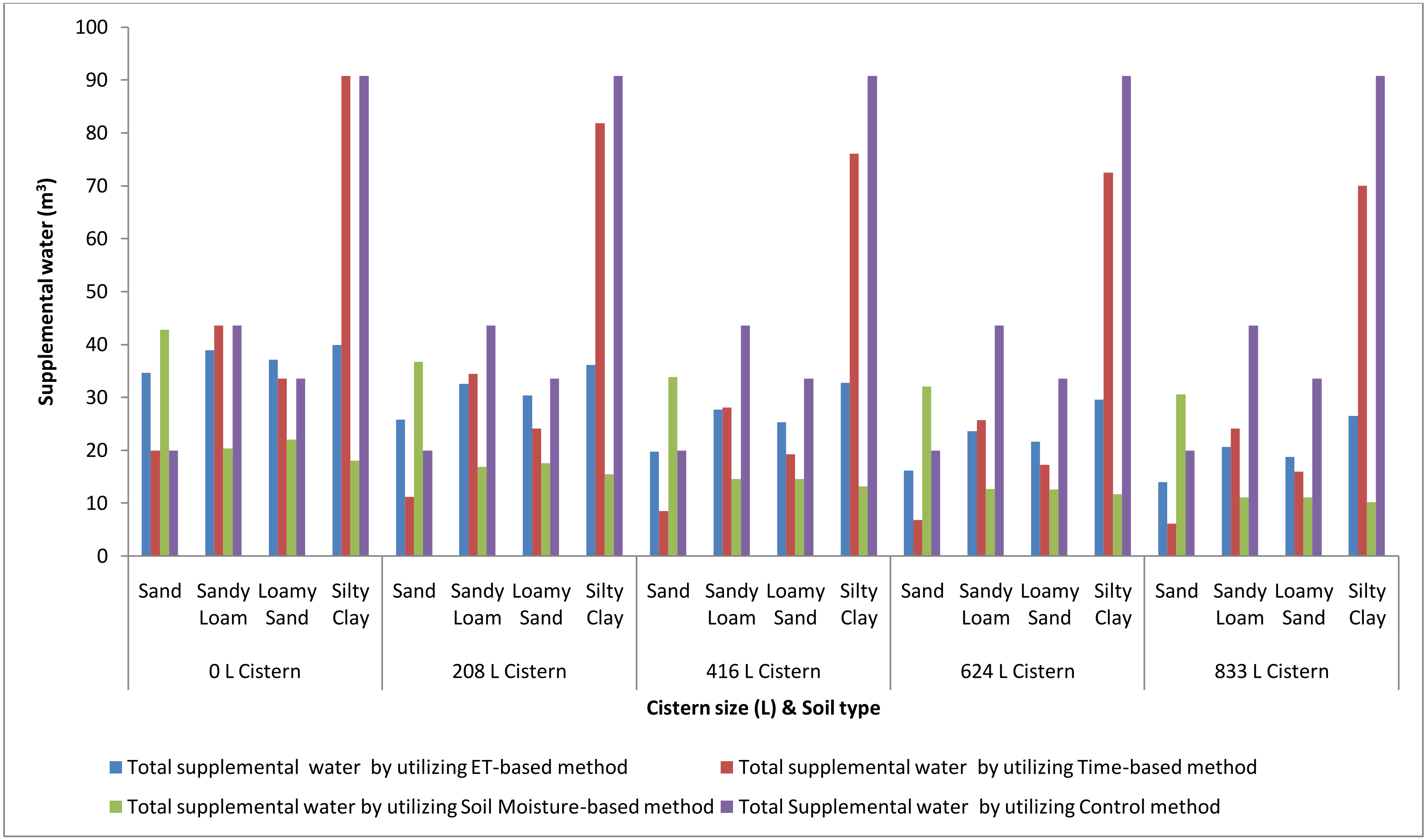


Figure 2. Comparison between different irrigation scheduling methods and total supplemental water by utilizing different cistern sizes.

