INVESTIGATING RAINWATER HARVESTING AS A STORMWATER BEST MANAGEMENT PRACTICE AND AS A FUNCTION OF IRRIGATION WATER USE

A Thesis

by

SA’D ABDEL-HALIM SHANNAK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Water Management and Hydrological Science

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and as a Function of Irrigation Water Use

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Approved by:

Chair of Committee,	Bruce J. Lesikar
Committee Members,	Fouad Jaber
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ABSTRACT

Investigating Rainwater Harvesting as a Stormwater Best Management Practice
and as a Function of Irrigation Water Use.
(December 2010)

Sa’d Abdel-Halim Shannak, B.S., University of Jordan
Chair of Advisory Committee: Dr. Bruce J. Lesikar

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.

DEDICATION

To my parents

Mr. Abdel-Halim Sa’d Eddin Shannak

Mrs. Fatima Abdullah Shannak

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My first and most earnest gratitude goes to the Almighty Allah for materializing my dream. I thank God also for the opportunity he gave me to meet and interact with wonderful people through this research.

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INTRODUCTION

Urban areas are expanding rapidly in the United States; runoff is increasing due to the increasing impervious cover. Urban growth contributes in increasing stormwater runoff which in turn causes an increase in the frequency and severity of flooding, and thus accelerating channel erosion, and altering of stream beds composition. Moreover, increased stormwater runoff contributes in changing the character and volume of energy inputs to the stream. As a result, infiltration and base flows will be reduced and urban runoff volumes, the frequency of flooding and peak runoff flow rates will increase. The consequences of urbanization will be reflected not only on the hydrological cycle and infrastructures, but also on human health. Urban runoff has a significant role in transporting pollutants such as chemicals, sediments, pesticides, fertilizers, and oils into water bodies, where they harmfully affect water quality. Best management practices (BMPs) were developed to negate the effect of urbanization on stormwater by reducing the runoff volume and peak flows as well as improving the water quality. BMPs can be costly and form a burden for municipalities and states. Thus, selecting proper, cost effective solutions is crucial.

A rainwater harvesting system (RWH) can be a good example for a cost effective approach that serves as a BMP. RWH consists of collecting rainwater from the available catchment area during rain events, diverting this water through gutters, channels and pipes into containers such as cisterns, tanks and reservoirs. RWH system is comprised of

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This thesis follows the style of *Applied Engineering in Agriculture.*

the following components at various stages: First, a catchment surface which is usually a rooftop; second, a conveyance apparatus diverting rainwater through gutters and downspouts from the roof to the storage container; third, removing debris and dust before it goes to the tank through leaf screens, first flush diverters, and roof washers; fourth, a storage container; fifth, a delivery system that either includes pumps or is gravity-fed; sixth, a treatment and purification system in case the harvested water is used for in-home or potable purposes (TWDB, 2005).

While RWH has been extensively used as an alternative source of water, it has not been studied as a stormwater BMP. RWH can reduce stormwater runoff volumes, and delay and decrease peak runoff flow rates. Collected water can be used later for irrigation or filtered and reused for household activities such as toilet flushing. Rain barrels can be used for collecting and storing stormwater runoff on small scale applications, while cisterns can be used on large scale applications.

Installation cost is one of the factors that affect selecting RWH to be applied as a BMP. RWH can be a cost effective solution in the long run. All in all, in comparison to other BMPs, RWH is a promising water conservation practice that can be used to reduce the negative impact of urban runoff. By storing and diverting runoff from impervious areas such as roofs, RWH system reduces the undesirable impacts of runoff that would otherwise flow rapidly into water bodies and contribute to flooding and erosion problems (Prince George’s County, 1999). The effectiveness of RWH as a stormwater BMP depends on the size of the storage, the rainfall pattern and the use of the harvested water. For landscape applications, the use will vary based on the irrigation system and scheduling approach.

Though different policies requiring the use of RWH as a BMP are already in place, little research has addressed the effectiveness of implementing RWH 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 result in 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 developed a model to simulate daily water balance for three irrigation methods: time-based irrigation scheduling, evapotranspiration-based scheduling, and soil moisture-based scheduling. Four soil types were considered; Sand, Sandy Loam, Loamy Sand, and Silty Clay. Three depletion ratios were used to adjust irrigation volume applied; 40%, 50%, 60% and 75%. Based on this study; the effectiveness of RWH will be addressed through the reduction in volume of water runoff as well as potable water used for irrigation. Each one of these factors costs municipalities and states millions of dollars on a yearly basis to solve the negative impact that might result from urban water runoff.

Although RWH is considered a BMP, the effectiveness of such system has not been extensively studied (Gilroy and McCuen, 2009). There is no international or national standard that determines the effectiveness of BMPs. Most of the studies that have been conducted related to BMPs effectiveness have provided very limited data that could be useful for comparing BMP design and selection among BMP types (Strecker et al., 2001).

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 as a stormwater BMP creates a need to do this study. Furthermore, most of the available research that have mentioned RWH 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.

This study presents a simulation model, and the results of analysis, evaluating the potential for utilizing RWH as a stormwater BMP based on the precipitation data for the last two years for the Dallas-Texas area and specifically for the Urban Solutions Center of Texas A&M University system. The results of this study will provide guidelines for developing stormwater management policies in a cost effective way. Also, this work will provide insight into how RWH system can be both a public need in terms of stormwater management and erosion control and a benefit to the facility owners by savings on their water bills as well as saving power on a national level. This study will also provide a better understanding of the complex storage-use dynamics of RWH system.

RESEARCH 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.

LITERATURE REVIEW

Background

Water management has played a central role in human history. The efficient allocation and distribution of water is one of the staples of modern society. Agriculture and animal domestication began as early as 10,000 BC. The ancients understood the value of water and this can be seen by their choice of settlement locations near and around large sources of potable water such as the Indus Valley and the Nile River (Gupta, 2004; Possehl, 1990).

The ancient Egyptians invented the first hydraulic engineering mechanisms and constructed a vast network of canals, dikes and the shaduf (a mechanical device used to transfer water from one level to another). This satisfied the growing need to transport and distribute water efficiently for modern agriculture and domestication needs (Janick, 2002). RWH has a long tradition that can be traced as far back as 6000 years ago and has been an important source of water for human societies up to the present (Gould and Nissen-Petersen, 1999). The oldest earthworks used for the collection of rainwater can be dated as far back as 4500 BC in the Thar Desert, Rajasthan (Pandey et al., 2005). Also, the Egyptian army used the desert to their advantage thousands of years ago by stashing secret cashes of rainwater collected throughout the desert in underground cisterns carved out of solid rock (Anonymous, 2005). As technology advanced it became less necessary to rely on natural sources of water distribution such as rivers; human engineering took an increasing role in the control of water distribution. Once urbanization began, centralized water supply systems replaced the need to harvest water (Pandey et al., 2005).

More recently, people have become reacquainted with the power of water harvesting due to the rising environmental and economic costs of providing water by centralized water systems or by well drilling (Waterfall, 2006). By 2002, up to 100,000 residential RWH systems were in use in the US, and in Australia alone over 800,000 people rely on roof caught rainwater (Heyworth et al., 1998; TWDB, 2005). The past few decades have seen a surge in commercial applications of rainwater harvesting (Gray and Yudeslson, 2009). The possible benefits from RWH are multilayered and include some of the following (Kinkade-Levario, 2007; Texas Rainwater Harvesting Evaluation Committee, 2006; TWDB, 2005): reduction in the demand for developing other water resources; protection of water quality from nonpoint source pollution; reduction in peak demand; reduction of storm water runoff and erosion in urban environments; elimination of the need of water softeners and salts; and landscape irrigation.

RWH system combines the benefits of water reuse with runoff mitigation and groundwater recharge. Efforts have been carried out to develop RWH approaches for different usages; domestic, agricultural, industrial, and commercial. RWH system can help public water systems reduce peak demands and help delay the need for expanding water treatment plants. It is not only about the expansion of water treatment plants and the additional cost that can be caused by that, but also about saving energy that is used to operate wastewater treatment plants and reducing the load on it (Krishna, 2007). That will affect the quality of outputs of the wastewater treatment plants positively. RWH system has a role in promoting the ecological and environmental conservation. Furthermore, it has indirect beneficial effects on eco-environmental improvement by its feedback mechanism in the comprehensive agricultural management system (Xiaoyan et al., 2002).

Effectiveness of BMPs

Different factors are used to contrast the effectiveness of BMPs. The impacts of BMP on water quality as well as quantity are one of the most important factors to consider. Zhen et al. (2006) developed a software that helps in BMP planning and selection. This software utilizes GIS and technology that integrates BMP processes simulation models and applies system optimization technique. This software identifies the near optimal solution and the cost-benefit trade off curve.

To ensure the high efficiency of BMPs' performance, (Schneider and McCuen, 2006) proposed different steps to validate and calibrate BMPs such as identifying storm characteristics that is important for BMPs' performance, identifying hydrological criteria such as peak reduction and trap efficiency. Paying no attention to the BMPs' validation, which aims to determine the compliance of practices in reducing stormwater negative impacts, will put the accuracy of BMPs into the unknown fate and waste constructions' costs and efforts. Furthermore, a study conducted by (Pennington et al., 2003) showed that BMPs can be insufficient in some cases that require meeting water quality standards, and other complementary programs might be needed to achieve the desirable objectives.

Hood et al. (2007) conducted a study in Southeastern Connecticut that aimed to compare the effectiveness of Low Impact residential development with traditional development. Results showed that peak discharge from traditional development was 1,100% greater than runoff from Low Impact Development. The lag times of (LID) were drastically greater than the tradition development. The study showed that LID was very effective in reducing peak discharge depth, runoff coefficient, discharge volume, and lag times.

Finally, the American Society for Civil Engineering Urban Water Resources Research Council developed a National Stormwater BMP database that aims to create BMP performance evaluation protocols and guidelines that would serve designers and users. This database involves two parts; first, a standardized approach to document BMPs test information. Second, sources of data on historical BMP tests and researches (Clary et al., 2002).

All of the previously mentioned studies in this section “Effectiveness of BMPs” investigate the importance of validating the effectiveness of BMPs before installing it. Most of these studies require a large area in order to effectively reduce the amount of runoff as well as stormwater peak runoff. And at this point the benefit of RWH becomes evident because it does not require a large area to be installed and its effectiveness can be maximized in conjunction with several irrigation scheduling methods and cistern storages.

Effectiveness of RWH In Stormwater Reduction

This study has a particular focus on the role of RWH in reducing the negative impact of urban runoff. Runoff occurs when the soil is saturated or water cannot infiltrate anymore. RWH cisterns can reduce stormwater runoff volumes, and delay and reduce peak runoff flow rates. Also, cisterns can be used in areas where soils are compacted, groundwater levels are high or hot-spot conditions that prevent infiltration exist (Reed, 2005).

A cistern’s size has a significant role in determining the controlled runoff. One cistern may provide a useful amount of water for garden irrigation, but it will have little effect on the overall runoff volumes, especially if the entire tank is not drained in between storms. Greater effectiveness can be achieved by having more storage volume and by designing the system with a continuous discharge to an infiltration mechanism, so that there is always an available volume for retention (MAPC, 2009). Maximizing the benefit of RWH can be attained by applying it on neighborhood and community scales. By increasing the size of catchment area, we increase the amount of water captured, and as a result decrease the urban runoff and the disadvantages that can be produced. Furthermore, the size of the cistern will affect the amount of storage and consequently delay the time to peak flow. On the other hand, BMPs’ designer cannot increase the size of the BMPs randomly, because that will be reflected on the overall cost. Therefore, optimizing and selecting the most cost effective size of cistern and BMP construction is crucial. Reducing the impervious cover will lower the size of BMPs construction and that will be reflected positively on the costs. The factors that affect the effectiveness of BMPs have not been investigated extensively and most of the BMPs are arbitrarily sized and located (Gilroy and McCuen, 2009).

RWH receives attention from all countries around the world because it contributes to increasing water supplies for agriculture and domestic use, as well as reducing the negative impact of urban runoff. A renewed interest in this time-honored approach has emerged in Texas and elsewhere due to: the escalating environmental and economic costs of providing water by centralized water systems or by well drilling; the human and plant health benefits of rainwater; urban flood management; and the potential cost savings associated with rainwater collection systems (TWDB, 2005).

A study has been carried out by Schneider and McCuen (2006) to validate the effectiveness of a water cistern in reducing the peak flow rates of stormwater. It's not only the total number of storms that needs to be monitored, but also the characteristics of each storm such as storm duration, storm depth, and rainfall pattern. Also, hydrological performance factors such as peak and volume reduction need to be studied to determine the effectiveness of a water cistern as a BMP. Coombes et al. (2001) conducted a study that involved two scenarios to examine the effectiveness of rainwater tanks to reduce the amount of stormwater detentions. The scenarios involved combinations of onsite stormwater detention storage and the usage of 10kL rainwater tanks with 0 and 5kL of detention storage. The study showed that all scenarios proved a significant reduction in peak discharge. Airspace in the tank and the fraction of portion drained by rainwater tanks are the main factors that can cause variation in peak discharge from one tank to another. Another study conducted by Herrmann and Schimida (1999) aimed to quantify the effects of RWH system on the urban drainage system. A model was developed on a long term simulation of 10 years. Different parameters were investigated in this model: tank size, recurrence time of overflows, overflow reduction and other parameters. This study found that RWH system was significant in eliminating overflow runoff, and the system can be much more effective when it’s applied on a neighborhood scale and a densely populated district.

A study at Portland State University examined the feasibility of RWH system in an urban Portland neighborhood. The results found that installation of 17034 L cistern reduced the runoff by 68%, while installing a 5678 L cistern was most size efficient for in town homes in terms of cost efficiency and size suitability(Younos and Gowland, 2008). Moreover, Gilroy and McCuen (2009) showed in the study they conducted that rainwater cisterns are capable of controlling rooftop runoff for small stormwater events.

Furthermore, RWH system helps in reducing the amount of urban runoff that goes to the sewer system and reduces peak flow in sewer system. As a result, that will reduce the cost of expanding with new water treatment plants (Vaes and Berlamont, 2001). In Seoul city, Kim and Han (2009) found that a tank of 29 L/m2 can control the runoff of 30-years with the drainage pipes of a 10-year design period.

On the other hand, a study at Texas A&M University aimed to investigate the feasibility of RWH for irrigation purposes found that the RWH had a slight effect on reducing the stormwater runoff. A hydrological model was developed and rainwater events were simulated to find out that a peak flow for a 2-year 24-hour storm event which is equivalent to 4.42 inches of rainfall was reduced from 21.7 to 20.6 cubic meters per second. One hundred thirteen buildings with a total roof area of 60.5 acres was utilized as a catchment area which is located within a watershed encompasses 786 acres (Saour, 2009). This small effect of the RWH may be explained because of the use of a hydrological model without any field experiment. Also, the small amount of roof areas compared to the total area of the watershed might explain the slight effect on reducing stormwater runoff.

The storage system/container is considered as one of the largest costs of any roof water harvesting system. The small size storing system can be filled and emptied faster than the large size storing system that will be filled and emptied rarely. Climate condition and stormwater events play a significant role in determining the frequency of filling and emptying the storing system (Warwick, 2001). Sizing RWH depends on the catchment area, historical precipitation data, water demand, capture efficiency and the main use of the system (Bradford and Denich, 2007). Guo and Baetz (2007) concluded in a study they conducted to investigate the interactions between required storage size, climate, water use rate, and reliability that further increases in cistern size will only translate as an increase in reliability of a storage unit to supply water when needed.

The size of the cistern is a factor of cost and reliability in terms of preventing large volumes of urban runoff from entering the sewer system. Maximizing the effectiveness of the RWH system can be attained when water can be slowly released between stormwater events. Moreover, Younos and Gowland (2008) found in their study that any size of RWH system is capable of reducing the amount of stormwater directed to sewer systems.

Different methods can be used to determine the RWH system storing size. Computer modeling based on historical and observational data can be one option. Another option is using probabilistic approach and analytical equations as Lee et al.

(2000) did. Lee et al. (2000) developed equations to determine the size of the cistern required for agricultural uses during dry periods. Guo (1999) used another method to size stormwater detention basins; this method was a volume based method. This method is applicable to small urban catchments; but the reliability of sizing storm-water detention basins in small urban catchments depends on the average outflow of the runoff.

The optimization model can be used also to determine the optimal storage size. Mishra et al. (2008) developed a multi-objective optimization model to determine the optimal size of the auxiliary storage reservoir and the optimal cropping pattern. The optimization was successful in determining the optimal storage size considering land area and water allocation constraints.

Hardy et al. (2004) studied the effect of spatially distributed water tanks on stormwater peak discharge. They found that spatial distribution of water tanks is a function of: storage volume, rainfall intensity, and the temporal distribution of that rainfall. These factors direct the timing and shape the runoff hydrograph. They concluded that the effectiveness of water tanks in reducing peak discharge was decreased with increasing average rainfall intensity.

RWH system can be a good alternative to control urban runoff. It does not replace all the traditional flood control system, but it remains an economically attractive alternative that needs to be considered. A comparison of the annual costs of a cistern and a detention basin showed that a water cistern may offer a competitive alternative when considering the water losses due to evaporation from the detention basin (French, 1988).

Most of the studies previously mentioned refer to RWH system as a stormwater BMP. These studies analyzed the effectiveness of the system based on the storage size and other climatic factors. Also, it analyzed the effectiveness of RWH on a watershed scale rather than individual level. So far, none of the available previous research had examined the impact of RWH system combined with different irrigation management methods. None of these studies addressed the usage of water captured by RWH system in their analysis. None of them seem to collect runoff after it has been applied for irrigation. As a result, these entire components together add to originality for this study.

Irrigation Scheduling

The irrigation scheduling method can be one factor that impacts the effectiveness of RWH system in terms of reducing total volume of runoff and supplemental water for irrigation. This study involves three different irrigation scheduling methods (Soil moisture-based, ET-based and Time-based). Irrigation controllers are the most common equipment used for scheduling irrigation. In general, there are two types of controllers that are used in automatic irrigation systems; First, open control loop system that applies a present action, as done with simple mechanical irrigation timers. Second, close control loop system which receives feedback from sensors, makes decisions, and applies these decisions to the irrigation system (Zazueta et al., 2008).

Good irrigation management requires understanding soil water holding capacity and the factors that affect availability of soil water for plant. To avoid soil moisture content from reaching the permanent wilting point, a depletion ratio is defined. This value represents the percentage of total available soil water which may be safely depleted before irrigation water is applied again. The depletion ratio is a function of crop as well as evaporation. It can vary from 0.30 for shallow rooted plants to 0.70 for deep rooted plants. A value of 0.50 is the most common used value for many crops (Allen et al., 1998).

Soil Moisture-Based Irrigation

Calculating soil moisture content is an important practice in agriculture. It helps farmers manage their irrigation scheduling more efficiently. Also, it helps in maximizing the yield as well as using less water. Overwatering is a very common practice especially in countries which do not undergo water problems in terms of quantity. Furthermore, overwatering contributes in environmentally costly effects because of wasting energy, water and degradation of surface water supplies as a result of water runoff, and erosion. Soils full of water experience less amount of infiltration and high amount of runoff. This is because soil suction decreases with increases in soil water content (Ley et al., 2000; Werner, 1993). Accordingly, many studies were conducted to determine the correct frequency and duration of watering combined with a best technique for that. Irrigation based on soil moisture content has many advantages. This practice is easy to apply; it can be precise; it indicates how much water needs to be applied; soil moisture devices are commonly used and commercially available; and some soil moisture sensors (especially capacitance and time domain sensors) are readily automated (Jones, 2004).

The standard method for calculating soil water content in soil is the thermogravimetric method that requires drying a known volume of soil in oven at 105 °C then determining the weight loss. This method is time consuming and can be destructive to the soil samples, which implies that it is very hard to do repetitive measurements at the same location. Though, this method is crucial as a standard method for calibration and evaluation uses (Walker et al., 2004). Dukes et al., (2003) utilized in their study a soil moisture sensor that was buried within 10 cm deep of a field of bell pepper. They found that such a system reflects into the convenience for irrigation managers because once the system is set up, observation was needed on a weekly basis only. Moreover, the system translates into substantial water savings in comparison to scheduling irrigation based on average historical weather conditions. Bacci et al., (2008) found in their study that using a time-based fertigation control system often involves water loss or water shortage for plants, while using fertigation control based on plant water consumption as well as soil water content usually avoids these inconveniences.

A one year study conducted on a field of tomato with an automated irrigation system based on tensiometers readings found that switching the irrigation system on at tensiometers readings of 15 kPa performed the best for sandy soils. At 15 kPa, the system achieved high efficiency of water use and this efficiency was represented in terms of the rapid response of the irrigation system to plant needs. Furthermore, a substantial reduction in deep water percolation and ensuing chemical transport were achieved. Water conservation was also obtained in this study as a result of the use of low-volume high frequency concept that implies using irrigation based on soil moisture (Carpena et al., 2005).

Gaskin and Miller (1995) developed a probe that aimed to measure soil moisture content. This probe employed impedance analyzer to measure impedance mismatch reflections from an open-ended transmission line probe, and the analysis of this probe was carried out using voltage standing wave method. Results showed that this probe is capable for determining changes in soil water contents under simulated field conditions. In addition, this probe can be applied on a wide range of soils without a need for recalibration.

Another approach was developed by Fisher (2007) to measure soil moisture content in an economic way. A circuit board was designed in conjunction with a sensor that provides indication of the water potential or tension of the soil. The sensor was chosen for its low price $25-$30, the circuit was powered using a four standard AA-size alkaline batteries and the sensor was powered with an unregulated DC voltage source. The system was designed to monitor soil moisture contents by sending a voltage to a clock chip on a circuit. The circuit had two modes; activated mode and sleep mode. The switching between the two modes is according to soil moisture conditions.

Automated electronic soil moisture sensors that measure dielectric constant of the soil are another technique that it is becoming increasingly common either by using capacitance probes or time-domain reflectometry (TDR). These instruments are easy to set up and assist the accumulation of data (Malicki and Skierucha, 1989). A study conducted at Southeastern Arizona aimed to compare the performance of three commercially available electronic soil moisture probes under field application conditions. The sensors were used to measure the soil dielectric constant to determine the soil moisture content. A comparison between different types of soil moisture sensors and another between soil moisture sensors with water balance and infiltration model were conducted. Results showed that all sensors responded to precipitation events, but each one of them differed in response time and magnitude from each other. The Vitel Hydra Probe sensors (VHP) at 5cm depth always responded more quickly and often too much higher than TDR and Delta-T Devices (DTP). Also, the study identified that these soil moisture sensors had some limitation under certain depths and their accuracy in predicting soil moisture is a factor of depth limitation as well (Paige and Keefer, 2008).

ET-Based Irrigation

Evapotranspiration (ET), defined as the evaporation from the soil surface and the transpiration through plant canopies (Allen et al., 1998). Evapotranspiration (ET) is another factor that is considered in irrigation scheduling. It is truly an essential factor in designing irrigation projects. ET calculations can be used for various applications. For instance, it can be used to predict melt-water yield from mountains and as a result the amount of water runoff. It can also be used in developing flood control management plans and determining safe yields from aquifers. Different studies were conducted under this concept to evaluate the effectiveness of using ET in different fields such as: urban development, irrigation design, flood management plans, water quality studies, and environmental studies (Ward and Trimble, 2004).

Measuring ET is not an easy job. It requires specific devices and depends on various parameters such as weather parameters, crop factors, and management and environmental conditions. Moreover, measuring ET requires well trained personnel according to the complexity of the measurements as well as the high cost of equipments (Allen et al., 1999).

McKenney and Rosenberg (1993) conducted a study that aimed to generate estimates of the sensitivity of potential evapotranspiration to climate change. Different methods and equations to calculate the ET were applied. Those methods included: Thornthwaite, Blaney-Criddle, Hargreaves, Samani-Hargreaves, Jensen-Haise, Priestley-Taylor, Penman, and Penman-Monteith equations. The results showed that each method had different outcomes and in some cases significantly in their sensitivity to temperature and other climatic factors. Moreover, each method had certain results under specific conditions; location and time of year.

Modified Penman-Monteith equation (Allen et al., 1999) has been widely accepted during the last decade as a standard method for calculating evapotranspiration (ETo) estimates. Several investigations were conducted by FAO to address Penman-Monteith equation properly and accurately. This method offers the best results with minimum error in relation to a living grass reference crop (Steduto et al., 2002).

In order to estimate crop evapotranspiration; first Reference evapotranspiration - which is denoted by (ETo) and represents the rate of evapotranspiration from a reference surface that is not short of water- need to be known. This surface is a hypothetical grass reference with specific characteristics. Second, crop coefficient (Kc) that represents crop type, variety and development stage that needs to be considered as well. Finally, crop evapotranspiration can be calculated by multiplying ETo times Kc to obtain crop evapotranspiration which is denoted by (Etc) (Allen et al., 1998). ET controllers are irrigation controllers that utilize an estimation of ET to schedule irrigation. These controllers require programming according to specific landscape conditions to make them efficient (Riley, 2005).

A study was conducted by Haley et al. (2007) and aimed to determine if scheduling irrigation for residential homeowners in Florida based on historical evapotranspiration (ET) and by using automated controllers would lead to reduction in irrigation water use. Results found that the homes had 149 mm/month average monthly water use for irrigation. Applying irrigation by using automated controllers and based on historical ET data resulted in a 30 % reduction to reach 105 mm/month. Additional decrease was obtained when water was applied only to the depth of the root zone of plants.

White et al., (2004) conducted a study at Texas A&M University and within the College Station area that aimed to investigate the reduction in residential landscape water use. Landscape size, landscape coefficient and potential ET were considered in this study to develop water budgets for residential landscapes. Results found that considering landscape coefficient by multiplying it by potential ET would result with irrigation water savings specifically during the summer months. Landscape coefficient with the amount of 0.7 was the best estimate and resulted in additional water savings without affecting landscape plant quality.

For the purpose of this study; published ET monthly data and crop coefficient factors (Tables 1 and 2) from TexasET Network (TexasET, 2010) were used to estimate irrigation scheduling for the ET treatment.

Table 1. Average monthly ETo (TexasET, 2010).

Average monthly ETo (PET) (cm/month)													
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dallas/Ft. Worth	5.0	6.3	10.1	12.9	15.7	18.0	17.7	18.5	13.9	10.6	6.6	5.3	141.9

Averages were computed using climatic data over the entire period of record available from the National Weather Service and compared to ETo rates based on the standardized Penman-Monteith equation where available (August 2005).

Table 2. Monthly crop coefficient (Kc) values for warm season turfgrass for the Dallas/Fort Worth area (TexasET, 2010).

Monthly crop coefficients (Kc) for warm season turfgrasses												
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dallas/Ft. Worth	0	0.1	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.1	0

Time-Based Irrigation

Davis et al. (2010) conducted a study that aimed to assess the ability of three different brands of ET-based controllers to schedule irrigation and compare it to a time clock schedule irrigation intended to emulate homeowner irrigation schedules. The time based scheduling was programmed to operate twice a week. Results found that all ET treatments applied less water in comparison to time based treatment, the average water saving was between 35% and 43% for ET controllers.

Another study was conducted in Florida by Lailhacar et al., (2008) and aimed to compare the irrigation water use to irrigate Bermudagrass found that there is a significant difference between the averages of time-based and soil moisture based treatments with 1044 and 420 mm irrigation depth, respectively. Therefore, soil moisture-based treatment is significantly more water conservative. Carpena et al., (2005) found that utilizing tensiometers for irrigating a field of tomato resulted in 73% reduction in water use when compared to timer-based irrigation. Also, ET-based irrigation resulted with additional water saving.

MATERIALS AND METHODS

Data and Site Location

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:

- Volumes of water runoff leaving the roofs and the turfgrass irrigated area;
- Total irrigation demand;
- Volume of overflow from the cistern during storm events.

- Volume of rainwater captured and used for irrigation.
- Supplemental water used for irrigation.

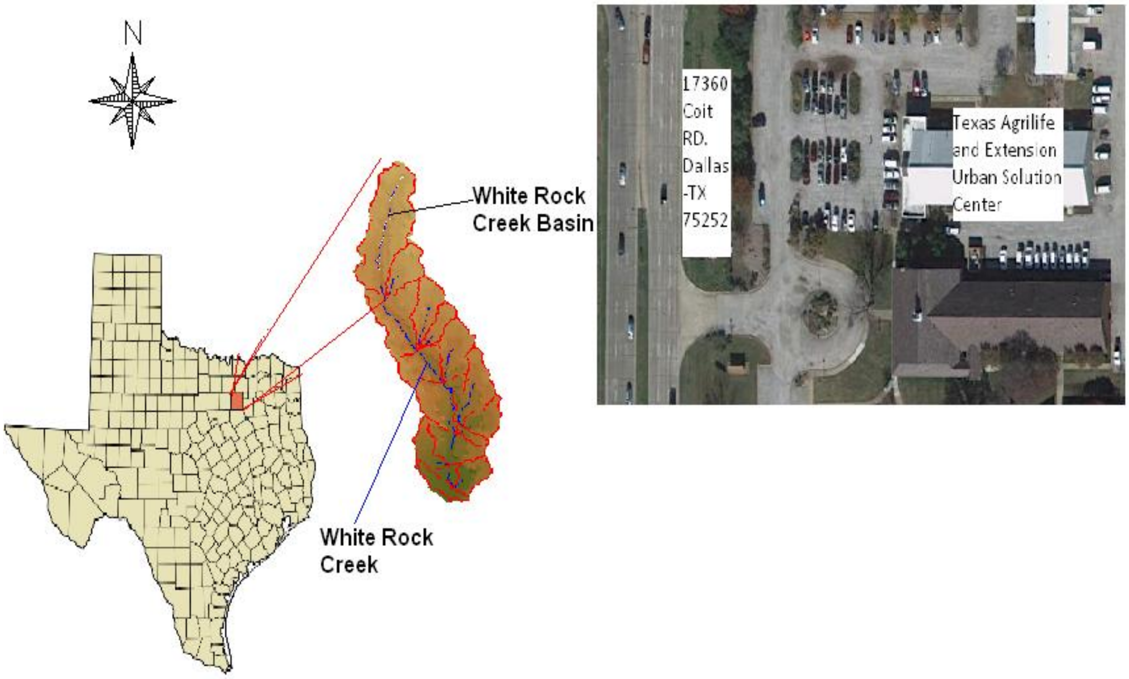

Figure 1. **Urban Solutions Center of Texas A&M University location.**

Several variables were considered as well in finding the previous measurements (Tables 3 and 4). 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/ m2 , 1.5cm /m2 , 3.0 cm/ m2 , 4.5cm/ m2 , 6 cm/ m2 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:

Table 3.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 4. **Soil hydraulic properties considered as an input data in the simulation.**

Parameter/ Soil Type	**Sand**	**Sandy Loam**	**Loamy**	**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 m2 and a plot area of 20.9 m2. 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 m3 (13.9 m2 × 0.0254 m) and a 1 roof runoff coefficient.

The following equations were developed to calculate the output of the simulation:

1) Water Demand (m^3)

$$D = \left(ET \times A_p \times K_c\right) - (P \times A_p) \tag{1}$$

where: D= water demand (m^3) for values greater than 0

ET= evapotranspiration (m)

A_p= plot area (m^2)

K_c= crop coefficient

P= precipitation (m)

2) Water runoff from roof (m^3)

$$RO_r = (P \times A_r) \times RC \tag{2}$$

where: RO_r= water runoff from roof (m^3)

A_r= roof area (m^2)

RC= roof runoff coefficient

3) Storage in cistern (m^3)

$$S_c = S_{prev.} + RO_r - I \qquad (3)$$

where: S_c= storage in cistern (m^3)

S_{prev}= storage in cistern from previous day (m^3)

I= volume of irrigation applied (m^3)

Note that total water storage in a cistern can not exceed the total volume of a cistern and additional water input will result in overflow.

4) Overflow from Cistern(m^3)

$$O = RO_r + S_{Prev.} - S_m - I \qquad (4)$$

where: O= overflow from cistern (m^3)

S_m= maximum storage capacity of the cistern (m^3)

Note that overflow occurs only when total water inputs RO_r and S_{prev} subtracted from I are greater than S_m.

5) Soil available water content (m^3)

$$AWC = AWC_{Prev.} - D + I + (P \times A_p) + O - RO_p \qquad (5)$$

where: AWC= soil available water content (m^3)

$AWC_{prev.}$= available water content from previous day (m^3)

RO_p= water runoff leaving the plot (m^3)

Note that if AWC is greater than F.C value the AWC will be the F.C value, otherwise it will be the calculated value.

6) Volume of irrigation applied

$$\mathrm{I} = \mathrm{IWC}_{\mathrm{max}} - \mathrm{AWC} \qquad (6)$$

where: $\mathrm{IWC}_{\mathrm{max}}$= maximum water content for irrigation (m^3)

7) Supplemental Irrigation from Potable Water

$$\mathrm{I}_{\mathrm{S}} = \mathrm{I} - \mathrm{S}_{\mathrm{C}} \qquad \text{For } \mathrm{I} > \mathrm{S}_c \text{ otherwise} = 0 \qquad (7)$$

where: I_s= supplemental irrigation from potable water (m^3)

8) Free drainage (water deep percolation)

$$\mathrm{F} = (\mathrm{T} \times \mathrm{A}_{\mathrm{P}} \times \mathrm{R}) - (\mathrm{F.C} \times \mathrm{A}_{\mathrm{P}} \times \mathrm{R}) \qquad (8)$$

where: F= free drainage (m^3)

T= saturation

R= depth of root zone (m)

F.C= field capacity

9) Water runoff

This research study investigates the impact of utilizing two methods (Mass-Balance and SCS Curve Number) in predicting total water runoff.

Runoff from plot (Mass-Balance method)

$$\mathrm{RO_P} = \mathrm{P} + \mathrm{O} - \mathrm{TAWC} - \mathrm{F} \tag{9}$$

where: TAWC= total available water content as a fraction of total soil depth

(F.C – P.W.P), where P.W.P is permanent wilting point.

F= free drainage (m^3)

10) Runoff from plot (SCS Curve Number Method)

$$\mathrm{Q} = \frac{(\mathrm{P} + \mathrm{O} - \mathrm{I_a})^2}{(\mathrm{P} + \mathrm{O} - \mathrm{I_a})} + \mathrm{S} \tag{10a}$$

where: Q= runoff (in)

S= potential maximum retention after runoff begins

I_a= initial abstraction

$$\mathrm{I_a} = 0.2 \times \mathrm{S} \tag{10b}$$

$$\mathrm{Q} = \frac{(\mathrm{P} - 0.2\mathrm{S})^2}{(\mathrm{P} + 0.8\mathrm{S})} \tag{10c}$$

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

It should be noted that all the variables are volume terms expressed in m3 applied on the RWH roof and the lawn area. The initial assumptions made to solve the above equations are as follows: the initial available water content in soil was at the maximum water content in soil. The maximum and minimum water content for irrigation were calculated as follows:

$$\mathrm{IWC_{min}} = \mathrm{PWP} + \left(\left(\frac{1-\mathrm{DR}}{2}\right) \times \mathrm{TAWC}\right) \times \mathrm{R} \tag{11}$$

where: $\mathrm{IWC_{min}}$=minimum water content for irrigation (in)

PWP= permanent wilting point (in)

DR= depletion ratio

R= depth of root zone (in)

$$\mathrm{IWC_{max}} = \mathrm{IWC_{min}} + (\mathrm{DR} \times \mathrm{TAWC} \times \mathrm{R}) \tag{12}$$

where: $\mathrm{IWC_{max}}$: maximum water content for irrigation (in)

Figure 2. represents a soil water profile that contains all the measurements which were introduced earlier in this section. Free drainage percentage was assumed to be a difference of soil water content at field capacity and soil water content at saturation. Maximum and minimum water content for irrigation were measured according to certain depletion ratios for each treatment.

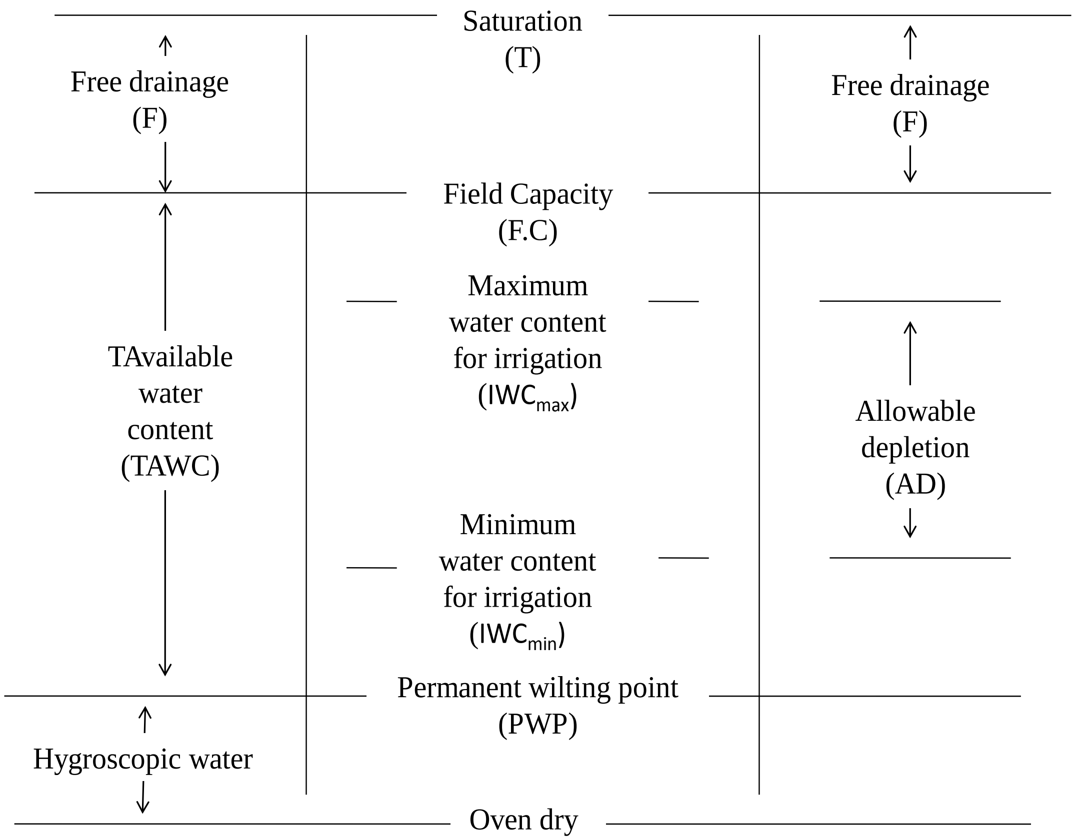

Figure 2. Soil water profile.

The initial overflow from the cistern is equal to zero. The initial cumulative storage in the cistern equals to the volume capacity size of cistern. This condition was selected to provide sufficient water to perform the initial irrigation. In case the cistern storage is less than the irrigation requirements and irrigation is to occur, then potable water is added to supplement the difference between the irrigation required and the current cistern storage volume. Additionally, if the volume of runoff from roof plus the initial volume of the cistern is greater than the maximum storage capacity of the cistern, then overflow from the cistern occurs. Therefore, within this work a logical model using a Mass-Balance approach with a couple of basic and reasonable assumptions was developed. Free drainage was assumed to be any volume of water above field capacity and below water content at saturation (Equation 8). Irrigation intervals were determined using equation 13:

$$\mathrm{IT} = \frac{\mathrm{IWC_{max}} - \mathrm{IWC_{min}}}{\mathrm{ETc}} \tag{13}$$

where: IT= irrigation intervals (days)

ETc= crop evapotranspiration (in)

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc} \tag{13a}$$

where: ETo= reference evapotranspiration (in)

Kc= crop coefficient (Table 4)

Statistical Analysis

The main type of statistical analysis conducted in this study was comparison between mean differences. First: a statistical test for $\mu1 - \mu2$ was conducted to test a hypothesis about the difference between two population means (one irrigation method compound with RWH system and a control treatment without RWH). The differences in sample means were judged statistically as significant or not, by comparing them to the variation within samples.

The null and alternative hypotheses are:

H_0: $\mu1 = \mu2$

H_a: At least one of the population means differs from the rest.

A significant level of $\alpha < 0.05$ was selected to ensure the probability of being wrong concluding in favor of research hypothesis is small. This way, if the research hypothesis is true, there is a chance of 5% of being wrong and 95% of being correct. In other words, the type I error which could be committed if we reject the null hypothesis when it is true will be controlled and the alternative hypothesis is going to prove beyond a reasonable doubt (Ott and Longnecker, 2008).

One way-Analysis of variance test and comparison between means were conducted to determine the significance between variables (cistern size, depletion ratio, soil depth, soil type, and irrigation scheduling method) in reducing total volume of runoff and potable water used for irrigation. The SPSS version 16 statistical package was utilized to run these tests.

To facilitate the complexity of conducting a comparison between variables; treatments were categorized according to cistern size utilized. The total number of variables this research ends up with is 960 variables as equation 14 shows.

$$\mathrm{N} = \mathrm{ST} \times \mathrm{DR} \times \mathrm{SD} \times \mathrm{IS} \times \mathrm{C} = 4 \times 4 \times 3 \times 4 \times 5 = 960 \qquad (14)$$

where: N = number of variables

ST= number of soil types= 4

DR= number of depletion ratios= 4

SD= number of soil depths= 3

IS= number of irrigation scheduling methods= 4

C = cistern sizes utilized= 5

RESULTS

RWH Model Development

RWH system is an acceptable approach that can be used in urban environment to reduce the negative impact of stormwater runoff. Cistern size is a key factor that can influence the effectiveness of the system. Several approaches were suggested to estimate RWH system storage size. Lee et al. (2000) used a probabilistic approach and analytical equations. Another option is what Guo (1999) used a volume based method to size stormwater detention basin. This method is applicable to small urban catchments, though, the reliability of this method depends on the average outflow of the runoff. Mishra et al., (2008) proposed using an optimization model to determine the optimal storage size. This multi-objective optimization model determined the optimal size of the auxiliary storage reservoir and the optimal cropping pattern.

Although all these models have different approaches in sizing RWH storage system, the Mass-Balance approach has not been extensively mentioned or studied. Therefore, this research investigates using a Mass-Balance approach to determine the impact of RWH storage system in respect to reducing volume of water runoff as well as total volume of potable water used for irrigation (supplemental water) for the research area at Urban Solutions Center at Dallas – Texas.

The development of a RWH model based on Mass-Balance method was a very valuable tool for investigating the RWH system as a stormwater BMP. The RWH model used soil water content to predict how the total volume of runoff leaving the plots as well as total volume of supplemental water applied to meet irrigation needs when storage in the cistern was insufficient to meet the irrigation demand. The irrigation scheduling for each treatment was based on different methods; time-based, soil moisture-based, ET-based, and control treatment without cistern. For all the treatments the following rules were considered to estimate total volumes of water runoff and potable water used for irrigation. First, the soil storage cannot exceed the volume associated with saturation and deep percolation is equal to the difference between Field Capacity and saturation. Second, when the cistern fills up; uniform overflowing will start occurring over the plot which in turn contributes to the total runoff over the plot. Third, when the cistern storage volume is insufficient to meet irrigation requirements; supplemental water needs to be added. Fourth, the initial condition of the cistern is to be full of water at the start of the experiment and to provide sufficient water to perform the initial irrigation.

This study focused on critical factors that would affect the water balance on the site: cistern size, irrigation scheduling method, soil depth, depletion ratio, and soil type. These factors form the RWH system used to meet lawn irrigation requirements and reduce the total amount of water runoff. Because of the complexity and the interactions between research variables (960 variables as described by equation 14), default values will be used for some factors (Soil depth of 15.2 cm and 50% depletion ratio) when evaluating the remaining variables; irrigation scheduling methods, cistern sizes, and soil type.

Runoff –Mass Balance vs. Runoff-Curve Number

Estimating total water runoff based on Curve Number method is a common approach used in designing and evaluating the effectiveness of BMPs (Equation 10). This study investigated the impacts of utilizing Mass-Balance and Curve Number methods in estimating total water runoff. For the purpose of this investigation, a 15.2 cm soil depth and 50% depletion ratio were considered as constants variables, and cistern size, irrigation scheduling method, and soil type as changing variables.

The total water runoff predicted by the Mass-Balance and Curve Number methods for varying soil types and cistern sizes as fixed variables (ET-based irrigation scheduling method, 15.2 cm soil depth, and 50 % depletion ratio) is presented in Table 5. Silty Clay soil had the greatest total water runoff predicted based on both methods and Sand soil had the least total water runoff predicted. By utilizing 0L, 208L, 416 L cistern; runoff-Mass-Balance method resulted in a higher volume of runoff than Curve Number method for all soil types except for Silty Clay, while utilizing 624L and 833L cistern; total water runoff predicted that resulted from Curve Number method was greater than Mass- Balance method for all soil types except for Sandy Loam soil (Figure 3). Based on Curve Number method, there were significance differences among most soil types utilized except for the following: Sand and Loamy Sand, Sandy Loam and Sand, and Sandy Loam and Loamy Sand. Based on Mass-Balance method, there were significant differences among all soil types utilized and total water runoff (Table 6).

Table 5. Total water runoff (m^3) predicted by Curve Number and Mass-Balance methods when using an ET-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
0 L Cistern	Sand	2.49	55	3.57	43.18
	Sandy Loam	8.69	71	9.65	11.07
	Loamy Sand	5.58	65	7.18	28.79
	Silty Clay	15.15	80	13.13	-13.33
208 L Cistern	Sand	2.14	55	2.88	34.78
	Sandy Loam	7.90	71	8.48	7.34
	Loamy Sand	4.92	65	6.18	25.60
	Silty Clay	14.17	80	12.38	-12.62
416 L Cistern	Sand	1.87	55	2.52	34.71
	Sandy Loam	7.06	71	7.58	7.36
	Loamy Sand	4.32	65	5.28	22.25
	Silty Clay	13.18	80	11.34	-13.97
624 L Cistern	Sand	1.65	55	2.23	35.48
	Sandy Loam	6.40	71	6.77	5.75
	Loamy Sand	3.86	65	4.67	20.96
	Silty Clay	12.29	80	10.46	-14.90
833 L Cistern	Sand	1.53	55	2.16	41.80
	Sandy Loam	6.00	71	6.14	2.44
	Loamy Sand	3.63	65	4.16	14.67
	Silty Clay	11.72	80	9.89	-15.59

Figure 3. Comparison between total volumes of water runoff predicted (Curve Number and Mass-Balance method) by utilizing different cistern sizes and ET-based irrigation scheduling method.

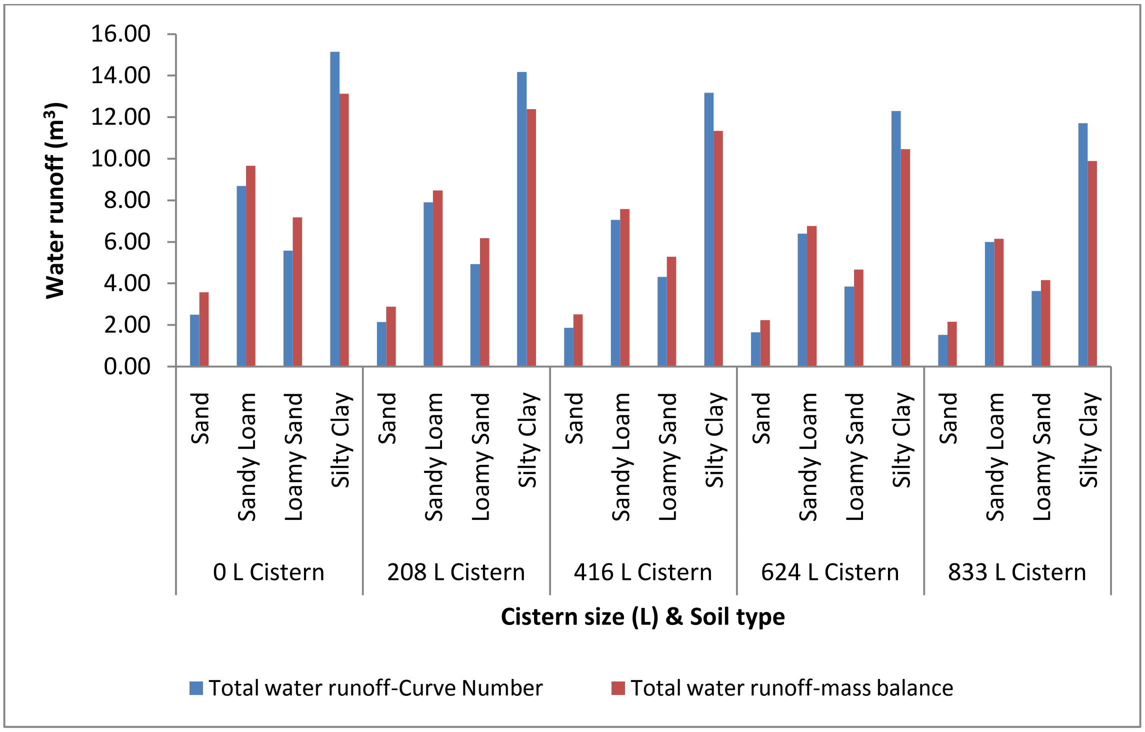

Table 6. Mean differences comparison between predicted water runoff with respect to soil types and an ET-based irrigation scheduling method.

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
Total water runoff-Curve Number (m^3)	1	2	-5.28	0.63	0.00	-6.60	-3.95
		3	-2.53	0.63	0.001	-3.85	-1.20
		4	-11.37	0.63	0.00	-12.69	-10.04
	2	1	5.28	0.63	0.00	3.95	6.60
		3	2.75	0.63	0.00	1.42	4.07
		4	-6.09	0.63	0.00	-7.42	-4.76
	3	1	2.53	0.63	0.001	1.20	3.85
		2	-2.75	0.63	0.00	-4.07	-1.42

Table 6. Continued.