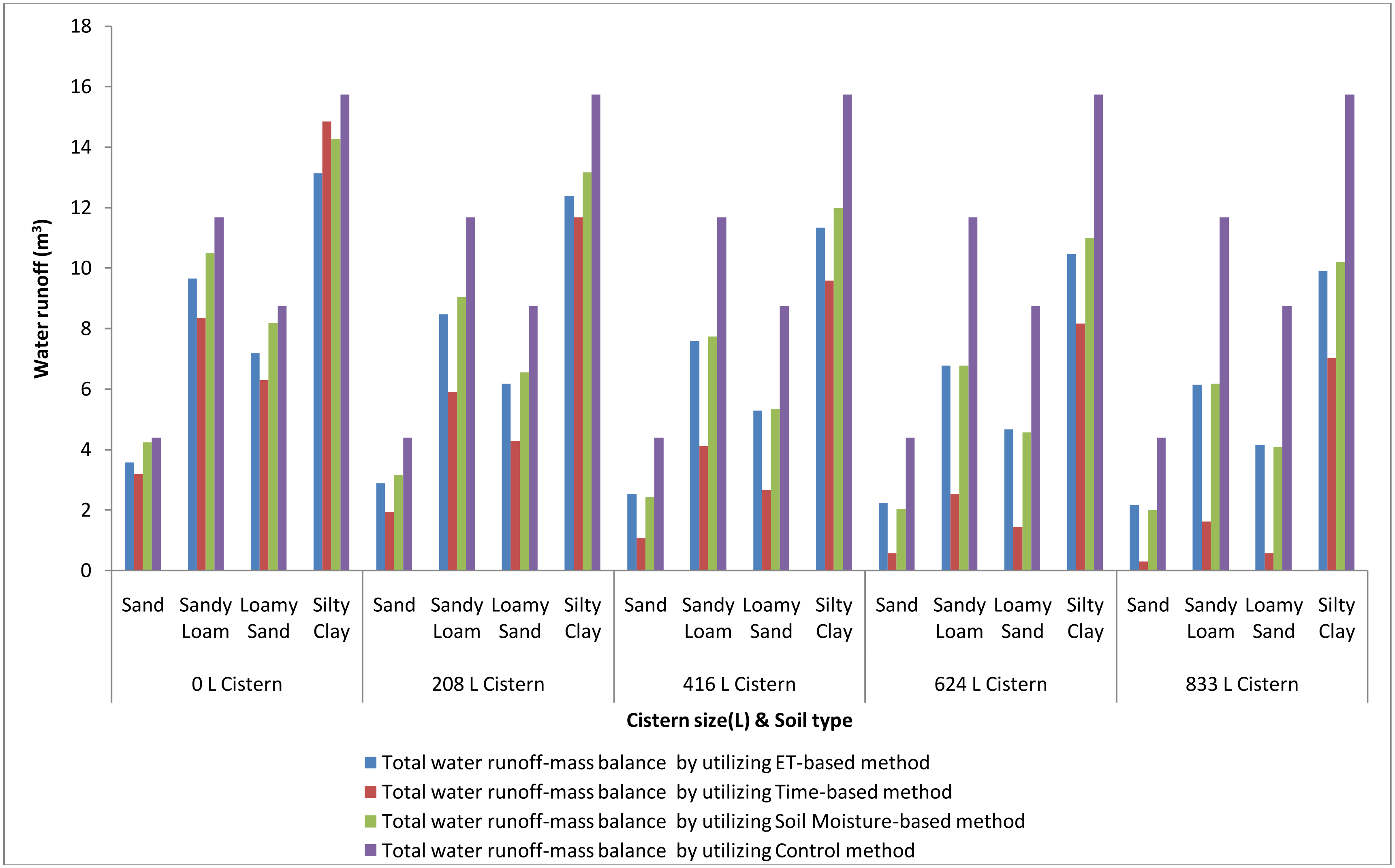


Figure 3. Comparison between different irrigation scheduling methods and total volumes of water runoff-mass balance method by utilizing different cistern sizes.