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
		4	-8.84	0.63	0.00	-10.17	-7.51
	4	1	11.37	0.63	0.00	10.04	12.69
		2	6.09	0.63	0.00	4.76	7.42
		3	8.84	0.63	0.00	7.51	10.17
Total water runoff-Mass Balance (m^3)	1	2	-5.05	0.74	0.00	-6.62	-3.48
		3	-2.82	0.74	0.002	-4.40	-1.25
		4	-8.77	0.74	0.00	-10.34	-7.20
	2	1	5.05	0.74	0.00	3.48	6.62
		3	2.23	0.74	0.008	0.66	3.80
		4	-3.71	0.74	0.00	-5.29	-2.14
	3	1	2.82	0.74	0.002	1.25	4.40
		2	-2.23	0.74	0.008	-3.80	-0.66
		4	-5.94	0.74	0.00	-7.52	-4.37
	4	1	8.77	0.74	0.00	7.20	10.34
		2	3.71	0.74	0.00	2.14	5.29
		3	5.94	0.74	0.00	4.37	7.52

* The mean difference is significant at the 0.05 level.
1= Sand, 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

The second comparison between the two methods for estimating total water runoff was based on Soil Moisture irrigation scheduling method, 15.2 cm soil depth and 50 % depletion ratio. The total water runoff predicted from utilizing the Mass-Balance and Curve Number methods is presented in Table 7. Silty Clay soil had the greatest total water runoff predicted based on the two methods and Sand soil had the least total water runoff predicted. By utilizing 0L, 208L, 416 L, and 833 L cistern; runoff-Mass-Balance method resulted in greater volume of runoff than Curve Number method for all soil types except for Silty Clay (Figure 4). Based on Curve Number method and Mass-Balance method, there were significant differences among all soil types utilized (Table 8).

Table 7. Total water runoff (m^3) predicted by Curve Number and Mass-Balance methods when using a Soil Moisture-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
0 L Cistern	Sand	2.54	55	4.24	66.51
	Sandy Loam	8.70	71	10.50	20.79
	Loamy Sand	5.76	65	8.18	42.01
	Silty Clay	15.36	80	14.27	-7.12
208 L Cistern	Sand	2.16	55	3.16	46.29
	Sandy Loam	7.71	71	9.03	17.11
	Loamy Sand	4.96	65	6.56	32.47
	Silty Clay	14.28	80	13.17	-7.78
416 L Cistern	Sand	1.78	55	2.42	35.88
	Sandy Loam	6.93	71	7.74	11.63
	Loamy Sand	4.31	65	5.34	23.96
	Silty Clay	13.21	80	11.98	-9.33
624 L Cistern	Sand	1.49	55	2.03	36.38
	Sandy Loam	6.31	71	6.78	7.39
	Loamy Sand	3.85	65	4.56	18.31

Table 7. Continued.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
	Silty Clay	12.29	80	10.99	-10.60
833 L Cistern	Sand	1.34	55	1.99	48.23
	Sandy Loam	5.94	71	6.17	3.92
	Loamy Sand	3.61	65	4.09	13.31
	Silty Clay	11.67	80	10.21	-12.55

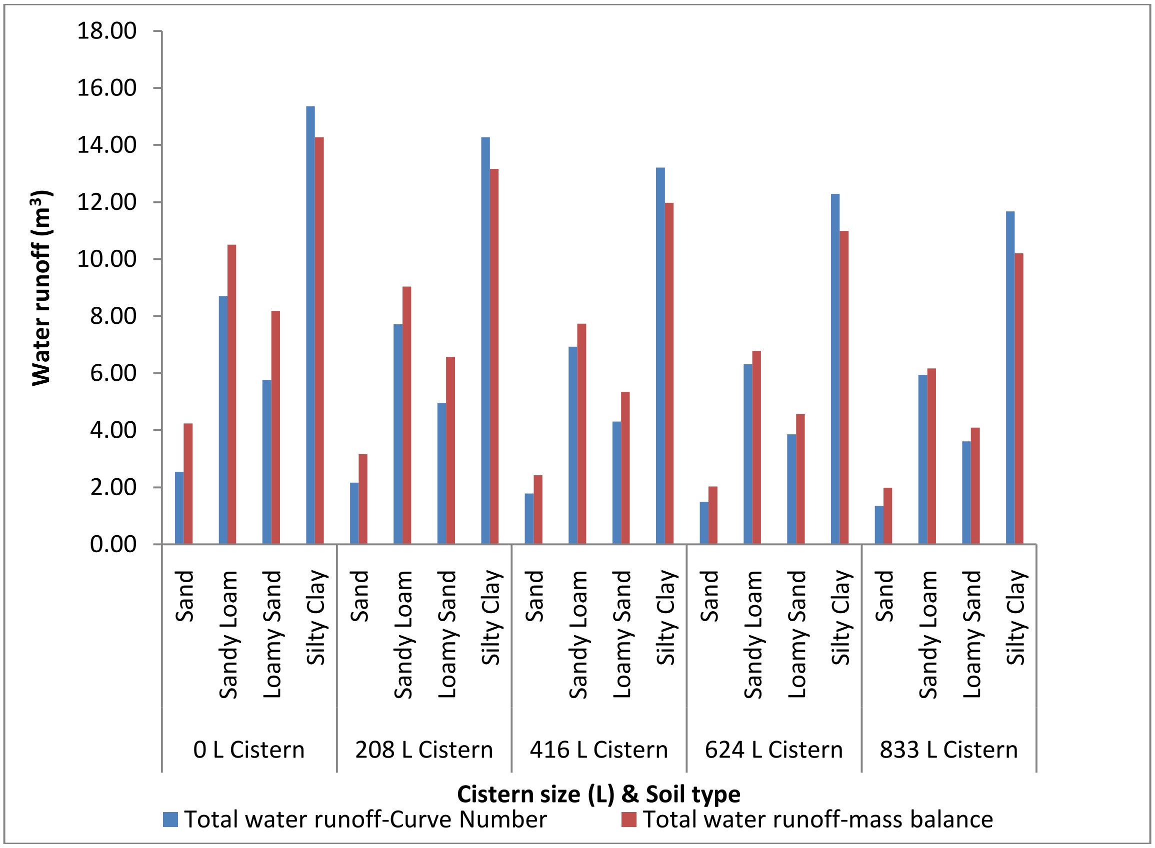

Figure 4. Comparison between total volumes of water runoff (Curve Number and Mass-Balance method) and soil types by utilizing different cistern sizes and Soil Moisture-based irrigation scheduling method.

Table 8. Mean differences comparison between predicted water runoff with respect to soil types and a Soil Moisture-based irrigation scheduling method.

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
Total water runoff-Curve Number (m^3)	1	2	-5.26	0.67	0.00	-6.67	-3.84
		3	-2.64	0.67	0.00	-4.05	-1.22
		4	-11.50	0.67	0.00	-12.92	-10.09
	2	1	5.26	0.67	0.00	3.84	6.67
		3	2.62	0.67	0.00	1.21	4.04
		4	-6.24	0.67	0.00	-7.66	-4.83
	3	1	2.64	0.67	0.00	1.22	4.05
		2	-2.62	0.67	0.00	-4.04	-1.21
		4	-8.87	0.67	0.00	-10.28	-7.45
	4	1	11.50	0.67	0.00	10.09	12.92
		2	6.24	0.67	0.00	4.83	7.66
		3	8.87	0.67	0.00	7.45	10.28
Total water runoff-Mass-Balance (m^3)	1	2	-5.28	0.97	0.00	-7.33	-3.23
		3	-2.98	0.97	0.01	-5.03	-0.93
		4	-9.36	0.97	0.00	-11.41	-7.31
	2	1	5.28	0.97	0.00	3.23	7.33
		3	2.30	0.97	0.03	0.25	4.35
		4	-4.08	0.97	0.00	-6.13	-2.03
	3	1	2.98	0.97	0.01	0.93	5.03
		2	-2.30	0.97	0.03	-4.35	-0.25
		4	-6.38	0.97	0.00	-8.42	-4.33
	4	1	9.36	0.97	0.00	7.31	11.41
		2	4.08	0.97	0.00	2.03	6.13
		3	6.38	0.97	0.00	4.33	8.42

* The mean difference is significant at the 0.05 level.

1= Sand, 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

The third comparison between the two methods for estimating total water runoff was based on Time-based irrigation scheduling method, 15.2 cm soil depth and 50 % depletion ratio. The total water runoff predicted from utilizing Mass-Balance and Curve Number methods is presented in Table 9. Silty Clay soil had the greatest total water runoff predicted based on the two methods and Sand soil had the least total water runoff predicted. By utilizing 208L, and 416 L cistern; runoff-Mass-Balance method resulted in higher volume of runoff than Curve Number method for all soil types except for Silty Clay where Curve Number method estimated higher volume, while utilizing 0L cistern; total water runoff resulted from Curve Number method was least for all soil types (Figure 5).

Based on Curve Number method, there were significant differences only between Silt Clay soil and Sand, Silty Clay and Loamy Sand, and Silty Clay and Sandy Loam soil, while based on Mass-Balance method, there were significant differences among most soil types utilized except for the following: Sand and Loamy Sand, Sandy Loam and Loamy Sand (Table 10).

Table 9. Total water runoff (m^3) predicted by Curve Number and Mass-Balance methods when using a Time-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
0 L Cistern	Sand	2.06	55	3.20	55.53
	Sandy Loam	6.62	71	8.36	26.22
	Loamy Sand	4.56	65	6.30	38.14
	Silty Clay	14.67	80	14.84	1.18
208 L Cistern	Sand	1.51	55	1.95	29.23
	Sandy Loam	5.06	71	5.91	16.62
	Loamy Sand	3.38	65	4.28	26.70
	Silty Clay	11.88	80	11.68	-1.71
416 L Cistern	Sand	1.00	55	1.07	6.94
	Sandy Loam	3.90	71	4.12	5.78
	Loamy Sand	2.49	65	2.67	7.19
	Silty Clay	10.06	80	9.58	-4.77
624 L Cistern	Sand	0.67	55	0.57	-14.77
	Sandy Loam	3.01	71	2.52	-16.36
	Loamy Sand	1.85	65	1.45	-21.69
	Silty Clay	9.09	80	8.17	-10.06
833 L Cistern	Sand	0.45	55	0.30	-33.59
	Sandy Loam	2.56	71	1.62	-36.66
	Loamy Sand	1.44	65	0.58	-59.41
	Silty Clay	8.30	80	7.04	-15.18

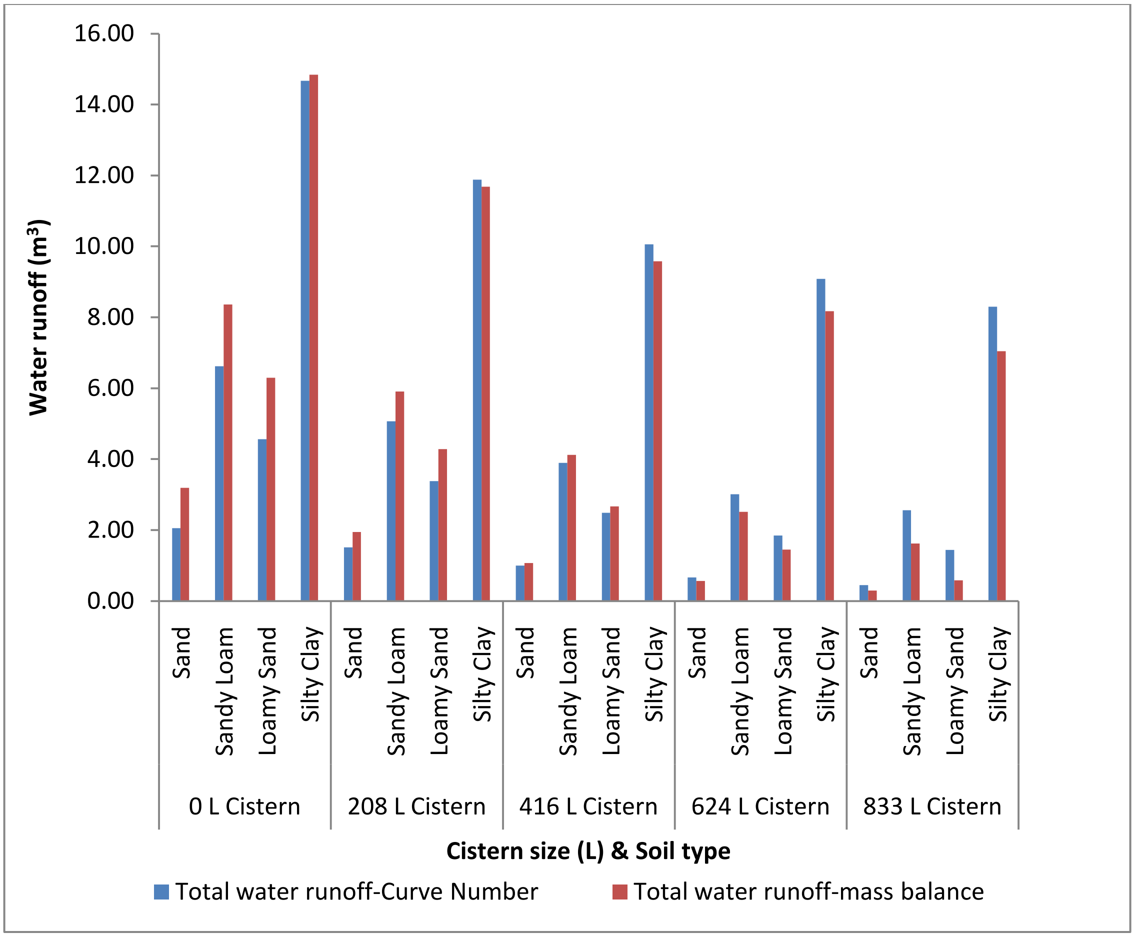

Figure 5. Comparison between total volumes of water runoff (Curve Number and Mass-Balance method) and soil types by utilizing different cistern sizes and Time-based irrigation scheduling method.

Table 10. Mean differences comparison between predicted water runoff with respect to soil types and a Time-based irrigation scheduling method.

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
Total water runoff-Mass-Balance (m^3)	1	2	-3.09	1.06	0.01	-5.33	-0.85
		3	-1.61	1.06	0.15	-3.85	0.63
		4	-9.66	1.06	0.00	-11.90	-7.42

Table 10. Continued.

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
	2	1	3.09	1.06	0.01	0.85	5.33
		3	1.49	1.06	0.18	-0.75	3.73
		4	-6.57	1.06	0.00	-8.81	-4.33
	3	1	1.61	1.06	0.15	-0.63	3.85
		2	-1.49	1.06	0.18	-3.73	0.75
		4	-8.06	1.06	0.00	-10.30	-5.82
	4	1	9.66	1.06	0.00	7.42	11.90
		2	6.57	1.06	0.00	4.33	8.81
		3	8.06	1.06	0.00	5.82	10.30
Total water runoff-Curve Number (m^3)	1	2	-3.09	1.53	0.06	-6.34	0.16
		3	-1.64	1.53	0.30	-4.89	1.61
		4	-8.85	1.53	0.00	-12.09	-5.60
	2	1	3.09	1.53	0.06	-0.16	6.34
		3	1.45	1.53	0.36	-1.80	4.69
		4	-5.76	1.53	0.00	-9.01	-2.51
	3	1	1.64	1.53	0.30	-1.61	4.89
		2	-1.45	1.53	0.36	-4.69	1.80
		4	-7.21	1.53	0.00	-10.45	-3.96
	4	1	8.85	1.53	0.00	5.60	12.09
		2	5.76	1.53	0.00	2.51	9.01
		3	7.21	1.53	0.00	3.96	10.45

* The mean difference is significant at the 0.05 level.
1= Sand, 2= Sandy Loam, 3= Loamy Sand, 4= Silty Clay
Note that numbers highlighted in grey color reflect non significance

The last comparison between the two methods for estimating total water runoff was based on Time-based irrigation scheduling method that does not utilize a cistern, 15.2 cm soil depth and 50 % depletion ratio. The total water runoff predicted from utilizing Mass-Balance and Curve Number methods is presented in Table 11. Silty Clay soil had the greatest total water runoff predicted based on the two methods and Sand soil had the least total water runoff predicted. Total volumes of water runoff resulted from Mass-Balance method was greater than water runoff resulted from Curve Number method among all soil types utilized (Figure 6).

Based on both methods: Curve Number and Mass-Balance, there were significant differences among all soil types utilized (Table 12).

Table 11. Total water runoff (m^3) predicted by Curve Number and Mass-Balance methods when using a Time-based irrigation scheduling method that does not utilize a cistern (control) for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
0 L Cistern	Sand	2.54	55	4.40	72.84
	Sandy Loam	8.70	71	11.68	34.31
	Loamy Sand	5.76	65	8.74	51.73
	Silty Clay	15.36	80	15.74	2.48
208 L Cistern	Sand	2.54	55	4.40	72.84
	Sandy Loam	8.70	71	11.68	34.31
	Loamy Sand	5.76	65	8.74	51.73
	Silty Clay	15.36	80	15.74	2.48
416 L Cistern	Sand	2.54	55	4.40	72.84
	Sandy Loam	8.70	71	11.68	34.31
	Loamy Sand	5.76	65	8.74	51.73
	Silty Clay	15.36	80	15.74	2.48
624 L Cistern	Sand	2.54	55	4.40	72.84
	Sandy Loam	8.70	71	11.68	34.31
	Loamy Sand	5.76	65	8.74	51.73

Table 11. Continued.

Cistern size (L)	Soil type	Total water runoff-Curve Number (m^3)	Curve Number	Total water runoff-Mass Balance (m^3)	% Error
	Silty Clay	15.36	80	15.74	2.48
833 L Cistern	Sand	2.54	55	4.40	72.84
	Sandy Loam	8.70	71	11.68	34.31
	Loamy Sand	5.76	65	8.74	51.73
	Silty Clay	15.36	80	15.74	2.48

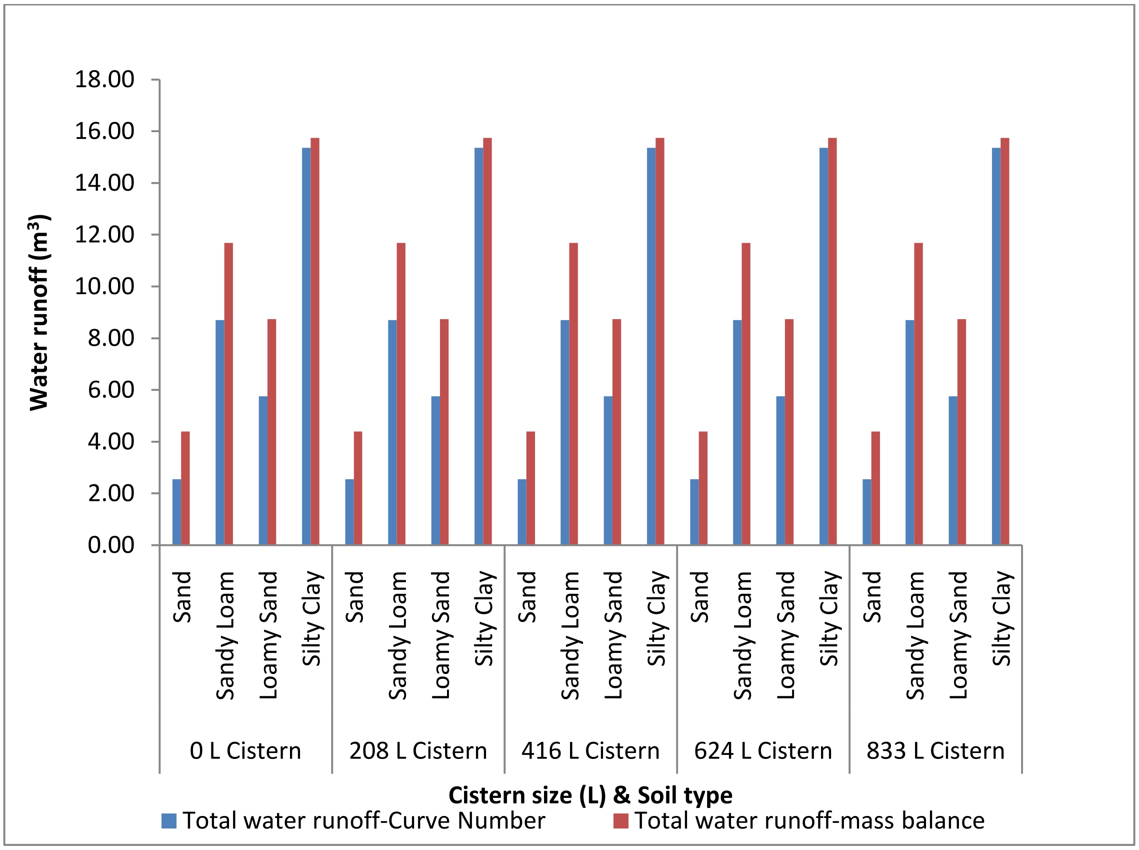

Figure 6. Comparison between total volumes of water runoff (Curve Number and Mass-Balance method) by utilizing different cistern sizes and Time-based irrigation scheduling method that does not utilize a cistern (control).

Table 12. Mean differences comparison between predicted water runoff with respect to soil types and a Time-based irrigation scheduling method that does not utilize a cistern (control).

Dependent variable	(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
						Lower bound	Upper bound
Total water runoff-Mass-Balance (m^3)	1	2	-6.15	0.00	0.00	-6.15	-6.15
		3	-3.22	0.00	0.00	-3.22	-3.22
		4	-12.82	0.00	0.00	-12.82	-12.82
	2	1	6.15	0.00	0.00	6.15	6.15
		3	2.94	0.00	0.00	2.94	2.94
		4	-6.67	0.00	0.00	-6.67	-6.67
	3	1	3.22	0.00	0.00	3.22	3.22
		2	-2.94	0.00	0.00	-2.94	-2.94
		4	-9.60	0.00	0.00	-9.60	-9.60
	4	1	12.82	0.00	0.00	12.82	12.82
		2	6.67	0.00	0.00	6.67	6.67
		3	9.60	0.00	0.00	9.60	9.60
Total water runoff-Curve Number (m^3)	1	2	-7.28	0.00	0.00	-7.28	-7.28
		3	-4.34	0.00	0.00	-4.34	-4.34
		4	-11.35	0.00	0.00	-11.35	-11.35
	2	1	7.28	0.00	0.00	7.28	7.28
		3	2.94	0.00	0.00	2.94	2.94
		4	-4.06	0.00	0.00	-4.06	-4.06
	3	1	4.34	0.00	0.00	4.34	4.34
		2	-2.94	0.00	0.00	-2.94	-2.94
		4	-7.00	0.00	0.00	-7.00	-7.00
	4	1	11.35	0.00	0.00	11.35	11.35
		2	4.06	0.00	0.00	4.06	4.06
		3	7.00	0.00	0.00	7.00	7.00

* The mean difference is significant at the 0.05 level.
1= Sand Soil, 2= Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Total Volumes of Water Runoff and Supplemental Water vs. Soil Type and ET Treatment

Soil type is a valuable factor that needs to be considered in reducing total volume of water runoff and potable water used for irrigation. Soil types utilized in this study had different impacts on total runoff and supplemental water predicted. Table 13 below explains a comparison between four soil types (Sand, Sandy Loam, Loamy Sand, Silty Clay) and its impact on total water runoff predicted and potable water used for irrigation (supplemental water) by utilizing 0 L cistern, 308 L cistern, 416 L cistern, 624 L cistern, and 833 L cistern. This comparison was based on ET-based irrigation scheduling method, 15.2 cm soil depth, and 50 % depletion ratio. The predicted runoff volumes were the least for Sand soil and greatest for Silty Clay as Figures 7 and 8 show. The predicted potable water volumes used for irrigation were the greatest for Sand soil and least for Silt Clay. There was a significant difference at 0.05 confidence level between all soil types and total water runoff predicted by utilizing ET-based irrigation scheduling method (Table 14). A comparison between means was conducted to determine any significant difference between soil types and total supplemental water and results show that there were no significant differences between all soil types and total supplemental water (Table 15). In general, by moving from coarse soil texture to fine soil texture; total water runoff and total supplemental water predicted increased, while by moving in the opposite direction from fine to coarse soil texture, total water runoff and total supplemental water predicted decreased.

Increasing cistern size decreased total water runoff, although not at a statistically significant level. Statistical analysis utilizing 95% confidence level shows that there is no statistically significant difference between total water runoff and cistern sizes, while a statistical analysis shows significance difference between total supplemental water used for irrigation and cistern size between all cistern sizes except for the following: 416 and 624 L, and 624 and 833 L cistern (Tables 16 and 17) respectively.

Table 13. Total water runoff (m^3) and total potable water used for irrigation (supplemental water) predicted by Mass-Balance method when using an ET-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
0 L Cistern	Sand	3.57	11.77
	Sandy Loam	9.65	9.86
	Loamy Sand	7.18	11.02
	Silty Clay	13.13	9.06
208 L Cistern	Sand	2.88	7.96
	Sandy Loam	8.48	5.84
	Loamy Sand	6.18	7.21
	Silty Clay	12.38	6.25
416 L Cistern	Sand	2.52	6.29
	Sandy Loam	7.58	5.54
	Loamy Sand	5.28	5.72
	Silty Clay	11.34	4.80
624 L Cistern	Sand	2.23	5.17
	Sandy Loam	6.77	4.43
	Loamy Sand	4.67	5.17
	Silty Clay	10.46	4.80
833 L Cistern	Sand	2.16	4.56

Table 13. Continued.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
	Sandy Loam	6.14	4.12
	Loamy Sand	4.16	4.49
	Silty Clay	9.89	3.77

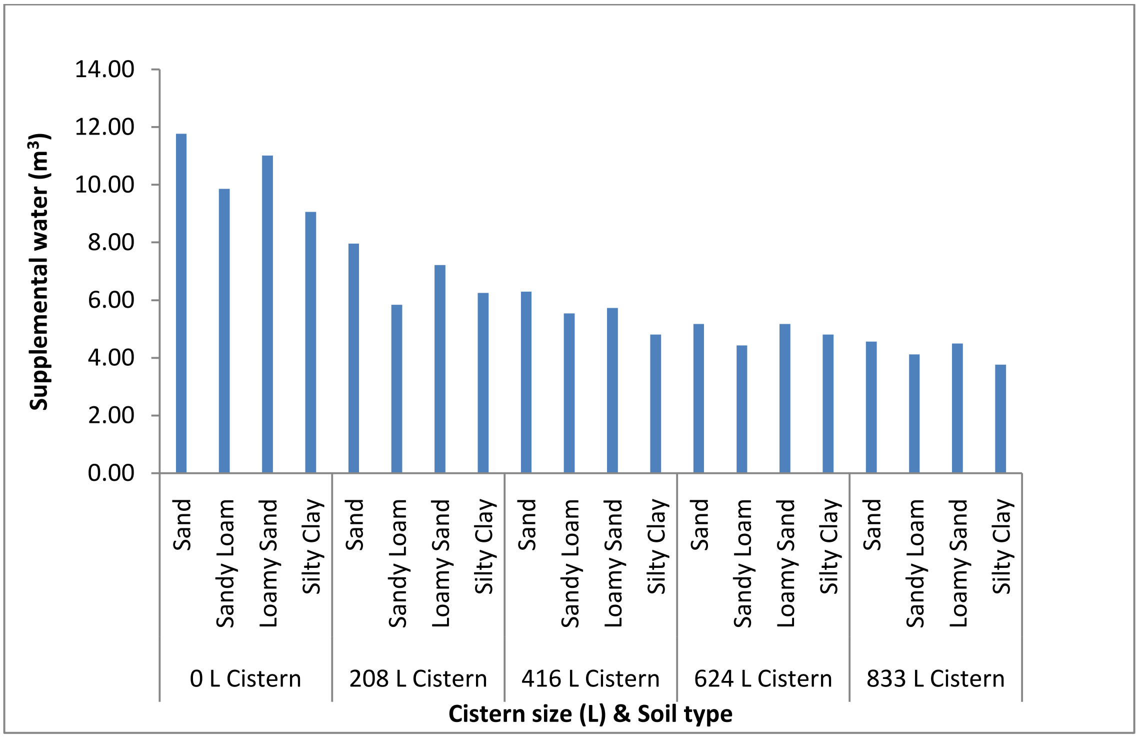

Figure 7. Comparison between different soil types and total volumes of supplemental water by utilizing different cistern sizes and ET-based scheduling method.

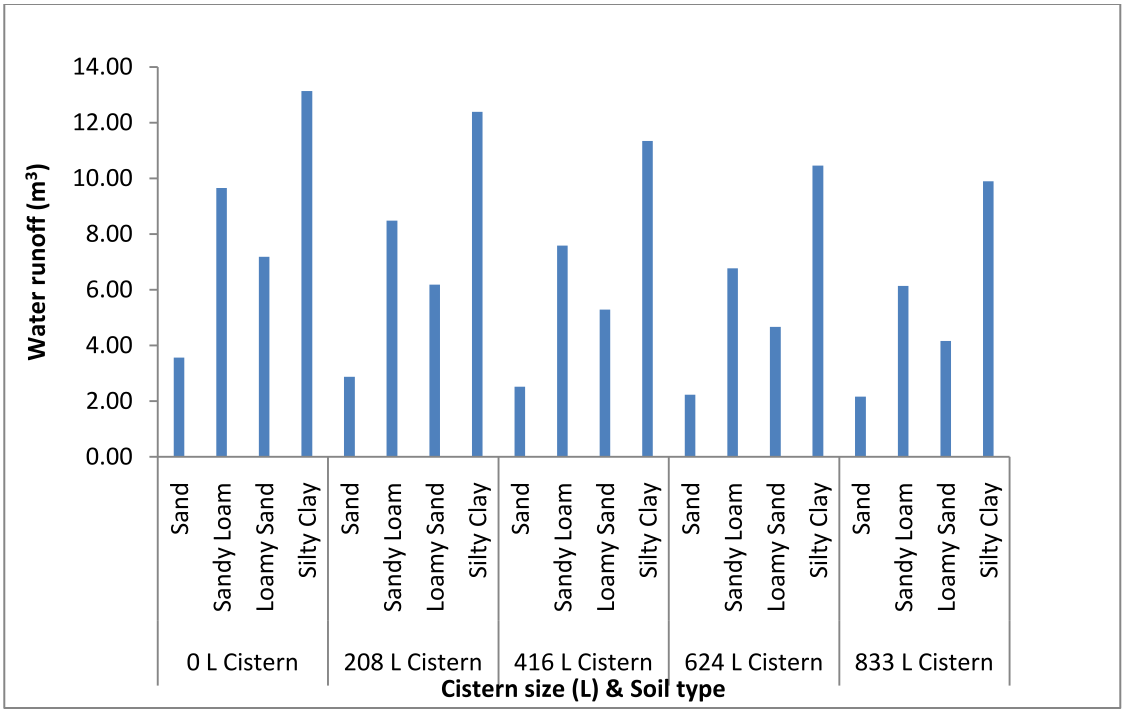

Figure 8. Comparison between different soil types and total volumes of water runoff by utilizing different cistern sizes and ET-based scheduling method.

Table 14. Mean differences comparison between predicted water runoff-Mass Balance method with respect to soil types and an ET-based irrigation scheduling method.

(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	-5.05	0.74	0.00	-6.62	-3.48
	3	-2.82	0.74	0.00	-4.40	-1.25
	4	-8.77	0.74	0.00	-10.34	-7.20
2	1	5.05	0.74	0.00	3.48	6.62
	3	2.23	0.74	0.01	0.66	3.80
	4	-3.71	0.74	0.00	-5.29	-2.14
3	1	2.82	0.74	0.00	1.25	4.40

Table 14. Continued.

(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
	2	-2.23	0.74	0.01	-3.80	-0.66
	4	-5.94	0.74	0.00	-7.52	-4.37
4	1	8.77	0.74	0.00	7.20	10.34
	2	3.71	0.74	0.00	2.14	5.29
	3	5.94	0.74	0.00	4.37	7.52

* The mean difference is significant at the 0.05 level.
1= Sand, 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 15. **Mean differences comparison between predicted supplemental water with respect to soil types and an ET-based irrigation scheduling method.**

(I) Soil type	(J) Soil type	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	1.19	1.57	0.46	-2.13	4.52
	3	0.43	1.57	0.79	-2.90	3.76
	4	1.42	1.57	0.38	-1.91	4.74
2	1	-1.19	1.57	0.46	-4.52	2.13
	3	-0.77	1.57	0.63	-4.09	2.56
	4	0.22	1.57	0.89	-3.10	3.55
3	1	-0.43	1.57	0.79	-3.76	2.90
	2	0.77	1.57	0.63	-2.56	4.09
	4	0.99	1.57	0.54	-2.34	4.32
4	1	-1.42	1.57	0.38	-4.74	1.91
	2	-0.22	1.57	0.89	-3.55	3.10
	3	-0.99	1.57	0.54	-4.32	2.34

* The mean difference is significant at the 0.05 level.
1= Sand , 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 16. Mean differences comparison between predicted water runoff-Mass Balance method with respect to cistern sizes and an ET-based irrigation scheduling method.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
0	208	0.90	2.63	0.74	-4.70	6.51
	416	1.70	2.63	0.53	-3.90	7.31
	624	2.35	2.63	0.39	-3.25	7.96
	833	2.79	2.63	0.31	-2.81	8.40
208	0	-0.90	2.63	0.74	-6.51	4.70
	416	0.80	2.63	0.76	-4.80	6.41
	624	1.45	2.63	0.59	-4.16	7.05
	833	1.89	2.63	0.48	-3.71	7.50
416	0	-1.70	2.63	0.53	-7.31	3.90
	208	-0.80	2.63	0.76	-6.41	4.80
	624	0.65	2.63	0.81	-4.96	6.25
	833	1.09	2.63	0.68	-4.52	6.69
624	0	-2.35	2.63	0.39	-7.96	3.25
	208	-1.45	2.63	0.59	-7.05	4.16
	416	-0.65	2.63	0.81	-6.25	4.96
	833	0.44	2.63	0.87	-5.16	6.05
833	0	-2.79	2.63	0.31	-8.40	2.81
	208	-1.89	2.63	0.48	-7.50	3.71
	416	-1.09	2.63	0.68	-6.69	4.52
	624	-0.44	2.63	0.87	-6.05	5.16

Table 17. Mean differences comparison between predicted supplemental water and with respect to cistern sizes and an ET-based irrigation scheduling method.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
0	208	3.62	0.55	0.00	2.45	4.79
	416	4.84	0.55	0.00	3.67	6.01
	624	5.54	0.55	0.00	4.37	6.71
	833	6.19	0.55	0.00	5.02	7.36
208	0	-3.62	0.55	0.00	-4.79	-2.45
	416	1.22	0.55	0.04	0.05	2.39
	624	1.92	0.55	0.00	0.75	3.09
	833	2.58	0.55	0.00	1.41	3.75
416	0	-4.84	0.55	0.00	-6.01	-3.67
	208	-1.22	0.55	0.04	-2.39	-0.05
	624	0.70	0.55	0.22	-0.47	1.87
	833	1.36	0.55	0.03	0.19	2.52
624	0	-5.54	0.55	0.00	-6.71	-4.37
	208	-1.92	0.55	0.00	-3.09	-0.75
	416	-0.70	0.55	0.22	-1.87	0.47
	833	0.66	0.55	0.25	-0.51	1.83
833	0	-6.19	0.55	0.00	-7.36	-5.02
	208	-2.58	0.55	0.00	-3.75	-1.41
	416	-1.36	0.55	0.03	-2.52	-0.19
	624	-0.66	0.55	0.25	-1.83	0.51

* The mean difference is significant at the 0.05 level.
Note that numbers highlighted in grey color reflect non significance

Total Volumes of Water Runoff and Supplemental Water vs. Soil Type and Time-Based Treatment

Scheduling irrigation based on time was another factor that this study considered to predict total water runoff and supplemental water. Table 18 below explains a comparison between four soil types (Sand, Sandy Loam, Loamy Sand, Silty Clay) and its impact on total water runoff predicted and potable water used for irrigation (supplemental water) by utilizing 0 L cistern, 308 L cistern, 416 L cistern, 624 L cistern, and 833 L cistern. This comparison was based on Time-based irrigation scheduling method, 15.2 cm soil depth, and 50 % depletion ratio .The predicted runoff volume was the least for Sand soil and the greatest for Silty Clay, while Sandy Loam had the greatest volume predicted of supplemental water used for irrigation and Silty Clay soil has the least as (Figures 9 and 10) show. There were significant differences at 0.05 confidence level between soil types and water runoff predicted and total potable water predicted used for irrigation by utilizing Time-based irrigation scheduling method for the following: Silty Clay and Sand, Silty Clay and Sandy Loam and Silty Clay and Loamy Sand soil (Tables 19 and 20). In general, by moving from coarse soil texture to fine soil texture; total water runoff and total supplemental water predicted increased, while by moving in the opposite direction from fine to coarse soil texture, total water runoff and total supplemental water predicted decreased.

Increasing cistern size decreased total water runoff and potable water used for irrigation predicted, although not at a statistically significant level. Tables 21 and 22 show that there is no statistically significant level at 95% between cistern sizes utilized and total water runoff predicted and total potable water used for irrigation predicted.

Table 18. Total water runoff (m^3) and total potable water used for irrigation (supplemental water) predicted by Mass-Balance method when using a Time-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
0 L Cistern	Sand	3.20	87.48
	Sandy Loam	8.36	174.96
	Loamy Sand	6.30	131.22
	Silty Clay	14.84	36.32
208 L Cistern	Sand	1.95	77.34
	Sandy Loam	5.91	165.69
	Loamy Sand	4.28	121.60
	Silty Clay	11.68	26.95
416 L Cistern	Sand	1.07	72.67
	Sandy Loam	4.12	161.69
	Loamy Sand	2.67	116.90
	Silty Clay	9.58	21.56
624 L Cistern	Sand	0.57	70.70
	Sandy Loam	2.52	159.10
	Loamy Sand	1.45	114.60
	Silty Clay	8.17	19.49
833 L Cistern	Sand	0.30	69.02
	Sandy Loam	1.62	157.60
	Loamy Sand	0.58	113.00
	Silty Clay	7.04	18.13

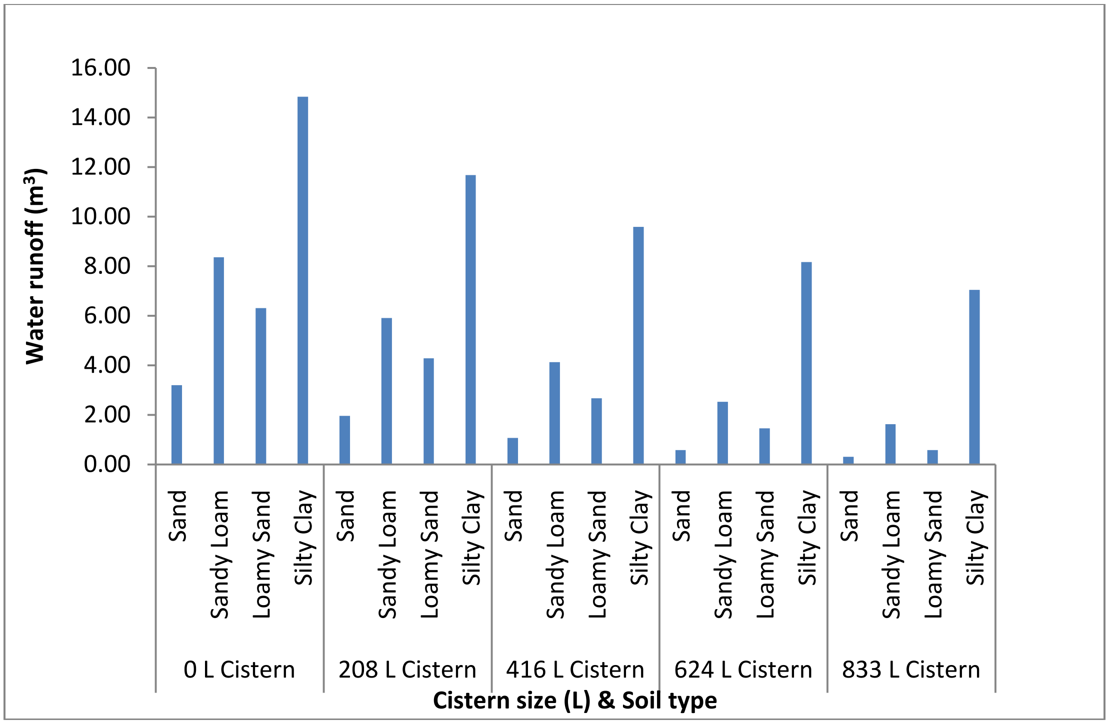

Figure 9. Comparison between different soil types and total volumes of water runoff by utilizing different cistern sizes and Time-based scheduling method.

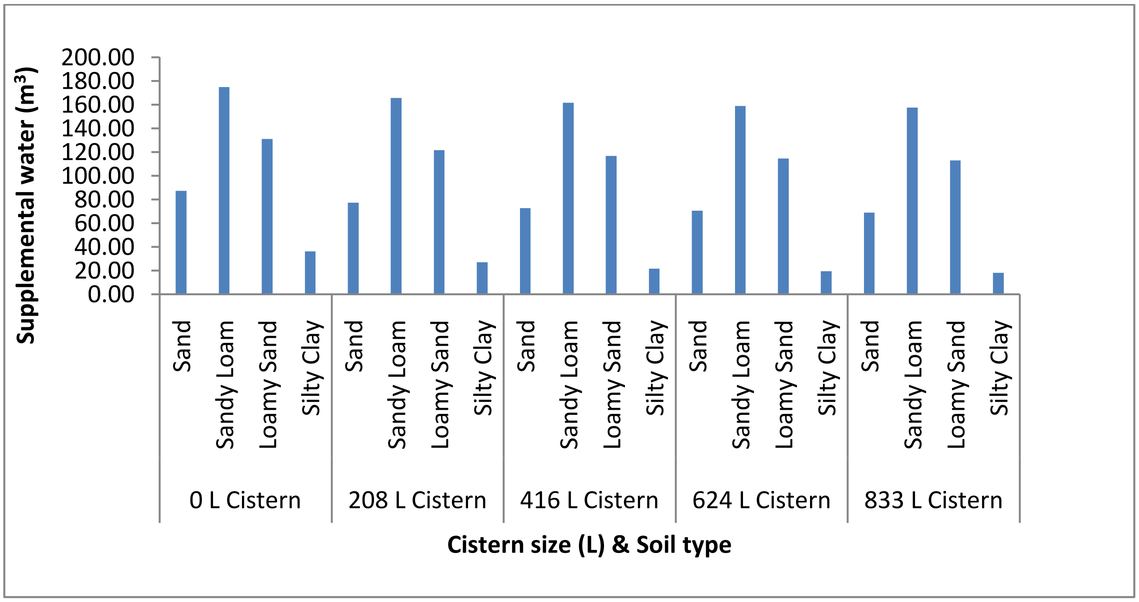

Figure 10. Comparison between different soil types and total volumes of supplemental water by utilizing different cistern sizes and ET-based scheduling method.

Table 19. Mean differences comparison between predicted water runoff-Mass Balance method with respect to soil types and a Time-based irrigation scheduling method.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	-3.09	1.53	0.06	-6.34	0.16
	3	-1.64	1.53	0.30	-4.89	1.61
	4	-8.84*	1.53	0.00	-12.09	-5.60
2	1	3.09	1.53	0.06	-0.16	6.34
	3	1.45	1.53	0.36	-1.80	4.70
	4	-5.75*	1.53	0.00	-9.00	-2.51
3	1	1.64	1.53	0.30	-1.61	4.89
	2	-1.45	1.53	0.36	-4.70	1.80
	4	-7.20*	1.53	0.00	-10.45	-3.96
4	1	8.84*	1.53	0.00	5.60	12.09
	2	5.75*	1.53	0.00	2.51	9.00
	3	7.20*	1.53	0.00	3.96	10.45

* The mean difference is significant at the 0.05 level.

1= Sand, 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 20. Mean differences comparison between predicted supplemental water with respect to soil types and a Time-based irrigation scheduling method.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	-88.37	4.60	0.00	-98.13	-78.61
	3	-44.02	4.60	0.00	-53.78	-34.26
	4	50.95	4.60	0.00	41.19	60.71
2	1	88.37	4.60	0.00	78.61	98.13
	3	44.34	4.60	0.00	34.58	54.10
	4	139.32	4.60	0.00	129.56	149.08

Table 20. Continued.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
3	1	44.02	4.60	0.00	34.26	53.78
	2	-44.34	4.60	0.00	-54.10	-34.58
	4	94.98	4.60	0.00	85.22	104.73
4	1	-50.95	4.60	0.00	-60.71	-41.19
	2	-139.32	4.60	0.00	-149.08	-129.56
	3	-94.98	4.60	0.00	-104.73	-85.22

* The mean difference is significant at the 0.05 level.
1= Sand, 2= Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 21. Mean differences comparison between predicted supplemental water with respect to cistern sizes and a Time-based irrigation scheduling method.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
0	208	9.60	42.20	0.82	-80.35	99.55
	416	14.29	42.20	0.74	-75.66	104.23
	624	16.52	42.20	0.70	-73.43	106.47
	833	18.06	42.20	0.67	-71.89	108.00
208	0	-9.60	42.20	0.82	-99.55	80.35
	416	4.69	42.20	0.91	-85.26	94.64
	624	6.92	42.20	0.87	-83.03	96.87
	833	8.46	42.20	0.84	-81.49	98.41
416	0	-14.29	42.20	0.74	-104.23	75.66
	208	-4.69	42.20	0.91	-94.64	85.26
	624	2.23	42.20	0.96	-87.71	92.18
	833	3.77	42.20	0.93	-86.18	93.72
624	0	-16.52	42.20	0.70	-106.47	73.43
	208	-6.92	42.20	0.87	-96.87	83.03
	416	-2.23	42.20	0.96	-92.18	87.71
	833	1.54	42.20	0.97	-88.41	91.48

Table 21. Continued.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
833	0	-18.06	42.20	0.67	-108.00	71.89
	208	-8.46	42.20	0.84	-98.41	81.49
	416	-3.77	42.20	0.93	-93.72	86.18
	624	-1.54	42.20	0.97	-91.48	88.41

Table 22. Mean differences comparison between predicted water runoff-Mass Balance method with respect to cistern sizes and a Time-based irrigation scheduling method.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
0	208	2.22	2.77	0.44	-3.69	8.13
	416	3.82	2.77	0.19	-2.09	9.72
	624	5.00	2.77	0.09	-0.91	10.90
	833	5.79	2.77	0.05	-0.12	11.70
208	0	-2.22	2.77	0.44	-8.13	3.69
	416	1.60	2.77	0.57	-4.31	7.50
	624	2.78	2.77	0.33	-3.13	8.68
	833	3.57	2.77	0.22	-2.34	9.48
416	0	-3.82	2.77	0.19	-9.72	2.09
	208	-1.60	2.77	0.57	-7.50	4.31
	624	1.18	2.77	0.68	-4.72	7.09
	833	1.98	2.77	0.49	-3.93	7.88
624	0	-5.00	2.77	0.09	-10.90	0.91
	208	-2.78	2.77	0.33	-8.68	3.13
	416	-1.18	2.77	0.68	-7.09	4.72
	833	0.79	2.77	0.78	-5.11	6.70

Table 22. Continued.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
833	0	-5.79	2.77	0.05	-11.70	0.12
	208	-3.57	2.77	0.22	-9.48	2.34
	416	-1.98	2.77	0.49	-7.88	3.93
	624	-0.79	2.77	0.78	-6.70	5.11

Total Water Runoff and Total Supplemental Water vs. Soil Type and Soil Moisture-Based Treatment

Scheduling irrigation based on soil moisture was another factor that this study considered to predict total water runoff and supplemental water. Table 23 below explains a comparison between four soil types (Sand, Sandy Loam, Loamy Sand, Silty Clay) and its impact on total water runoff predicted and potable water used for irrigation (supplemental water) by utilizing 0 L cistern, 208 L cistern, 416 L cistern, 624 L cistern, and 833 L cistern. This comparison was based on Soil Moisture-based irrigation scheduling method, 15.2 cm soil depth, and 50 % depletion ratio .The predicted runoff volume was the least for Sand soil and greatest for Silty Clay soil, while the predicted supplemental water was the least for Silty Clay soil and greatest for Sand soil as (Figures 11 and 12) respectively show. There was a significant difference at 0.05 confidence level between all soil types and total water runoff predicted with respect to Soil Moisture-based irrigation scheduling method (Table 24). A comparison between means was conducted to determine any significant difference between soil types and total supplemental water and results show that there were no significant difference among all soil types utilized (Table 25). In general, by moving from coarse soil texture to fine soil texture; total water runoff predicted increased and total potable water predicted decreased, while by moving in the opposite direction from fine to coarse soil texture, total water runoff predicted decreased and total potable water predicted increased.

Increasing cistern size decreased total potable water used for irrigation predicted, there were significance differences between all cistern sizes utilized and total supplemental water except for the followings: 416 and 624L cistern and 624L and 833L cisterns (Table 26). Increasing cistern size decreased total water runoff predicted, although not at a statistically significant level. Table 27 shows that there is no statistically significant difference at 95% confidence between cistern sizes utilized and total water runoff predicted.