9- Significance

Developing a RWH model based on Mass-Balance method was a significant tool in predicting the total volume of water runoff leaving irrigated turfgrass and the total potable water used for irrigation (supplemental water). This model was developed by combining different irrigation scheduling methods with a RWH system and a control treatment that does not utilize a RWH system. Each irrigation scheduling method had different impacts on the total volumes of water used for irrigation and as a result the total volume of water runoff leaving plots. Cistern size as well was investigated as a factor influencing volume of rain water captured, total water runoff leaving plots and total supplemental water. Increasing cistern size reduced total supplemental water and water runoff, although not at a significant level as results showed in the previous section. Soil depth, soil type, and depletion ratio were other factors that this study investigated to determine the effectiveness of RWH system as a stormwater BMP.

Through this research the following conclusions were developed:

- Soil Moisture and ET based irrigation scheduling methods are water conservative practices and contributed in reducing total volumes of potable water used for irrigation.
- Soil Moisture-based irrigation scheduling method contributed in utilizing least volumes of water which was reflected on keeping RWH cistern full of water more frequently and in its turn resulted with greater volumes of water runoff.
- Time-based irrigation scheduling method utilized greater volumes of water than Soil Moisture treatment that contributed in keeping RWH cistern not full of water and that predicted least volumes of water runoff.
- By moving from coarse soil texture to fine soil texture; total water runoff predicted increased and total potable water predicted increased, while by moving in the opposite direction from fine to coarse soil texture, total water runoff predicted and total potable water predicted decreased.
- Based on all the comparisons conducted to investigate the influence of Curve Number method and Mass-Balance method in estimating total volume of water runoff; both methods resulted in the greatest volumes of water runoff predicted for Silty Clay and the least volume of water runoff predicted for Sand.
- When utilizing ET-based and Soil Moisture-based irrigation scheduling methods, the Curve Number method predicted greater volumes of water runoff for Silty Clay for all cistern sizes utilized than the Mass-Balance method, while Mass-Balance method predicted greater volumes of water runoff for Sandy Loam, Loamy Sand and Sand soil in respect to all cistern sizes utilized. By utilizing Time-based irrigation scheduling method, the Mass-Balance method predicted greater volumes of total runoff for all cistern sizes and soil types utilized except for Silt Clay where the Curve Number method predicted greater volumes. Finally, the Mass-Balance method predicted greater total volumes of water runoff than the Curve Number method for the control treatment (0L cistern).
- Irrigation scheduling method affected predicted total volumes of water runoff and supplemental water. Control treatment that does not utilize a cistern had the greatest volume of predicted runoff among all soil types utilized, while Time-based treatment on average had the least volume of predicted runoff. ET-based irrigation method comes in the second order in term of least predicted runoff after the Time-based treatment. Soil Moisture-based treatment on average comes in the third order after both ET and Time-based.
- Soil Moisture treatment had the least volume of predicted supplemental water by utilizing all cistern sizes and Silty Clay soil. Control treatment continues to have the greatest volume of

predicted supplemental water among all cistern sizes utilized and by considering Silty-Clay soil type.

- ET-based irrigation method comes in the second order in terms of least predicted supplemental water after the Soil Moisture-based treatment. Time-based treatment on average comes in the third order after both ET and Soil Moisture-based.
- Increasing cistern size resulted in decreasing total predicted volumes of water runoff and supplemental water, although not at a statistically significance level.

10- Reference Cited

Engelke, M. C., R. H. White, P. F. Colbaugh, J. A. Reinert, K. Marcum, B. A. Ruemmele, and S. J. Morton. 1996. Crowne Zoysiagrass. Dallas TX: Texas A&M University. Available at: http://dallas.tamu.edu/turf/crowne.html.

NOAA. 2010. Dallas/Fort Worth climate overview. National Oceanic and Atmospheric Administration. Available at: http://www.srh.noaa.gov/fwd/?n=dnarrative.

TexasET. 2010. Texas historic weather averages. College Station: Texas A&M University. Available at: http://texaset.tamu.edu/etinfo.php.