Table 23. Total water runoff (m^3) and total potable water used for irrigation (supplemental water) predicted by Mass-Balance method when using a Soil Moisture-based irrigation scheduling method for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
0 L Cistern	Sand	4.24	23.81
	Sandy Loam	10.5	20.37
	Loamy Sand	8.18	22.06
	Silty Clay	14.27	18.07
208 L Cistern	Sand	3.16	19.01
	Sandy Loam	9.03	16.81
	Loamy Sand	6.56	17.51
	Silty Clay	13.17	15.50
416 L Cistern	Sand	2.42	15.92
	Sandy Loam	7.74	14.52
	Loamy Sand	5.34	14.61
	Silty Clay	11.98	13.22
624 L Cistern	Sand	2.03	13.77
	Sandy Loam	6.78	12.67
	Loamy Sand	4.56	12.57

Table 23. Continued.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
	Silty Clay	10.99	11.73
833 L Cistern	Sand	1.99	12.31
	Sandy Loam	6.17	11.11
	Loamy Sand	4.09	11.10
	Silty Clay	10.21	10.21

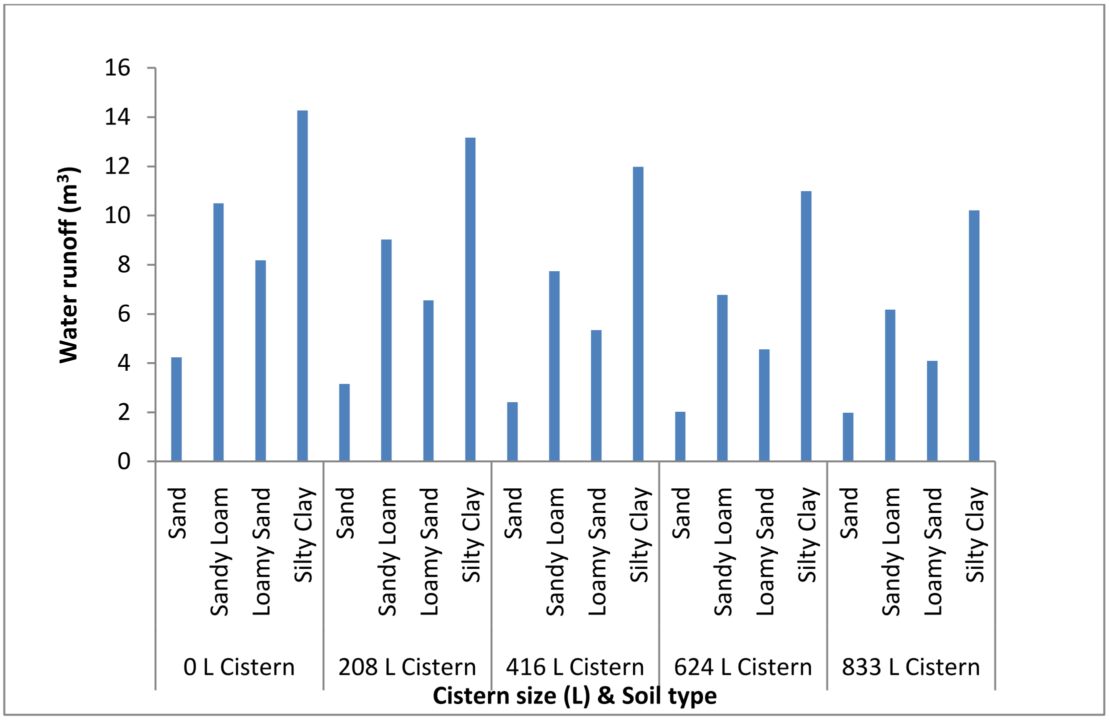

Figure 11. Comparison between different soil types and total volumes of water runoff by utilizing different cistern sizes and Soil Moisture- based scheduling method.

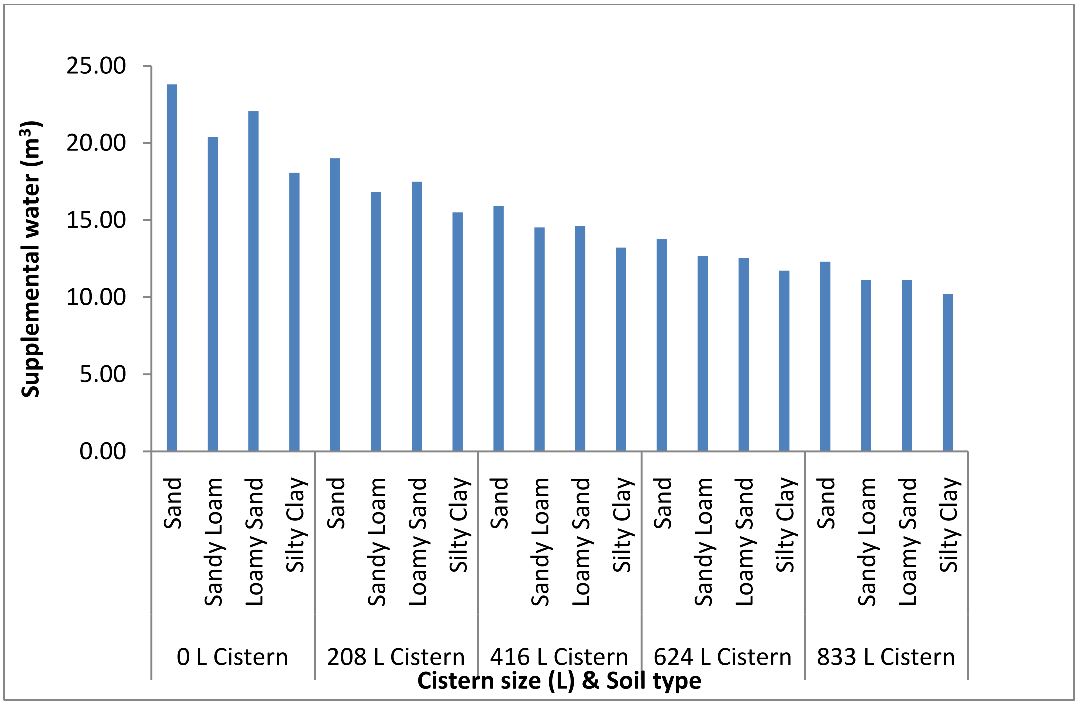

Figure 12. Comparison between different soil types and total volumes of supplemental water by utilizing different cistern sizes and Soil Moisture- based scheduling method.

Table 24. Mean differences comparison between predicted water runoff-Mass Balance method with respect to soil types and a Soil Moisture-based irrigation scheduling method.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	-5.27	0.97	0.00	-7.32	-3.23
	3	-2.97	0.97	0.01	-5.03	-0.93
	4	-9.35	0.97	0.00	-11.40	-7.31
2	1	5.27	0.97	0.00	3.23	7.32
	3	2.29	0.97	0.03	0.25	4.35
	4	-4.08	0.97	0.00	-6.13	-2.03
3	1	2.97	0.97	0.01	0.93	5.03
	2	-2.29	0.97	0.03	-4.35	-0.25

Table 24. Continued.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
	4	-6.37	0.97	0.00	-8.43	-4.33
4	1	9.35	0.97	0.00	7.31	11.40
	2	4.08	0.97	0.00	2.03	6.13
	3	6.37	0.97	0.00	4.33	8.43

*The mean difference is significant at the 0.05 level.
1= Sand , 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 25. Mean differences comparison between predicted supplemental water with respect to soil types and a Soil Moisture-based irrigation scheduling method.

(I) Soil type	(J) Soil type	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
1	2	1.87	2.51	0.47	-3.45	7.18
	3	1.39	2.51	0.59	-3.92	6.71
	4	3.22	2.51	0.22	-2.10	8.53
2	1	-1.87	2.51	0.47	-7.18	3.45
	3	-0.47	2.51	0.85	-5.79	4.84
	4	1.35	2.51	0.60	-3.96	6.67
3	1	-1.39	2.51	0.59	-6.71	3.92
	2	0.47	2.51	0.85	-4.84	5.79
	4	1.82	2.51	0.48	-3.49	7.14
4	1	-3.22	2.51	0.22	-8.53	2.10
	2	-1.35	2.51	0.60	-6.67	3.96
	3	-1.82	2.51	0.48	-7.14	3.49

*The mean difference is significant at the 0.05 level.
1= Sand, 2=Sandy Loam, 3= Loamy Sand, 4= Silty Clay

Table 26. **Mean differences comparison between predicted supplemental water with respect to cistern sizes and a Soil Moisture-based irrigation scheduling method.**

(I) Cistern size	(J) Cistern size	Mean difference (I-J)	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
0	208	3.87	1.04	0.00	1.66	6.08
	416	6.51	1.04	0.00	4.30	8.73
	624	8.40	1.04	0.00	6.18	10.61
	833	9.90	1.04	0.00	7.68	12.11
208	0	-3.87	1.04	0.00	-6.08	-1.66
	416	2.64	1.04	0.02	0.43	4.86
	624	4.53	1.04	0.00	2.31	6.74
	833	6.03	1.04	0.00	3.81	8.24
416	0	-6.51	1.04	0.00	-8.73	-4.30
	208	-2.64	1.04	0.02	-4.86	-0.43
	624	1.88	1.04	0.09	-0.33	4.10
	833	3.39	1.04	0.01	1.17	5.60
624	0	-8.40	1.04	0.00	-10.61	-6.18
	208	-4.53	1.04	0.00	-6.74	-2.31
	416	-1.88	1.04	0.09	-4.10	0.33
	833	1.50	1.04	0.17	-0.71	3.72
833	0	-9.90	1.04	0.00	-12.11	-7.68
	208	-6.03	1.04	0.00	-8.24	-3.81
	416	-3.39	1.04	0.01	-5.60	-1.17
	624	-1.50	1.04	0.17	-3.72	0.71

*The mean difference is significant at the 0.05 level.

Table 27. Mean differences comparison between predicted runoff-Mass-Balance method with respect to cistern sizes and a Soil Moisture-based irrigation scheduling method.

(I) Cistern size	(J) Cistern size	Mean difference (I-J)*	Std. error	Sig.*	95% Confidence interval	
					Lower bound	Upper bound
0	208	1.32	2.80	0.64	-4.65	7.29
	416	2.43	2.80	0.40	-3.54	8.40
	624	3.21	2.80	0.27	-2.76	9.18
	833	3.68	2.80	0.21	-2.29	9.65
208	0	-1.32	2.80	0.64	-7.29	4.65
	416	1.11	2.80	0.70	-4.86	7.08
	624	1.89	2.80	0.51	-4.08	7.86
	833	2.37	2.80	0.41	-3.61	8.34
416	0	-2.43	2.80	0.40	-8.40	3.54
	208	-1.11	2.80	0.70	-7.08	4.86
	624	0.78	2.80	0.78	-5.19	6.75
	833	1.26	2.80	0.66	-4.72	7.23
624	0	-3.21	2.80	0.27	-9.18	2.76
	208	-1.89	2.80	0.51	-7.86	4.08
	416	-0.78	2.80	0.78	-6.75	5.19
	833	0.48	2.80	0.87	-5.50	6.45
833	0	-3.68	2.80	0.21	-9.65	2.29
	208	-2.37	2.80	0.41	-8.34	3.61
	416	-1.26	2.80	0.66	-7.23	4.72
	624	-0.48	2.80	0.87	-6.45	5.50

* The mean difference is significant at the 0.05 level.

Total Volumes of Water Runoff and Supplemental Water vs. Soil Type and by Utilizing Control Treatment

The urban development scenario was simulated and compared to other RWH-irrigation systems by a control treatment that does not have a RWH component. This treatment reflects typical residents who are not aware of water conservation practices and does not utilize a cistern. Table 28 below explains a comparison between four soil types (Sand, Sandy Loam, Loamy Sand, Silty Clay) and its impact on total water runoff predicted and potable water used for irrigation (supplemental water) by utilizing 0 L cistern. This comparison was based on Time-based irrigation scheduling method that does not utilize a cistern, 15.2 cm soil depth, and 50 % depletion ratio. The predicted volumes of water runoff were the least for Sand soil and greatest for Silty Clay soil, while the predicted volumes of potable water used for irrigation were the least for Silty Clay and greatest for Sandy Loam (Figures 13 and 14) respectively show. In general, 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.

Table 28. Total water runoff (m^3) and total potable water used for irrigation (supplemental water) predicted by Mass-Balance method when using a Time-based irrigation scheduling method that does not utilize a cistern (control) for different soil types.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3)	Total supplemental water (m^3)
0 L Cistern	Sand	2.54	87.48
	Sandy Loam	8.70	174.96
	Loamy Sand	5.76	131.22
	Silty Clay	15.36	36.32

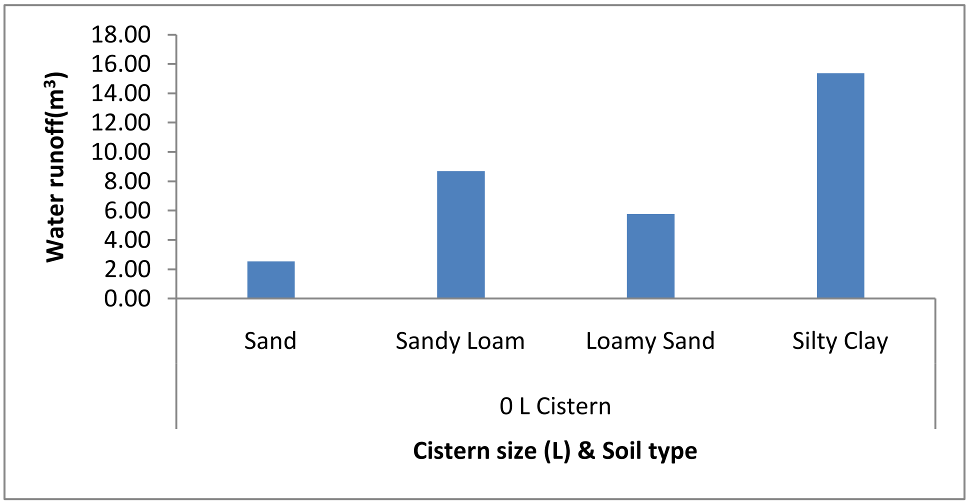

Figure 13. Comparison between different soil types and total volumes of water runoff by utilizing different cistern sizes and control scheduling method.

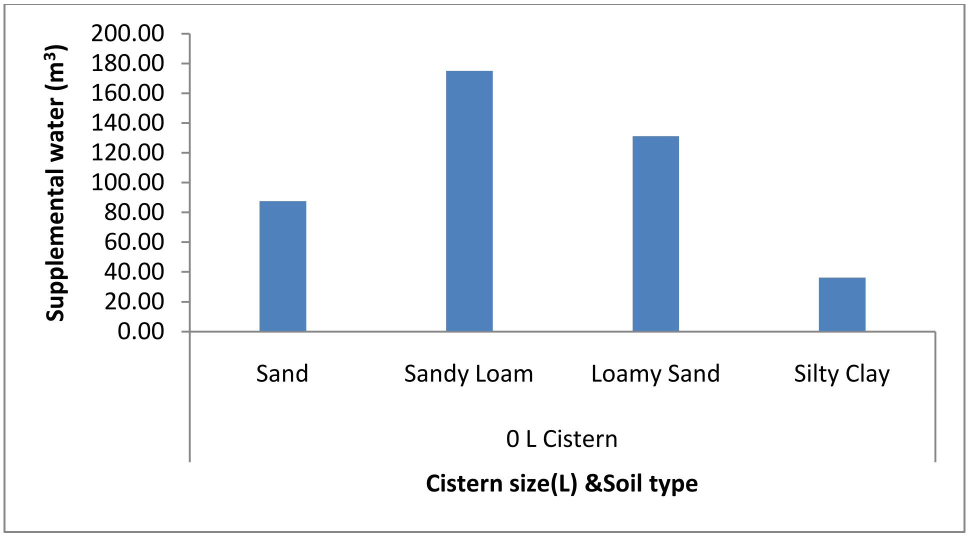

Figure 14. Comparison between different soil types and total volumes of supplemental water by utilizing different cistern sizes and control scheduling method.

Comparison Between Total Volumes of Water Runoff-Mass Balance Method and Soil Types by Utilizing Different Irrigation Scheduling Methods

Table 29 below shows a comparison between four irrigation scheduling methods; ET-based, Time-based, Soil Moisture-based, and control that does not utilize a cistern with total water runoff-Mass Balance method. Figure 15 illustrates a graphical 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.

Table 29. Total water runoff (m^3) predicted by Mass-Balance method when using a Time-based, ET-based, Soil Moisture-based, and control that does not utilize a cistern (control) irrigation scheduling methods for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total water runoff-Mass Balance (m^3) by utilizing ET-based method	Total water runoff-Mass Balance (m^3) by utilizing Time-based method	Total water runoff-Mass Balance (m^3) by utilizing Soil Moisture-based method	Total water runoff-Mass Balance (m^3) by utilizing Control method
0 L Cistern	Sand	3.57	3.2	4.24	4.4
	Sandy Loam	9.65	8.36	10.5	11.68
	Loamy Sand	7.18	6.3	8.18	8.74
	Silty Clay	13.13	14.84	14.27	15.74
208 L Cistern	Sand	2.88	1.95	3.16	4.4
	Sandy Loam	8.48	5.91	9.03	11.68
	Loamy Sand	6.18	4.28	6.56	8.74
	Silty Clay	12.38	11.68	13.17	15.74
416 L Cistern	Sand	2.52	1.07	2.42	4.4
	Sandy Loam	7.58	4.12	7.74	11.68
	Loamy Sand	5.28	2.67	5.34	8.74
	Silty Clay	11.34	9.58	11.98	15.74
624 L Cistern	Sand	2.23	0.57	2.03	4.4
	Sandy Loam	6.77	2.52	6.78	11.68
	Loamy Sand	4.67	1.45	4.56	8.74
	Silty Clay	10.46	8.17	10.99	15.74
833 L Cistern	Sand	2.16	0.3	1.99	4.4
	Sandy Loam	6.14	1.62	6.17	11.68
	Loamy Sand	4.16	0.58	4.09	8.74
	Silty Clay	9.89	7.04	10.21	15.74

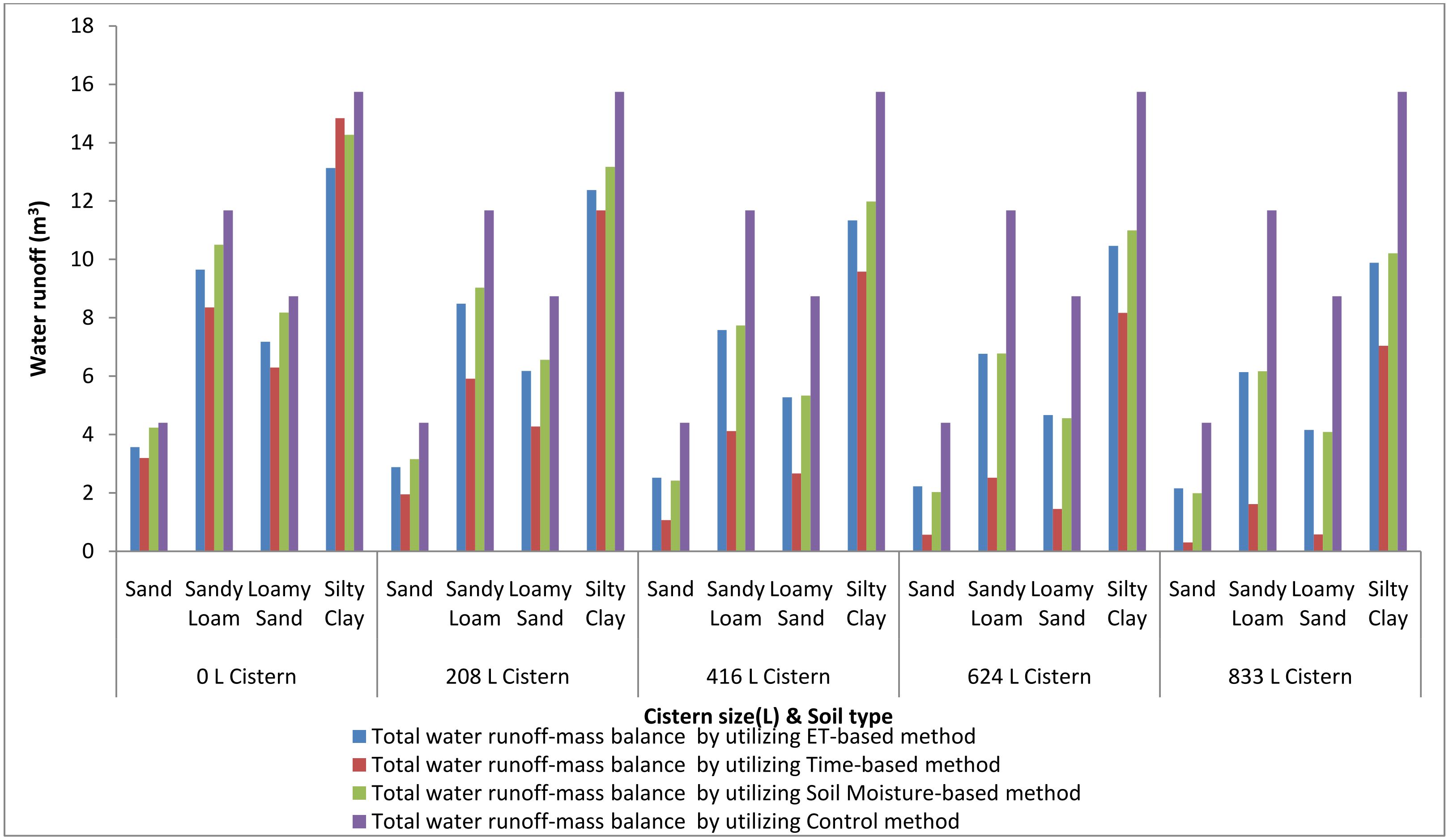

Figure 15. Comparison between different irrigation scheduling methods and total volumes of water runoff-Mass Balance method by utilizing different cistern sizes.

Comparison Between Total Volumes of Supplemental Water by Utilizing Different Irrigation Scheduling Methods

Table 30 below shows a comparison between four irrigation scheduling methods; ET-based, Time-based, Soil Moisture-based, and control that does not utilize a cistern with total water runoff-Mass Balance method. 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.

Figure 16 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 this figure; 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.

Table 30. Total supplemental water (m^3) predicted by Mass-Balance method when using a Time-based, ET-based, Soil Moisture-based, and control that does not utilize a cistern (control) irrigation scheduling methods for different soil types and cistern sizes.

Cistern size (L)	Soil type	Total supplemental water (m^3) by utilizing ET-based method	Total supplemental water (m^3) by utilizing Time-based method	Total supplemental water (m^3) by utilizing Soil Moisture-based method	Total Supplemental water (m^3) by utilizing Control method
0 L Cistern	Sand	34.68	19.97	42.76	19.97
	Sandy Loam	38.88	43.58	20.37	43.58
	Loamy Sand	37.13	33.59	22.06	33.59
	Silty Clay	39.9	90.79	18.07	90.79
208 L Cistern	Sand	25.8	11.14	36.69	19.97
	Sandy Loam	32.6	34.4	16.81	43.58
	Loamy Sand	30.34	24.15	17.51	33.59
	Silty Clay	36.12	81.87	15.50	90.79
416 L Cistern	Sand	19.71	8.52	33.87	19.97
	Sandy Loam	27.7	28.11	14.52	43.58
	Loamy Sand	25.28	19.26	14.61	33.59
	Silty Clay	32.71	76.03	13.22	90.79
624 L Cistern	Sand	16.15	6.82	32.09	19.97
	Sandy Loam	23.57	25.71	12.67	43.58
	Loamy Sand	21.67	17.26	12.57	33.59
	Silty Clay	29.53	72.47	11.73	90.79
833 L Cistern	Sand	14	6.08	30.53	19.97
	Sandy Loam	20.63	24.15	11.11	43.58
	Loamy Sand	18.77	15.91	11.10	33.59
	Silty Clay	26.46	70.04	10.21	90.79

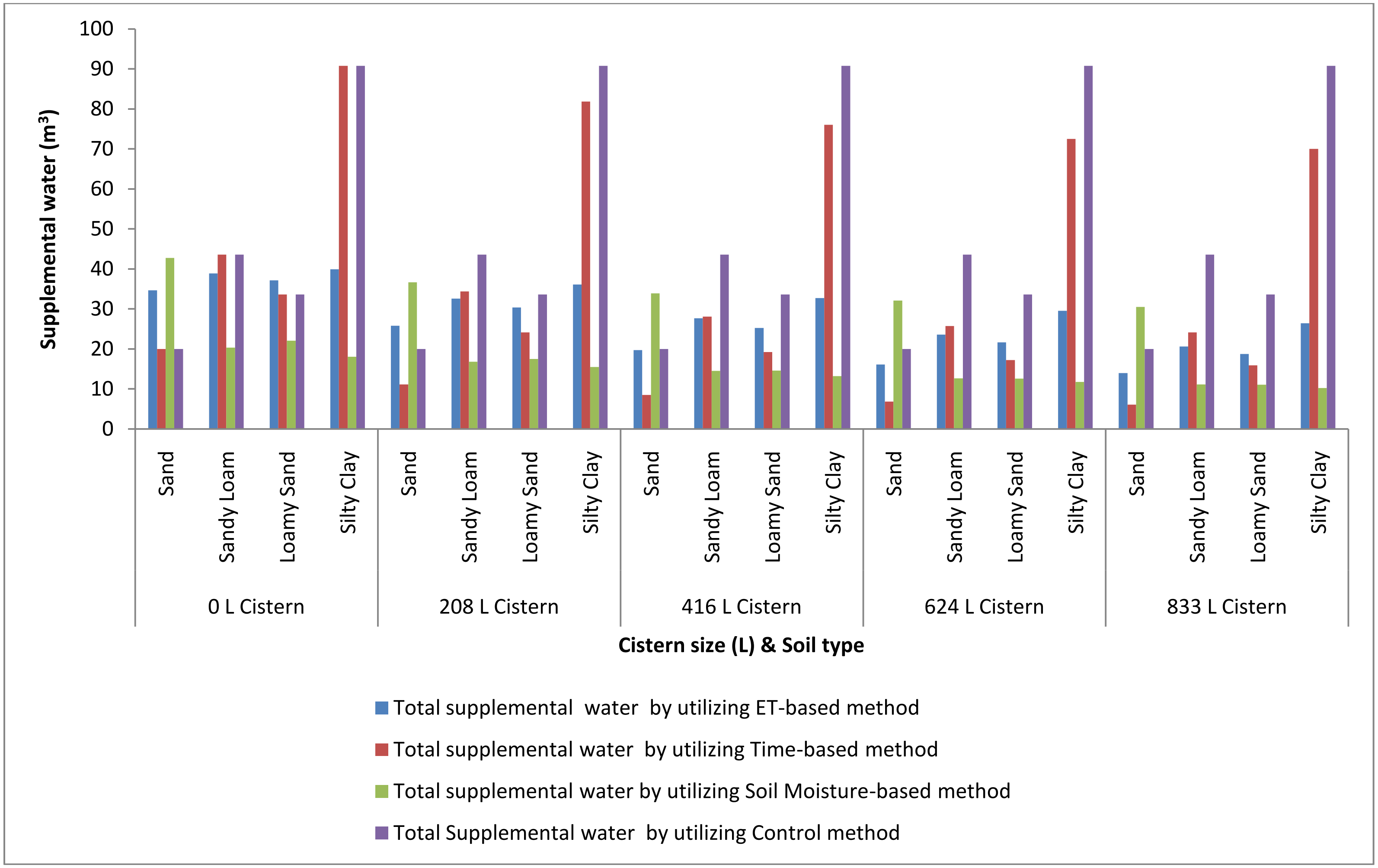

Figure 16. Comparison between different irrigation scheduling methods and total supplemental water by utilizing different cistern sizes.

DISCUSSION

RWH Model Development

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 (Table 3). The model presented several assumptions to solve equations for weather data on a daily basis for the period of (April 08- April 10). For all the treatments the following assumptions were considered to estimate total volumes of water runoff and potable water used for irrigation. First, the soil storage can not exceed the volume associated with saturation and deep percolation is equal to the difference between Field Capacity and saturation. Second, when the cistern fills up; uniform overflowing will start occurring over the plot which in turn contributes to the total runoff over the plot. Third, when the cistern storage volume is insufficient to meet irrigation requirements; supplemental water needs to be added. Fourth, operating assumption for the cistern was considered to be full of water to facilitate further calculations and to provide sufficient water to perform the initial irrigation.

The model estimated total volumes of water runoff leaving the roofs and the turfgrass irrigated area (Equation 2 and 9). Total irrigation demand was calculated on a daily basis for the Crowne zoysia grass using equation 1. Volume of overflow from the cistern during storm events was predicted as well as another source of water runoff happening on the plot (Equation 4). Volume of rainwater captured and used for irrigation and volume of potable water used for irrigation were predicted as input water entering the soil (Equation 3 and 7). From the mentioned equations and assumptions a logical RWH model was developed using a Mass-Balance approach. With this model, the efficiency of the system was evaluated in terms of reducing total water leaving plots and volume of potable water used for irrigation.

Runoff-Mass Balance vs. Runoff-Curve Number

Two methods were considered to predict total volume of water runoff leaving irrigated turfgrass; Curve Number (CN) and Mass-Balance (MB) methods. CN method is a function of the following parameters; soil type, soil cover, soil management and antecedent soil moisture conditions. While MB method accounts for all water that enters and exits a soil profile which would reflect the actual hydrological water movement in soil, losses, gains and eventually total water runoff that would result.

Coarse soil texture such as Sand has low water holding capacity which allows high free drainage to occur and less surface runoff to happen, while fine soil texture such as Clay has high water holding capacity that allows storing more water and results in more runoff. In the previous analysis of estimating total water runoff; this rule as well applies. It can be noticed from all the comparisons made between CN method and MB method that Silty Clay soil resulted in the greatest volume of runoff estimated, while Sand had the least volume of water runoff estimated.

The differences between both methods can be related to the assumptions that Curve Number method was based on, and these assumptions do not consider many important factors that would affect total water runoff. For instance, Curve Number method does not consider all the abstractions, losses that would affect the study area. Moreover, this method describes average trends of total depth loss and gain which prevents it from being perfectly predictive.

On the other hand, MB approach considers all the hydrological inputs and outputs that would affect total water runoff. For example, this study involved the following factors to estimate total water runoff: rainfall, overflow from cistern, field capacity of soil, current available water content, and free drainage. All these factors together reflect the actual situation of soil and can result in better and more precise prediction for total water runoff. All in all, Mass-Balance approach represents a valuable tool that can be used to design and evaluate BMPs’ effectiveness. It reflects the actual hydrological water movement in soil, losses, gains and eventually total water runoff that would result.

As presented in the results section and in Appendix C, the comparison between

CN and MB methods was based on considering: irrigation scheduling method, cistern size, soil depth, soil type and depletion ratio. MB predicted greater volumes of water runoff for all soil types except for Silty Clay soil by utilizing all cistern sizes than the CN method with respect to ET-based and Soil Moisture-based irrigation scheduling methods. When utilizing Time-based irrigation scheduling method, the CN method predicted least volumes of total runoff for all cistern sizes utilized except for (208,416, 624, 833L cistern sizes and Silty Clay), (624L cistern and Sand and Sandy Loam soils), and lastly by utilizing (833L cistern and Sand and Sandy Loam soils), where MB method predicted least total volumes of water runoff. Finally, the MB method predicted greater total volumes of water runoff than the CN method for the control treatment that does not utilize a cistern.

Irrigation Scheduling Method vs. Total supplemental Water and Water Runoff

The use of different irrigation scheduling methods and its impact on total water runoff and supplemental water was investigated. Based on the results presented above, it can be seen that the predicted volumes of water runoff and potable were the least for Sand soil and greatest for Silty Clay soil, for the ET-based, Time-based and control irrigation scheduling methods, while the predicted supplemental water volumes were the least for Silty Clay and greatest for Sand.

Moreover, Appendix C showed a comparison between different irrigation scheduling methods with respect to cistern size, soil depth, soil type, and depletion ratio. The results of this appendix are in agreement with the results discussed in the previous section. For instance Table C-1 showed that ET-based treatment had the least total volume of water runoff-Mass Balance method predicted with the amount of 0 m3 with respect to Sand soil, 60% depletion, 30.5 soil depth and 0 L cistern among all treatments that utilized 0 L cistern, while Time-based and control treatment had the greatest volume of water runoff predicted with respect to Silty Clay soil, 40, 50, 60, 75% depletion, and 0 L cistern. When utilizing 208 L cistern, Time-based treatment with respect to Sand soil, 40, 50, 60, 75% depletion and 30.5 cm soil depth had the least volume of water runoff-Mass Balance method predicted with the amount of 0 m3. Also, ET-based treatment with respect to Sand soil 60% depletion, and 30.5 cm soil depth continued to have the least volume of water runoff-Mass Balance method predicted with amount of 0 m3. By increasing the cistern size to 416 L and 624 L, the following treatments continued to have the least total volume of water runoff predicted with the amount of 0 m3: when utilizing Time-based treatment, Sand soil, 40, 50, 60, 75% depletion and 30.5cm soil depth. Furthermore, ET-based treatment with respect to Sand soil, 50, 60, 75% depletion and 30.5 had the least volume of water runoff-Mass Balance method predicted. When utilizing 833 L cistern, all treatments mentioned for 416 L and 624 L cistern sizes continued to have the least volume of water runoff predicted -Mass Balance method, in addition to Time-based treatment with respect to Loamy Sand soil, 40, 50, 60, 75% depletion and 30.5cm soil depth.

Also, irrigation scheduling method had an impact on total volume of potable water used for irrigation (supplemental water). By utilizing: Time-based treatment and Sandy Loam soil, Control treatment and Sandy Loam soil, Soil Moisture-based and Sand soil, and ET-based treatment Sand soil the total volumes of potable water predicted were the greatest among all cistern sizes utilized, while by utilizing Silty Clay soil in respect to all irrigation scheduling methods, the total volumes of potable water predicted were the least among all cistern sizes utilized.

Appendix B and Table C-6 in Appendix C discussed the impacts of irrigation scheduling methods with respect to soil type, depletion ratio, soil depth, and cistern size. The predicted supplemental water was the greatest for the Control treatment that does not utilize a cistern among all cistern sizes utilized except when utilizing 0L cistern and Sand soil, while Soil Moisture-based treatment on average had the least volume of predicted supplemental water except when utilizing sand soil. 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.

CONCLUSIONS

Stormwater runoff has negative impacts on the water resources, human health and environment. This research investigated the effectiveness of a Rain Water Harvesting (RWH) system as a stormwater Best Management Practice. Soil type, soil depth, depletion ratio, irrigation scheduling method, and cistern size are the factors that were studied using a RWH model to determine the effectiveness of RWH system in reducing potable water used for irrigation and total volume of water runoff from an irrigated turfgrass plot. 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.

FUTURE RESEARCH

RWH as a stormwater BMP is a new concept in the United States and as a result not extensively studied. Within this work, many areas and variables were considered to evaluate the effectiveness of a RWH system in reducing the volume of water runoff and potable water used for irrigation (supplemental water). On the other hand, many areas need to be addressed. The following areas need to be considered:

- Implement a field experiment that can validate the RWH model predictions of decreasing water runoff when using a cistern to collect rainfall.
- Study the effects of using different types of turfgrass to evaluate the effectiveness of the RWH system. This study considered only one type of turfgrass which is Crowne zoysia grass.
- Investigate the runoff water quality. The mass loading of contaminants leaving the plots is an important aspect that needs to be addressed.
- Analysis of different roof areas, cistern volumes and yard area sizes to optimize the reduction in water runoff.

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APPENDIX A

EVALUATION OF PREDICTED WATER RUNOFF VOLUMES

Comparison of runoff estimates

Each irrigation method (Time-based, ET-based, Soil moisture-based, and control "Time-based that does not utilize a cistern") had a different impact on the total volume of runoff leaving the plots. Runoff volume was estimated in two methods; Mass-Balance method and Soil Conservation Service Curve Number method (SCS-CN). Volume of water runoff according to Mass-Balance method was estimated for each treatment by considering a cistern size of 416 L and the results came as follows:

Table A-1. Runoff estimates (m^3) - Mass Balance method for the period (April 08-April 10) by utilizing time-based irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	15.2	1.07	4.12	2.67	9.61
Time-based	40	22.9	0.16	1.39	0.60	5.27
Time-based	40	30.5	0.00	0.29	0.01	2.83
Time-based	50	15.2	1.07	4.12	2.67	9.58
Time-based	50	22.9	0.16	1.39	0.60	5.05
Time-based	50	30.5	0.00	0.29	0.01	2.75
Time-based	60	15.2	1.07	4.12	2.67	9.31
Time-based	60	22.9	0.16	4.01	0.60	5.03
Time-based	60	30.5	0.00	0.29	0.01	2.69
Time-based	75	15.2	1.07	4.12	2.67	9.01
Time-based	75	22.9	0.16	1.39	0.60	4.88
Time-based	75	30.5	0.00	0.29	0.01	2.69

Table A-2. Runoff estimates (m^3) - Mass Balance method for the period (April 08-April 10) by utilizing ET-based irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
ET	40	15.2	2.52	7.55	5.14	11.48
ET	40	22.9	0.52	3.76	1.98	6.65
ET	40	30.5	0.10	1.51	0.64	4.21
ET	50	15.2	2.52	7.58	5.28	11.34
ET	50	22.9	0.66	3.75	1.98	6.67
ET	50	30.5	0.10	1.51	0.60	4.27
ET	60	15.2	2.28	7.58	4.98	11.66
ET	60	22.9	0.66	3.91	1.98	6.69
ET	60	30.5	0.10	1.51	0.74	4.33
ET	75	15.2	2.30	7.33	5.26	10.23
ET	75	22.9	0.66	3.67	1.78	6.84
ET	75	30.5	0.10	1.40	0.74	4.01

Table A-3. Runoff estimates (m^3) - Mass Balance method for the period (April 08-April 10) by utilizing soil moisture-based irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Soil Moisture	40	15.2	2.42	7.92	5.31	11.44
Soil Moisture	40	22.9	0.66	3.85	1.98	6.74
Soil Moisture	40	30.5	0.10	1.51	0.74	3.89
Soil Moisture	50	15.2	2.42	7.74	5.34	11.98
Soil Moisture	50	22.9	0.66	3.67	1.98	6.83
Soil Moisture	50	30.5	0.10	1.41	0.74	4.06
Soil Moisture	60	15.2	2.29	7.76	5.57	11.54
Soil Moisture	60	22.9	0.66	3.69	1.98	6.75
Soil Moisture	60	30.5	0.10	1.51	0.74	4.12

Table A-3 Continued

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Soil Moisture	75	15.2	2.23	7.88	5.66	11.54
Soil Moisture	75	22.9	0.66	4.06	1.78	6.68
Soil Moisture	75	30.5	0.10	1.40	0.74	4.21

Table A-4. Runoff estimates (m^3) - Mass Balance method for the period (April 08-April 10) by utilizing Control irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Control	40	15.2	4.40	11.68	8.74	14.75
Control	40	22.9	0.79	6.41	3.50	10.24
Control	40	30.5	0.10	2.71	0.95	6.68
Control	50	15.2	4.40	11.68	8.74	15.74
Control	50	22.9	0.79	6.41	3.50	10.24
Control	50	30.5	0.10	2.71	0.95	6.68
Control	60	15.2	4.40	11.68	8.74	15.86
Control	60	22.9	0.79	6.41	3.50	10.24
Control	60	30.5	0.10	2.71	0.95	6.68
Control	75	15.2	4.40	11.68	8.74	16.03
Control	75	22.9	0.79	6.41	3.50	10.25
Control	75	30.5	0.10	2.71	0.95	6.68

Volume of water runoff according to Soil Conservation Service Curve Number method (SCS-CN) was estimated for each treatment by considering a cistern size of 416

L and the results came as follows:

Table A-5. Runoff estimates (m^3) – SCS-CN method for the period (April 08-April 10) by utilizing time-based irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	15.2	1.00	3.90	2.49	10.57
Time-based	40	22.9	1.00	3.90	2.49	9.70
Time-based	40	30.5	1.00	3.90	2.49	9.43
Time-based	50	15.2	1.00	3.90	2.49	10.06
Time-based	50	22.9	1.00	3.90	2.49	9.45
Time-based	50	30.5	1.00	3.90	2.49	9.35
Time-based	60	15.2	1.00	3.90	2.49	9.70
Time-based	60	22.9	1.00	6.62	2.49	9.39
Time-based	60	30.5	1.00	3.90	2.49	9.27
Time-based	75	15.2	1.00	3.90	2.49	9.45
Time-based	75	22.9	1.00	3.90	2.49	9.30
Time-based	75	30.5	1.00	3.90	2.49	9.16

Table A-6. Runoff estimates (m^3) – SCS-CN method for the period (April 08-April 10) by utilizing soil moisture-based irrigation scheduling.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Soil Moisture	40	15.2	1.79	6.72	4.27	12.92
Soil Moisture	40	22.9	1.76	7.14	4.64	13.43
Soil Moisture	40	30.5	1.79	7.39	4.66	13.58
Soil Moisture	50	15.2	1.78	6.93	4.31	13.21
Soil Moisture	50	22.9	1.78	7.11	4.54	13.43

Table A-6 Continued

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Soil Moisture	50	30.5	1.86	7.31	4.62	13.81
Soil Moisture	60	15.2	1.75	6.83	4.33	13.12
Soil Moisture	60	22.9	1.78	6.93	4.52	13.45
Soil Moisture	60	30.5	1.82	7.35	4.49	13.78
Soil Moisture	75	15.2	1.72	6.88	4.43	13.22
Soil Moisture	75	22.9	1.83	7.35	4.34	13.83
Soil Moisture	75	30.5	1.85	7.22	4.82	13.76

Table A-7. Runoff estimates (m^3) – SCS-CN method for the period (April 08-April 10) by utilizing ET-based irrigation scheduling.

Irrigation Scheduling	Depletion %	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
ET	40	15.2	1.87	7.00	4.22	12.93
ET	40	22.9	1.71	6.90	4.60	13.73
ET	40	30.5	1.94	7.12	4.51	13.61
ET	50	15.2	1.87	7.06	4.32	13.18
ET	50	22.9	1.78	7.17	4.43	13.65
ET	50	30.5	1.97	7.54	4.69	13.81
ET	60	15.2	1.81	7.09	4.26	13.03
ET	60	22.9	1.75	7.32	4.41	13.82
ET	60	30.5	1.97	7.65	4.81	13.89
ET	75	15.2	1.81	7.01	4.39	13.00
ET	75	22.9	1.82	7.34	4.56	13.79
ET	75	30.5	1.95	7.69	4.82	13.72

Table A-8. Runoff estimates (m^3) – SCS-CN method for the period (April 08-April 10) by utilizing Control irrigation scheduling.

Irrigation Scheduling	Depletion %	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Control	40	15.2	2.54	8.70	5.76	15.36
Control	40	22.9	2.54	8.70	5.76	15.36
Control	40	30.5	2.54	8.70	5.76	15.36
Control	50	15.2	2.54	8.70	5.76	15.36
Control	50	22.9	2.54	8.70	5.76	15.36
Control	50	30.5	2.54	8.70	5.76	15.36
Control	60	15.2	2.54	8.70	5.76	15.36
Control	60	22.9	2.54	8.70	5.76	15.36
Control	60	30.5	2.54	8.70	5.76	15.36
Control	75	15.2	2.54	8.70	5.76	15.36
Control	75	22.9	2.54	8.70	5.76	15.36
Control	75	30.5	2.54	8.70	5.76	15.36

Irrigation Scheduling vs. Runoff

The impact of irrigation scheduling method on water runoff according to Mass-Balance was estimated for each treatment by considering a cistern size of 416 L and the results came as follows:

Table A-9. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 40% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	15.2	1.07	4.12	2.67	9.61
Soil Moisture	40	15.2	2.42	7.92	5.31	11.44
ET	40	15.2	2.52	7.55	5.14	11.48
Control	40	15.2	4.40	11.68	8.74	14.75

Table A-10. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 40% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	22.9	0.16	0.60	1.39	5.27
Soil Moisture	40	22.9	0.66	1.98	3.85	6.74
ET	40	22.9	0.52	1.98	3.76	6.65
Control	40	22.9	0.79	3.50	6.41	10.24

Table A-11. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 40% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	30.5	0.00	0.29	0.01	2.83
Soil Moisture	40	30.5	0.10	1.51	0.74	3.89
ET	40	30.5	0.10	1.51	0.64	4.21
Control	40	30.5	0.10	2.71	0.95	6.68

Table A-12. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 50% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	15.2	1.07	4.12	2.67	9.58
Soil Moisture	50	15.2	2.42	7.74	5.34	11.98
ET	50	15.2	2.52	7.58	5.28	11.34
Control	50	15.2	4.40	11.68	8.74	15.74

Table A-13. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 50% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	22.9	0.16	1.39	0.60	5.05
Soil Moisture	50	22.9	0.66	3.67	1.98	6.83
ET	50	22.9	0.66	3.75	1.98	6.67
Control	50	22.9	0.79	6.41	3.50	10.24

Table A-14. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 50% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	30.5	0.00	0.29	0.01	2.75
Soil Moisture	50	30.5	0.10	1.41	0.74	4.06
ET	50	30.5	0.10	1.51	0.60	4.27
Control	50	30.5	0.10	2.71	0.95	6.68

Table A-15. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 60% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	15.2	1.07	4.12	2.67	9.31
Soil Moisture	60	15.2	2.29	7.76	5.57	11.54
ET	60	15.2	2.28	7.58	4.98	11.66
Control	60	15.2	4.40	11.68	8.74	15.86

Table A-16. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 60% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	22.9	0.16	4.01	0.60	5.03
Soil Moisture	60	22.9	0.66	3.69	1.98	6.75
ET	60	22.9	0.66	3.91	1.98	6.69
Control	60	22.9	0.79	6.41	3.50	10.24

Table A-17. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 60% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	30.5	0.00	0.29	0.01	2.69
Soil Moisture	60	30.5	0.10	1.51	0.74	4.12
ET	60	30.5	0.10	1.51	0.74	4.33
Control	60	30.5	0.10	2.71	0.95	6.68

Table A-18. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 75% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	15.2	1.07	4.12	2.67	9.01
Soil Moisture	75	15.2	2.23	7.88	5.66	11.54
ET	75	15.2	2.30	7.33	5.26	10.23
Control	75	15.2	4.40	11.68	8.74	16.03

Table A-19. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 75% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	22.9	0.16	1.39	0.60	4.88
Soil Moisture	75	22.9	0.66	4.06	1.78	6.68
ET	75	22.9	0.66	3.67	1.78	6.84
Control	75	22.9	0.79	6.41	3.50	10.25

Table A-20. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying Mass Balance method for the period (April 08-April 10) by utilizing 75% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	30.5	0.00	0.29	0.01	2.69
Soil Moisture	75	30.5	0.10	1.40	0.74	4.21
ET	75	30.5	0.10	1.40	0.74	4.01
Control	75	30.5	0.10	2.71	0.95	6.68

The impact of irrigation scheduling method on water runoff according to Soil Conservation Service Curve Number (SCS-CN) method was estimated for each treatment and the results came as follows:

Table A-21. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 40% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	15.2	1.00	3.90	2.49	10.57
Soil Moisture	40	15.2	1.79	6.72	4.27	12.92
ET	40	15.2	1.87	7.00	4.22	12.93
Control	40	15.2	2.54	8.70	5.76	15.36

Table A-22. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 40% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	22.9	1.00	3.90	2.49	9.70
Soil Moisture	40	22.9	1.76	7.14	4.64	13.43
ET	40	22.9	1.71	6.90	4.60	13.73
Control	40	22.9	2.54	8.70	5.76	15.36

Table A-23. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 40% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	30.5	1.00	3.90	2.49	9.43
Soil Moisture	40	30.5	1.79	7.39	4.66	13.58
ET	40	30.5	1.94	7.12	4.51	13.61
Control	40	30.5	2.54	8.70	5.76	15.36

Table A-24. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 50% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	15.2	1.00	3.90	2.49	10.06
Soil Moisture	50	15.2	1.78	6.93	4.31	13.21
ET	50	15.2	1.87	7.06	4.32	13.18
Control	50	15.2	2.54	8.70	5.76	15.36

Table A-25. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 50% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	22.9	1.00	3.90	2.49	9.45
Soil Moisture	50	22.9	1.78	7.11	4.54	13.43
ET	50	22.9	1.78	7.17	4.43	13.65
Control	50	22.9	2.54	8.70	5.76	15.36

Table A-26. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 50% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	30.5	1.00	3.90	2.49	9.35
Soil Moisture	50	30.5	1.86	7.31	4.62	13.81
ET	50	30.5	1.97	7.54	4.69	13.81
Control	50	30.5	2.54	8.70	5.76	15.36

Table A-27. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 60% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	15.2	1.00	3.90	2.49	9.70
Soil Moisture	60	15.2	1.75	6.83	4.33	13.12
ET	60	15.2	1.81	7.09	4.26	13.03
Control	60	15.2	2.54	8.70	5.76	15.36

Table A-28. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 60% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	22.9	1.00	6.62	2.49	9.39
Soil Moisture	60	22.9	1.78	6.93	4.52	13.45
ET	60	22.9	1.75	7.32	4.41	13.82
Control	60	22.9	2.54	8.70	5.76	15.36

Table A-29. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 60% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	**Depletion%**	**Soil Depth(cm)**	**Runoff estimates (m^3) for different soil types**			
			Sand	**Sandy Loam**	**Loamy Sand**	**Silty-clay**
Time-based	60	30.5	1.00	3.90	2.49	9.27
Soil Moisture	60	30.5	1.82	7.35	4.49	13.78
ET	60	30.5	1.97	7.65	4.81	13.89
Control	60	30.5	2.54	8.70	5.76	15.36

Table A-30. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 75% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	**Depletion%**	**Soil Depth(cm)**	**Runoff estimates (m^3) for different soil types**			
			Sand	**Sandy Loam**	**Loamy Sand**	**Silty-clay**
Time-based	75	15.2	1.00	3.90	2.49	9.45
Soil Moisture	75	15.2	1.72	6.88	4.43	13.22
ET	75	15.2	1.81	7.01	4.39	13.00
Control	75	15.2	2.54	8.70	5.76	15.36

Table A-31. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 75% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	**Depletion%**	**Soil Depth(cm)**	**Runoff estimates (m^3) for different soil types**			
			Sand	**Sandy Loam**	**Loamy Sand**	**Silty-clay**
Time-based	75	22.9	1.00	3.90	2.49	9.30
Soil Moisture	75	22.9	1.83	7.35	4.34	13.83
ET	75	22.9	1.82	7.34	4.56	13.79
Control	75	22.9	2.54	8.70	5.76	15.36

Table A-32. Comparison of the impacts of four irrigation scheduling methods on the total runoff (m^3) – applying SCS-CN method for the period (April 08-April 10) by utilizing 75% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Runoff estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	30.5	1.00	3.90	2.49	9.16
Soil Moisture	75	30.5	1.85	7.22	4.82	13.76
ET	75	30.5	1.95	7.69	4.82	13.72
Control	75	30.5	2.54	8.70	5.76	15.36

APPENDIX B

EVALUATION OF PREDICTED POTABLE IRRIGATION WATER DEMAND RELATIVE TO IRRIGATION SCHEDULING METHOD

Irrigation Scheduling vs. Supplemental Water

The impact of irrigation scheduling method on total supplemental water used was estimated for each treatment and the results came as follows:

Table B-1. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 40% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	15.2	72.67	161.69	116.90	15.52
Soil Moisture	40	15.2	16.12	14.51	14.96	12.88
ET	40	15.2	6.30	5.80	6.13	5.29
Control	40	15.2	87.48	174.96	131.22	29.05

Table B-2. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 40% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	22.9	72.67	161.69	116.90	28.11
Soil Moisture	40	22.9	14.96	13.07	13.85	10.68
ET	40	22.9	6.07	5.37	5.93	3.85
Control	40	22.9	87.48	174.96	131.22	43.58

Table B-3. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 40% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	40	30.5	72.67	161.69	116.90	43.03
Soil Moisture	40	30.5	14.51	11.75	13.07	9.18
ET	40	30.5	5.84	4.85	5.37	5.39
Control	40	30.5	87.48	174.96	131.22	58.11

Table B-4. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 50% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	15.2	72.67	161.69	116.90	21.56
Soil Moisture	50	15.2	15.92	14.52	14.61	13.22
ET	50	15.2	6.29	5.54	5.72	4.80
Control	50	15.2	87.48	174.96	131.22	36.32

Table B-5. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 50% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	22.9	72.67	161.69	116.90	39.27
Soil Moisture	50	22.9	14.61	12.77	14.00	11.08
ET	50	22.9	5.72	5.37	5.65	3.65
Control	50	22.9	87.48	174.96	131.22	54.47

Table B-6. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 50% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	50	30.5	72.67	161.69	116.90	57.83
Soil Moisture	50	30.5	14.52	11.27	12.77	9.49
ET	50	30.5	5.54	4.19	5.37	4.26
Control	50	30.5	87.48	174.96	131.22	72.63

Table B-7. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 60% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	15.2	72.67	161.69	116.90	28.11
Soil Moisture	60	15.2	15.64	14.56	15.30	12.44
ET	60	15.2	6.10	5.51	5.41	4.44
Control	60	15.2	87.48	174.96	131.22	43.58

Table B-8. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 60% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion %	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	22.9	72.67	174.96	116.90	50.44
Soil Moisture	60	22.9	15.30	13.11	14.05	10.80
ET	60	22.9	5.41	4.96	5.42	3.18
Control	60	22.9	87.48	174.96	131.22	65.37

Table B-9. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 60% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	60	30.5	72.67	161.69	116.90	72.40
Soil Moisture	60	30.5	14.56	12.39	13.11	9.79
ET	60	30.5	5.51	3.82	4.96	4.26
Control	60	30.5	87.48	174.96	131.22	87.16

Table B-10. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 75% depletion, and 15.2 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	15.2	72.67	161.69	116.90	39.27
Soil Moisture	75	15.2	15.54	14.25	14.87	13.00
ET	75	15.2	5.79	5.24	5.40	4.18
Control	75	15.2	87.48	174.96	131.22	54.47

Table B-11. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 75% depletion, and 22.9 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	22.9	72.67	161.69	116.90	66.95
Soil Moisture	75	22.9	14.87	12.59	13.96	10.30
ET	75	22.9	5.40	4.36	5.45	3.10
Control	75	22.9	87.48	174.96	131.22	81.71

Table B-12. Comparison of the impacts of four irrigation scheduling methods on supplemental water (m^3) for the period (April 08-April 10) by utilizing 75% depletion, and 30.5 cm soil depth.

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Supplemental water estimates (m^3) for different soil types			
			Sand	Sandy Loam	Loamy Sand	Silty-clay
Time-based	75	30.5	72.67	161.69	116.90	94.19
Soil Moisture	75	30.5	14.25	12.80	12.59	11.26
ET	75	30.5	5.14	3.00	4.36	4.03
Control	75	30.5	87.48	174.96	131.22	108.95

APPENDIX C

EVALUATION OF PREDICTED WATER RUNOFF VOLUMES RELATIVE TO CISTERN SIZE

Cistern Size vs. Runoff

The impact of using several cistern sizes (0L, 208L, 416L, 624L, 833L) on the total volume of water runoff according to Mass-Balance was estimated for each treatment and the results came as follows:

Table C-1. Comparison of the impacts of cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 0 L cistern size and considering Mass-Balance and Curve Number methods to estimate total water runoff.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 0 L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Time-based	40	15.20	3.20	2.06	8.36	6.62	6.30	4.56	13.96	14.78
Time-based	40	22.90	0.51	2.06	4.01	6.62	2.34	4.56	9.45	14.58
Time-based	40	30.50	0.00	2.06	1.66	6.62	0.52	4.56	5.93	14.42
Time-based	50	15.20	3.20	2.06	8.36	6.62	6.30	4.56	14.84	14.67
Time-based	50	22.90	0.51	2.06	4.01	6.62	2.34	4.56	9.27	14.46

Table C-1. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 0 L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Time-based	50	30.50	0.00	2.06	1.66	6.62	0.52	4.56	5.93	14.31
Time-based	60	15.20	3.20	2.06	8.36	6.62	6.30	4.56	14.83	14.58
Time-based	60	22.90	0.51	2.06	4.01	6.62	2.34	4.56	9.18	14.35
Time-based	60	30.50	0.00	2.06	1.66	6.62	0.52	4.56	5.93	14.28
Time-based	75	15.20	3.20	2.06	8.36	6.62	6.30	4.56	14.81	14.46
Time-based	75	22.90	0.51	2.06	4.01	6.62	2.34	4.56	9.08	14.28
Time-based	75	30.50	0.00	2.06	1.66	6.62	0.52	4.56	5.93	14.28
Soil Moisture	40	15.20	4.22	2.54	10.84	8.70	8.23	5.76	14.10	15.36
Soil Moisture	40	22.90	0.78	2.54	5.20	8.70	2.63	5.76	7.61	15.36
Soil Moisture	40	30.50	0.10	2.54	1.79	8.70	0.82	5.76	4.46	15.36
Soil Moisture	50	15.20	4.24	2.54	10.50	8.70	8.18	5.76	14.27	15.36
Soil Moisture	50	22.90	0.72	2.54	5.06	8.70	3.02	5.76	7.90	15.36
Soil Moisture	50	30.50	0.10	2.54	1.86	8.70	0.85	5.76	4.61	15.36
Soil Moisture	60	15.20	4.18	2.54	10.61	8.70	8.20	5.76	14.11	15.36
Soil Moisture	60	22.90	0.78	2.54	5.59	8.70	2.79	5.76	7.77	15.36
Soil Moisture	60	30.50	0.10	2.54	1.67	8.70	0.92	5.76	4.59	15.36
Soil Moisture	75	15.20	4.16	2.54	10.82	8.70	8.31	5.76	13.80	15.36
Soil Moisture	75	22.90	0.81	2.54	5.12	8.70	2.83	5.76	8.07	15.36

Table C-1. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 0 L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Soil Moisture	75	30.50	0.10	2.54	1.75	8.70	0.74	5.76	4.76	15.36
ET	40	15.20	3.57	2.49	9.77	8.64	7.46	5.58	13.40	15.36
ET	40	22.90	0.69	2.45	4.81	8.68	2.82	5.76	7.45	15.36
ET	40	30.50	0.10	2.45	1.67	8.52	0.74	5.76	4.93	15.36
ET	50	15.20	3.57	2.49	9.65	8.69	7.18	5.58	13.13	15.15
ET	50	22.90	0.69	2.45	4.80	8.68	2.45	5.38	7.63	15.36
ET	50	30.50	0.10	2.54	1.67	8.34	0.74	5.76	5.09	15.29
ET	60	15.20	3.45	2.47	9.26	8.48	7.27	5.61	13.01	15.20
ET	60	22.90	0.67	2.47	4.31	8.61	2.45	5.47	7.69	15.36
ET	60	30.50	0.10	2.45	1.67	8.67	0.74	5.72	5.13	15.36
ET	75	15.20	3.49	2.47	9.26	8.48	6.94	5.44	11.96	15.09
ET	75	22.90	0.66	2.35	4.29	8.58	2.45	5.75	7.69	15.32
ET	75	30.50	0.10	2.45	1.67	8.70	0.74	5.72	4.94	15.19
Control	40	15.20	4.40	2.54	11.68	8.70	8.74	5.76	14.75	15.36
Control	40	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	40	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	50	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.74	15.36
Control	50	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36

Table C-1. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 0 L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Control	50	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	60	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.86	15.36
Control	60	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	60	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	75	15.20	4.40	2.54	11.68	8.70	8.74	5.76	16.03	15.36
Control	75	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.25	15.36
Control	75	30.50	3.20	2.06	8.36	6.62	6.30	4.56	13.96	14.78

Table C-2. Comparison of the impacts of cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 208 L cistern size and considering Mass-Balance and Curve Number methods to estimate total water runoff.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 208L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Time-based	40	15.20	13.96	1.95	5.91	5.06	4.28	3.38	11.21	12.08
Time-based	40	22.90	9.45	0.37	2.70	5.06	1.31	3.38	7.42	11.79

Table C-2. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 208L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Time-based	40	30.50	5.93	0.00	0.85	5.06	0.22	3.38	4.30	11.66
Time-based	50	15.20	14.84	1.95	5.91	5.06	4.28	3.38	11.68	11.88
Time-based	50	22.90	9.27	0.37	2.70	5.06	1.31	3.38	7.29	11.68
Time-based	50	30.50	5.93	0.00	0.85	5.06	0.22	3.38	4.22	11.58
Time-based	60	15.20	14.83	1.95	5.91	5.06	4.28	3.38	11.68	11.79
Time-based	60	22.90	9.18	0.37	4.01	6.62	1.31	3.38	7.27	11.62
Time-based	60	30.50	5.93	0.00	0.85	5.06	0.22	3.38	4.16	11.50
Time-based	75	15.20	14.81	1.95	5.91	5.06	4.28	3.38	11.53	11.68
Time-based	75	22.90	9.08	0.37	2.70	5.06	1.31	3.38	7.13	11.53
Time-based	75	30.50	5.93	0.00	0.85	5.06	0.22	3.38	4.16	11.50
Soil Moisture	40	15.20	14.10	3.07	9.36	7.59	6.53	4.94	12.74	13.99
Soil Moisture	40	22.90	7.61	0.66	4.30	7.86	2.20	5.14	7.24	14.38
Soil Moisture	40	30.50	4.46	0.10	1.67	8.07	0.74	5.18	4.09	14.58
Soil Moisture	50	15.20	14.27	3.16	9.03	7.71	6.56	4.96	13.17	14.28
Soil Moisture	50	22.90	7.90	0.66	4.21	7.87	2.30	5.10	7.49	14.38
Soil Moisture	50	30.50	4.61	0.10	1.62	7.98	0.74	5.19	4.37	14.68
Soil Moisture	60	15.20	14.11	2.99	9.23	7.67	6.93	4.99	12.92	14.20
Soil Moisture	60	22.90	7.77	0.66	4.40	7.80	2.36	5.13	6.95	14.54

Table C-2. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 208L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Soil Moisture	60	30.50	4.59	0.10	1.67	8.17	0.74	5.12	4.52	14.65
Soil Moisture	75	15.20	13.80	2.97	9.40	7.75	6.83	5.07	12.74	14.30
Soil Moisture	75	22.90	8.07	0.66	4.51	8.03	2.06	5.00	7.35	14.66
Soil Moisture	75	30.50	4.76	0.10	1.48	7.93	0.74	5.31	4.55	14.65
ET	40	15.20	13.40	2.88	8.60	7.84	6.18	4.92	12.49	14.33
ET	40	22.90	7.45	0.66	4.40	7.84	2.24	5.18	7.10	14.54
ET	40	30.50	4.93	0.10	1.67	7.89	0.74	5.19	4.63	14.31
ET	50	15.20	13.13	2.88	8.48	7.90	6.18	4.92	12.38	14.17
ET	50	22.90	7.63	0.66	4.40	7.98	2.24	4.94	7.19	14.66
ET	50	30.50	5.09	0.10	1.67	8.02	0.74	5.30	4.79	14.63
ET	60	15.20	13.01	2.62	8.36	7.90	5.81	4.82	12.75	14.11
ET	60	22.90	7.69	0.66	4.07	8.08	2.24	4.96	7.26	14.64
ET	60	30.50	5.13	0.10	1.67	8.21	0.74	5.38	4.85	14.70
ET	75	15.20	11.96	2.60	7.99	7.71	6.03	4.93	11.22	13.78
ET	75	22.90	7.69	0.66	3.95	7.99	2.03	5.13	7.36	14.62
ET	75	30.50	4.94	0.10	1.55	8.24	0.74	5.31	4.43	14.47
Control	40	15.20	14.75	4.40	11.68	8.70	8.74	5.76	14.75	15.36
Control	40	22.90	10.24	0.79	6.41	8.70	3.50	5.76	10.24	15.36

Table C-2. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 208L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Control	40	30.50	6.68	0.10	2.71	8.70	0.95	5.76	6.68	15.36
Control	50	15.20	15.74	4.40	11.68	8.70	8.74	5.76	15.74	15.36
Control	50	22.90	10.24	0.79	6.41	8.70	3.50	5.76	10.24	15.36
Control	50	30.50	6.68	0.10	2.71	8.70	0.95	5.76	6.68	15.36
Control	60	15.20	15.86	4.40	11.68	8.70	8.74	5.76	15.86	15.36
Control	60	22.90	10.24	0.79	6.41	8.70	3.50	5.76	10.24	15.36
Control	60	30.50	6.68	0.10	2.71	8.70	0.95	5.76	6.68	15.36
Control	75	15.20	16.03	4.40	11.68	8.70	8.74	5.76	16.03	15.36
Control	75	22.90	10.25	0.79	6.41	8.70	3.50	5.76	10.25	15.36
Control	75	30.50	6.68	0.10	2.71	8.70	0.95	5.76	6.68	15.36

Table C-3. Comparison of the impacts of Cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 416 L cistern size and considering Mass-Balance and Curve Number methods to estimate total runoff.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 416L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN
Time-based	40	15.20	1.07	1.00	4.12	3.90	2.67	2.49	9.61	10.57
Time-based	40	22.90	0.16	1.00	1.39	3.90	0.60	2.49	5.27	9.70
Time-based	40	30.50	0.00	1.00	0.29	3.90	0.01	2.49	2.83	9.43
Time-based	50	15.20	1.07	1.00	4.12	3.90	2.67	2.49	9.58	10.06
Time-based	50	22.90	0.16	1.00	1.39	3.90	0.60	2.49	5.05	9.45
Time-based	50	30.50	0.00	1.00	0.29	3.90	0.01	2.49	2.75	9.35
Time-based	60	15.20	1.07	1.00	4.12	3.90	2.67	2.49	9.31	9.70
Time-based	60	22.90	0.16	1.00	4.01	6.62	0.60	2.49	5.03	9.39
Time-based	60	30.50	0.00	1.00	0.29	3.90	0.01	2.49	2.69	9.27
Time-based	75	15.20	1.07	1.00	4.12	3.90	2.67	2.49	9.01	9.45
Time-based	75	22.90	0.16	1.00	1.39	3.90	0.60	2.49	4.88	9.30
Time-based	75	30.50	0.00	1.00	0.29	3.90	0.01	2.49	2.69	9.16
Soil Moisture	40	15.20	2.42	1.79	7.92	6.72	5.31	4.27	11.44	12.92
Soil Moisture	40	22.90	0.66	1.76	3.85	7.14	1.98	4.64	6.74	13.43
Soil Moisture	40	30.50	0.10	1.79	1.51	7.39	0.74	4.66	3.89	13.58

Table C-3. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 416L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN
Soil Moisture	50	15.20	2.42	1.78	7.74	6.93	5.34	4.31	11.98	13.21
Soil Moisture	50	22.90	0.66	1.78	3.67	7.11	1.98	4.54	6.83	13.43
Soil Moisture	50	30.50	0.10	1.86	1.41	7.31	0.74	4.62	4.06	13.81
Soil Moisture	60	15.20	2.29	1.75	7.76	6.83	5.57	4.33	11.54	13.12
Soil Moisture	60	22.90	0.66	1.78	3.69	6.93	1.98	4.52	6.75	13.45
Soil Moisture	60	30.50	0.10	1.82	1.51	7.35	0.74	4.49	4.12	13.78
Soil Moisture	75	15.20	2.23	1.72	7.88	6.88	5.66	4.43	11.54	13.22
Soil Moisture	75	22.90	0.66	1.83	4.06	7.35	1.78	4.34	6.68	13.83
Soil Moisture	75	30.50	0.10	1.85	1.40	7.22	0.74	4.82	4.21	13.76
ET	40	15.20	2.52	1.87	7.55	7.00	5.14	4.22	11.48	12.93
ET	40	22.90	0.52	1.71	3.76	6.90	1.98	4.60	6.65	13.73
ET	40	30.50	0.10	1.94	1.51	7.12	0.64	4.51	4.21	13.61
ET	50	15.20	2.52	1.87	7.58	7.06	5.28	4.32	11.34	13.18
ET	50	22.90	0.66	1.78	3.75	7.17	1.98	4.43	6.67	13.65
ET	50	30.50	0.10	1.97	1.51	7.54	0.60	4.69	4.27	13.81
ET	60	15.20	2.28	1.81	7.58	7.09	4.98	4.26	11.66	13.03
ET	60	22.90	0.66	1.75	3.91	7.32	1.98	4.41	6.69	13.82
ET	60	30.50	0.10	1.97	1.51	7.65	0.74	4.81	4.33	13.89

Table C-3. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 416L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN	Mass-Bal.	CN
ET	75	15.20	2.30	1.81	7.33	7.01	5.26	4.39	10.23	13.00
ET	75	22.90	0.66	1.82	3.67	7.34	1.78	4.56	6.84	13.79
ET	75	30.50	0.10	1.95	1.40	7.69	0.74	4.82	4.01	13.72
Control	40	15.20	4.40	2.54	11.68	8.70	8.74	5.76	14.75	15.36
Control	40	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	40	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	50	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.74	15.36
Control	50	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	50	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	60	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.86	15.36
Control	60	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	60	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	75	15.20	4.40	2.54	11.68	8.70	8.74	5.76	16.03	15.36
Control	75	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.25	15.36
Control	75	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36

Table C-4. Comparison of the impacts of Cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 624 L cistern size and considering Mass-Balance and Curve Number methods to estimate total runoff.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 624L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-balance	CN	Mass-balance	CN	Mass-balance	CN	Mass-balance	CN
Time-based	40	15.20	0.57	0.67	2.52	3.01	1.45	1.85	8.48	9.66
Time-based	40	22.90	0.00	0.67	0.55	3.01	0.20	1.85	3.92	8.50
Time-based	40	30.50	0.00	0.67	0.00	3.01	0.00	1.85	1.85	7.84
Time-based	50	15.20	0.57	0.67	2.52	3.01	1.45	1.85	8.17	9.09
Time-based	50	22.90	0.00	0.67	0.55	3.01	0.20	1.85	3.48	7.94
Time-based	50	30.50	0.00	0.67	0.00	3.01	0.00	1.85	1.73	7.66
Time-based	60	15.20	0.57	0.67	2.52	3.01	1.45	1.85	7.57	8.50
Time-based	60	22.90	0.00	0.67	4.01	6.62	0.20	1.85	3.34	7.73
Time-based	60	30.50	0.00	0.67	0.00	3.01	0.00	1.85	1.71	7.58
Time-based	75	15.20	0.57	0.67	2.52	3.01	1.45	1.85	6.84	7.94
Time-based	75	22.90	0.00	0.67	0.55	3.01	0.20	1.85	3.19	7.61
Time-based	75	30.50	0.00	0.67	0.00	3.01	0.00	1.85	1.71	7.47
Soil Moisture	40	15.20	2.03	1.50	6.81	6.08	4.57	3.82	10.51	12.03
Soil Moisture	40	22.90	0.65	1.54	3.49	6.52	1.78	4.18	6.29	12.54
Soil Moisture	40	30.50	0.10	1.58	1.40	6.77	0.74	4.20	3.74	12.76

Table C-4. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 624L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-balance	CN	Mass-balance	CN	Mass-balance	CN	Mass-balance	CN
Soil Moisture	50	15.20	2.03	1.49	6.78	6.31	4.56	3.85	10.99	12.29
Soil Moisture	50	22.90	0.66	1.57	3.31	6.47	1.78	4.11	6.33	12.53
Soil Moisture	50	30.50	0.10	1.67	1.40	6.69	0.74	4.15	3.82	12.92
Soil Moisture	60	15.20	2.06	1.49	6.75	6.22	4.79	3.88	10.58	12.26
Soil Moisture	60	22.90	0.66	1.57	3.45	6.34	1.78	4.08	6.32	12.57
Soil Moisture	60	30.50	0.09	1.62	1.40	6.74	0.74	4.05	3.88	12.87
Soil Moisture	75	15.20	1.91	1.44	6.94	6.24	4.92	3.96	10.56	12.28
Soil Moisture	75	22.90	0.60	1.61	3.59	6.69	1.78	3.85	6.18	12.94
Soil Moisture	75	30.50	0.10	1.64	1.40	6.59	0.74	4.35	3.93	12.88
ET	40	15.20	2.23	1.65	6.74	6.34	4.40	3.68	10.19	11.64
ET	40	22.90	0.31	1.42	3.31	6.24	1.78	4.07	6.21	12.89
ET	40	30.50	0.10	1.74	1.40	6.51	0.64	4.04	3.93	12.82
ET	50	15.20	2.23	1.65	6.77	6.40	4.67	3.86	10.46	12.29
ET	50	22.90	0.58	1.56	3.14	6.46	1.78	4.02	6.23	12.89
ET	50	30.50	0.10	1.75	1.40	7.00	0.44	4.16	3.93	12.92
ET	60	15.20	2.16	1.60	6.77	6.40	4.55	3.91	10.81	12.22
ET	60	22.90	0.66	1.60	3.46	6.72	1.78	3.95	6.21	12.90
ET	60	30.50	0.10	1.75	1.40	7.02	0.74	4.38	3.93	12.99

Table C-4. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 624L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-balance	CN	Mass-balance	CN	Mass-balance	CN	Mass-balance	CN
ET	75	15.20	2.13	1.55	6.67	6.39	4.84	4.02	9.52	12.14
ET	75	22.90	0.66	1.65	3.42	6.74	1.78	4.14	6.37	12.87
ET	75	30.50	0.10	1.74	1.40	7.09	0.74	4.39	3.56	12.98
Control	40	15.20	4.40	2.54	11.68	8.70	8.74	5.76	14.75	15.36
Control	40	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	40	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	50	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.74	15.36
Control	50	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	50	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	60	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.86	15.36
Control	60	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	60	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	75	15.20	4.40	2.54	11.68	8.70	8.74	5.76	16.03	15.36
Control	75	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.25	15.36
Control	75	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36

Table C-5. Comparison of the impacts of Cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 833 L cistern size and considering Mass-Balance and Curve Number methods to estimate total runoff.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 833L cistern										
Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Time-based	40	15.20	0.30	0.45	1.62	2.56	0.58	1.44	7.35	8.86
Time-based	40	22.90	0.00	0.45	0.25	2.56	0.00	1.44	2.97	7.71
Time-based	40	30.50	0.00	0.45	0.00	2.56	0.00	1.44	0.99	6.77
Time-based	50	15.20	0.30	0.45	1.62	2.56	0.58	1.44	7.04	8.30
Time-based	50	22.90	0.00	0.45	0.25	2.56	0.00	1.44	2.16	6.88
Time-based	50	30.50	0.00	0.45	0.00	2.56	0.00	1.44	0.99	6.57
Time-based	60	15.20	0.30	0.45	1.62	2.56	0.58	1.44	6.44	7.71
Time-based	60	22.90	0.00	0.45	4.01	6.62	0.00	1.44	2.04	6.64
Time-based	60	30.50	0.00	0.45	0.00	2.56	0.00	1.44	0.99	6.44
Time-based	75	15.20	0.30	0.45	1.62	2.56	0.58	1.44	5.35	6.88
Time-based	75	22.90	0.00	0.45	0.25	2.56	0.00	1.44	1.89	6.49
Time-based	75	30.50	0.00	0.45	0.00	2.56	0.00	1.44	0.99	6.36
Soil Moisture	40	15.20	2.02	1.38	6.14	5.73	4.09	3.58	9.60	11.38
Soil Moisture	40	22.90	0.65	1.44	3.25	6.12	1.78	3.88	5.89	12.00
Soil Moisture	40	30.50	0.10	1.47	1.40	6.41	0.74	3.91	3.61	12.36
Soil Moisture	50	15.20	1.99	1.34	6.17	5.94	4.09	3.61	10.21	11.67

Table C-5. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 833L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
Soil Moisture	50	22.90	0.66	1.47	3.08	6.08	1.78	3.84	5.92	11.99
Soil Moisture	50	30.50	0.10	1.55	1.40	6.39	0.74	3.87	3.55	12.54
Soil Moisture	60	15.20	2.06	1.38	6.21	5.87	4.26	3.63	9.89	11.66
Soil Moisture	60	22.90	0.66	1.47	3.10	5.94	1.78	3.79	5.97	12.10
Soil Moisture	60	30.50	0.09	1.51	1.40	6.35	0.74	3.76	3.50	12.32
Soil Moisture	75	15.20	1.90	1.32	6.35	5.87	4.40	3.69	9.82	11.63
Soil Moisture	75	22.90	0.60	1.48	3.41	6.32	1.78	3.61	5.95	12.48
Soil Moisture	75	30.50	0.10	1.51	1.40	6.25	0.74	4.09	3.52	12.25
ET	40	15.20	2.16	1.53	6.14	5.93	3.88	3.44	9.44	11.05
ET	40	22.90	0.29	1.31	2.95	5.85	1.78	3.78	5.77	12.27
ET	40	30.50	0.10	1.61	1.40	6.13	0.64	3.76	3.52	12.24
ET	50	15.20	2.16	1.53	6.14	6.00	4.16	3.63	9.89	11.72
ET	50	22.90	0.58	1.46	2.75	6.07	1.78	3.75	5.77	12.26
ET	50	30.50	0.10	1.61	1.40	6.63	0.44	3.88	3.52	12.25
ET	60	15.20	2.16	1.50	6.14	6.00	4.25	3.69	10.11	11.66
ET	60	22.90	0.66	1.50	3.08	6.33	1.78	3.67	5.75	12.26
ET	60	30.50	0.10	1.61	1.40	6.64	0.74	4.10	3.52	12.32
ET	75	15.20	2.13	1.45	6.13	6.00	4.42	3.75	9.03	11.60

Table C-5. Continued.

Runoff estimates (m^3) for different soil types by utilizing Mass-Balance method and Curve Number (CN)method with 833L cistern

Irrigation Scheduling	Depletion%	Soil Depth(cm)	Sand		Sandy Loam		Loamy Sand		Silty-clay	
			Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN	Mass-Balance	CN
ET	75	22.90	0.66	1.53	3.08	6.35	1.78	3.89	5.92	12.25
ET	75	30.50	0.10	1.61	1.40	6.78	0.74	4.11	3.44	12.63
Control	40	15.20	4.40	2.54	11.68	8.70	8.74	5.76	14.75	15.36
Control	40	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	40	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	50	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.74	15.36
Control	50	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	50	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	60	15.20	4.40	2.54	11.68	8.70	8.74	5.76	15.86	15.36
Control	60	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.24	15.36
Control	60	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36
Control	75	15.20	4.40	2.54	11.68	8.70	8.74	5.76	16.03	15.36
Control	75	22.90	0.79	2.54	6.41	8.70	3.50	5.76	10.25	15.36
Control	75	30.50	0.10	2.54	2.71	8.70	0.95	5.76	6.68	15.36

Cistern Size vs. Supplemental water

The impact of using several cistern sizes (0L, 208L, 416L, 624L, 833L) on the total supplemental for each treatment was estimated and the results came as follows:

Table C-6. Comparison of the impacts of Cistern size on the total volume of runoff (m^3) for the period (April 08-April 10) by utilizing 833 L cistern size and considering Mass-Balance and Curve Number methods to estimate total runoff

Supplemental water estimates (m^3) for different soil types and by utilizing different cistern sizes (L)																						
I	D	SD	0L cistern				208 L cistern				416 L cistern				624 L cistern				833L cistern			
			S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC
TB	40	15.2	87	175	131	29	77	166	122	20	73	162	117	16	71	159	115	14	69	158	113	12
TB	40	22.9	87	175	131	44	77	166	122	34	73	162	117	28	71	159	115	26	69	158	113	24
TB	40	30.5	87	175	131	58	77	166	122	49	73	162	117	43	71	159	115	40	69	158	113	37
TB	50	15.2	87	175	131	36	77	166	122	27	73	162	117	22	71	159	115	19	69	158	113	18
TB	50	22.9	87	175	131	54	77	166	122	45	73	162	117	39	71	159	115	36	69	158	113	34
TB	50	30.5	87	175	131	73	77	166	122	64	73	162	117	58	71	159	115	54	69	158	113	52
TB	60	15.2	87	175	131	44	77	166	122	34	73	162	117	28	71	159	115	26	69	158	113	24
TB	60	22.9	87	175	131	65	77	175	122	56	73	175	117	50	71	175	115	47	69	175	113	45
TB	60	30.5	87	175	131	87	77	166	122	78	73	162	117	72	71	159	115	69	69	158	113	66
TB	75	15.2	87	175	131	54	77	166	122	45	73	162	117	39	71	159	115	36	69	158	113	34
TB	75	22.9	87	175	131	82	77	166	122	73	73	162	117	67	71	159	115	63	69	158	113	61

Table C-6. Continued.

Supplemental water estimates (m^3) for different soil types and by utilizing different cistern sizes (L)

I	D	SD	0L cistern				208 L cistern				416 L cistern				624 L cistern				833L cistern			
			S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC
TB	75	30.5	87	175	131	109	77	166	122	100	73	162	117	94	71	159	115	91	69	158	113	88
SM	40	15.2	24	21	22	18	19	17	18	15	16	15	15	13	14	13	13	11	13	11	12	10
SM	40	22.9	22	18	20	15	18	15	16	13	15	13	14	11	13	11	12	9	12	10	11	8
SM	40	30.5	21	16	18	12	17	14	15	11	15	12	13	9	13	10	11	8	11	9	10	7
SM	50	15.2	24	20	22	18	19	17	18	16	16	15	15	13	14	13	13	12	12	11	11	10
SM	50	22.9	22	19	20	15	18	15	16	13	15	13	14	11	13	11	12	9	11	10	11	8
SM	50	30.5	20	16	19	13	17	14	15	11	15	11	13	9	13	10	11	8	11	8	10	7
SM	60	15.2	24	20	22	17	19	17	18	15	16	15	15	12	14	13	13	11	12	12	12	10
SM	60	22.9	22	18	20	14	18	16	17	12	15	13	14	11	13	11	12	9	12	10	11	8
SM	60	30.5	20	17	18	12	17	14	16	12	15	12	13	10	13	11	11	8	12	10	10	7
SM	75	15.2	24	21	22	18	19	17	18	15	16	14	15	13	13	12	13	11	12	11	11	10
SM	75	22.9	22	18	20	14	18	15	17	12	15	13	14	10	13	11	12	9	11	9	11	7
SM	75	30.5	21	16	18	14	17	15	15	12	14	13	13	11	12	11	11	10	11	10	9	8
ET	40	15.2	12	10	12	10	8	6	8	7	6	6	6	5	5	5	6	5	5	4	5	4
ET	40	22.9	12	10	10	7	8	7	6	6	6	5	6	4	5	5	5	3	5	4	4	3
ET	40	30.5	10	8	10	8	6	7	7	7	6	5	5	5	5	5	5	4	5	4	4	4
ET	50	15.2	12	10	11	9	8	6	7	6	6	6	6	5	5	4	5	5	5	4	4	4
ET	50	22.9	11	10	10	7	7	7	6	5	6	5	6	4	5	5	4	3	4	4	4	3
ET	50	30.5	10	8	10	8	6	6	7	6	6	4	5	4	4	4	5	3	4	4	4	2

Table C-6. Continued.

Supplemental water estimates (m^3) for different soil types and by utilizing different cistern sizes (L)																						
I	D	SD	0L cistern				208 L cistern				416 L cistern				624 L cistern				833L cistern			
			S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC	S	SL	LS	SC
E T	60	15.2	11	10	10	8	8	6	7	6	6	6	5	4	5	4	5	4	4	4	4	4
E T	60	22.9	10	9	10	7	7	6	6	5	5	5	5	3	5	5	4	2	4	3	4	2
E T	60	30.5	10	8	9	8	6	6	6	6	6	4	5	4	4	4	5	3	4	4	3	2
E T	75	15.2	11	9	10	7	7	6	7	5	6	5	5	4	5	4	5	4	4	4	4	3
E T	75	22.9	10	8	9	7	7	5	6	5	5	4	5	3	5	4	4	2	4	3	4	2
E T	75	30.5	9	6	8	7	6	5	5	5	5	3	4	4	4	3	4	3	4	3	3	3
TW	40	15.2	87	175	131	29	87	175	131	29	87	175	131	29	87	175	131	29	87	175	131	29
TW	40	22.9	87	175	131	44	87	175	131	44	87	175	131	44	87	175	131	44	87	175	131	44
TW	40	30.5	87	175	131	58	87	175	131	58	87	175	131	58	87	175	131	58	87	175	131	58
TW	50	15.2	87	175	131	36	87	175	131	36	87	175	131	36	87	175	131	36	87	175	131	36
TW	50	22.9	87	175	131	54	87	175	131	54	87	175	131	54	87	175	131	54	87	175	131	54
TW	50	30.5	87	175	131	73	87	175	131	73	87	175	131	73	87	175	131	73	87	175	131	73
TW	60	15.2	87	175	131	44	87	175	131	44	87	175	131	44	87	175	131	44	87	175	131	44
TW	60	22.9	87	175	131	65	87	175	131	65	87	175	131	65	87	175	131	65	87	175	131	65
TW	60	30.5	87	175	131	87	87	175	131	87	87	175	131	87	87	175	131	87	87	175	131	87
TW	75	15.2	87	175	131	54	87	175	131	54	87	175	131	54	87	175	131	54	87	175	131	54
TW	75	22.9	87	175	131	82	87	175	131	82	87	175	131	82	87	175	131	82	87	175	131	82
TW	75	30.5	87	175	131	109	87	175	131	109	87	175	131	109	87	175	131	109	87	175	131	109

I: Irrigation scheduling method
D: Depletion ratio(%) SD: Soil depth (cm)
S: Sand, SD: Sandy Loam, SL: Sandy Loam, SC: Silty Clay
TB: Time-based, SM: Soil Moisture-based, ET: Evapotranspiration-based, TW: Time-based that does not utilize a cistern

APPENDIX D

EVALUATION OF PREDICTED WATER RUNOFF AND TOTAL POTABLE IRRIGATION WATER DEMAND RELATIVE TO SOIL DEPTH

Total Water Runoff and Total Supplemental Water vs. Soil Depth

Soil depth had a significant impact on the total runoff among all cistern sizes utilized. The 15.2 cm soil depth had the highest amount of runoff, then the 22.9 cm soil depth and the lowest in terms of total runoff was at 30.5 cm soil depth for all cistern sizes utilized. Table D-1 below shows the total water runoff and supplemental water predicted by utilizing different soil depths at 15.2 cm, 22.9 cm, and 30.5 cm and different cistern sizes. By increasing soil depth, total potable water needed to meet irrigation requirements increased and by decreasing soil depth; total potable water predicted decreased.

Table D-1. Comparison between total water runoff (m^3) and total potable water used for irrigation (supplemental water) by utilizing different soil depths and cistern sizes.

Cistern size (L)	Soil depth cm	Total water runoff-mass (m^3)	Total supplemental water (m^3)
0 L Cistern	15.2	572.62	3975.46
	22.9	276.43	4085.01
	30.5	133.52	4212.83
208 L Cistern	15.2	501.43	3705.91
	22.9	246.87	3842.59
	30.5	118.80	3978.48
416 L Cistern	15.2	444.71	3567.89
	22.9	220.02	3711.76

Table D-1 Continued.

	30.5	105.28	3847.23
624 L Cistern	15.2	402.79	3488.81
	22.9	200.53	3633.50
	30.5	96.98	3766.06
833 L Cistern	15.2	375.43	3430.13
	22.9	188.27	3577.10
	30.5	91.36	3708.96

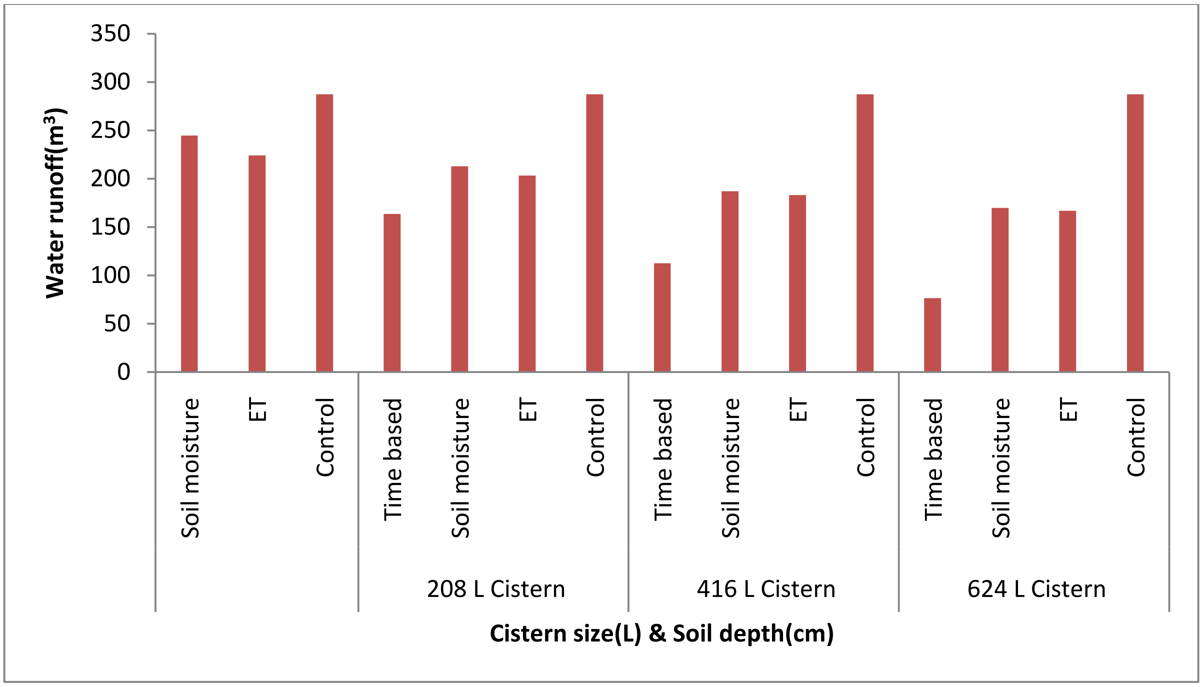

Figure D-1. Comparison between different soil depths and total water runoff by utilizing different cistern sizes.

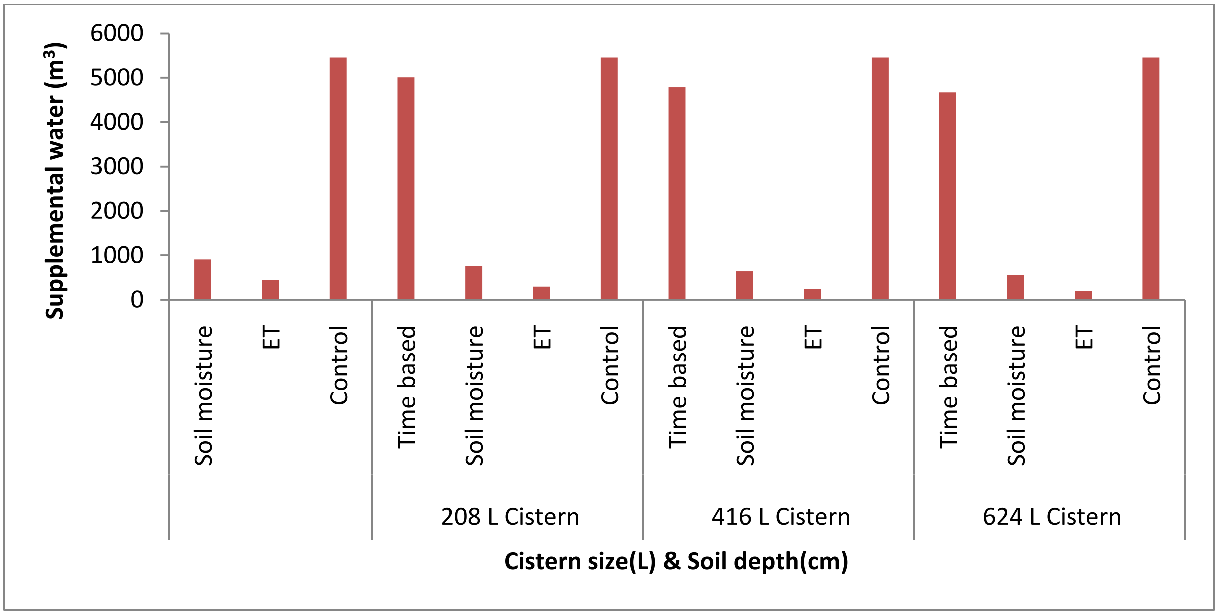

Figure D-2. Comparison between different soil depths and total supplemental water by utilizing different cistern sizes.

APPENDIX E

EVALUATION OF PREDICTED WATER RUNOFF AND TOTAL POTABLE IRRIGATION WATER DEMAND RELATIVE TO DEPLETION RATIO

Total water runoff and total supplemental water vs. depletion ratio

Increasing depletion ratios from 40 % to 60 % resulted in decreasing total water runoff predicted among all cistern sizes utilized, although not at a statistically significant level. Incasing depletion ration from 40% to 75% contributed in decreasing total potable water predicted among all cistern sizes utilized, although not at a statistically significant level. Table E-1 below shows the total amount of water runoff and supplemental water predicted by utilizing different depletion ratios.

Table E-1. Comparison between total water runoff (m^3) and total potable water used for irrigation (supplemental water) by utilizing different depletion ratios and cistern sizes.

Cistern size (L)	Depletion %	Total water runoff-mass (m^3)	Total supplemental water (m^3)
0 L Cistern	40	245.37	2970.58
	50	246.88	3030.92
	60	245.91	3089.91
	75	244.41	3182.61
208 L Cistern	40	215.86	2778.87
	50	217.85	2838.53
	60	218.65	2912.69
	75	214.70	2996.95
416 L Cistern	40	191.60	2677.91
	50	192.81	2737.77

Table E-1. Continued.

Cistern size (L)	Depletion %	Total water runoff-mass (m^3)	Total supplemental water (m^3)
	60	195.16	2815.13
	75	190.43	2896.07
624 L Cistern	40	173.86	2620.31
	50	174.83	2678.04
	60	178.49	2756.34
	75	173.12	2833.69
833 L Cistern	40	162.37	2576.92
	50	163.27	2634.23
	60	167.37	2715.60
	75	162.04	2789.43

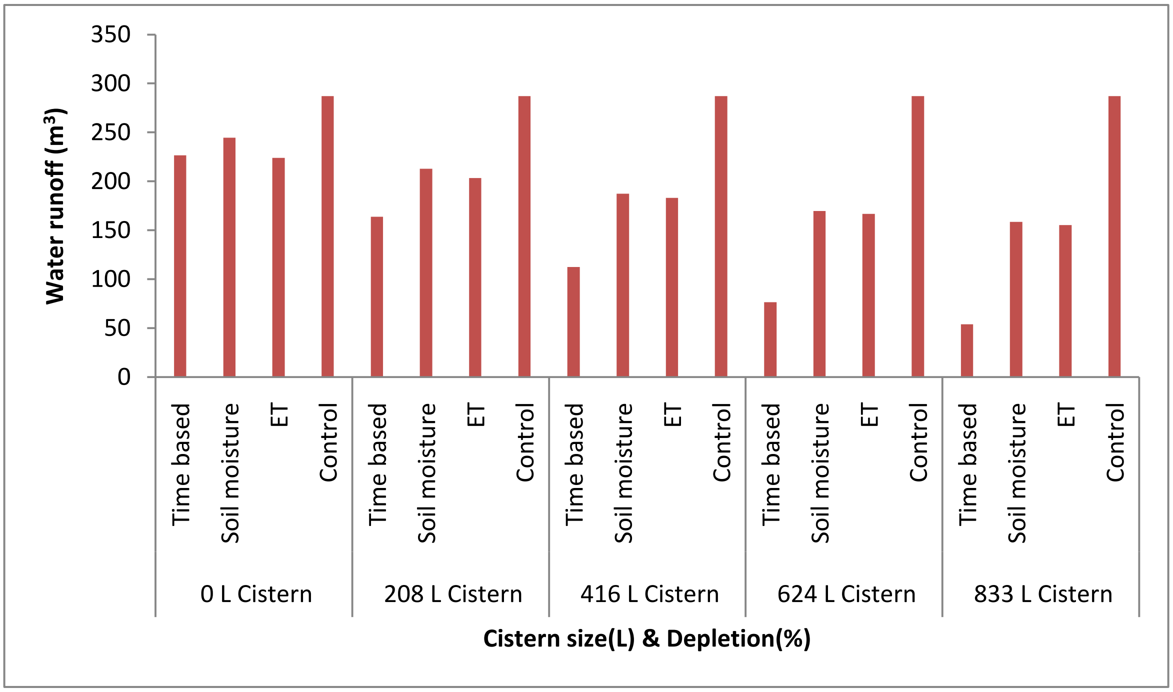

Figure E-1. Comparison between different depletion ratios and total water runoff by utilizing different cistern sizes.

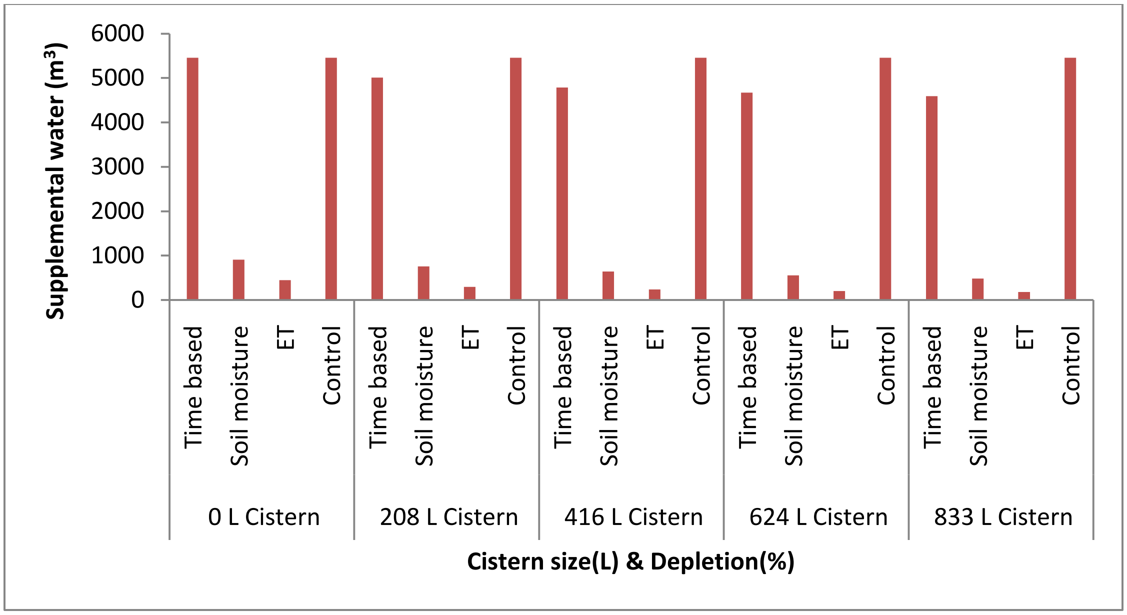

Figure E-2. Comparison between different depletion ratios and total supplemental water by utilizing different cistern sizes.

APPENDIX F

EVALUATION OF PREDICTED WATER RUNOFF AND TOTAL POTABLE IRRIGATION WATER DEMAND RELATIVE TO CISTERN SIZE

Total water runoff and total supplemental water vs. irrigation method

Irrigation scheduling method had different impacts on total water runoff and supplemental water predicted. The control treatment that involved Time-based irrigation scheduling without a cistern contributed in having the highest volume of water runoff and supplemental water among all cistern sizes except for one case that utilized 0 L cistern and where total runoff resulted from Time-based method was slightly higher than the control treatment. Soil Moisture-based method resulted in the lowest volume of supplemental water predicted, while it was the second highest method -after the control method that does not utilize a cistern- in total water runoff predicted. ET-based method continued to have the lowest volume of total runoff among all cistern sizes except for the 833 L cistern size where Time-based method had the lowest total runoff predicted.

Table F-1. Comparison between total water runoff (m^3) and total potable water used for irrigation (supplemental water) by utilizing different irrigation scheduling methods and cistern sizes.

Cistern size (L)	Irrigation scheduling method	Total water runoff mass (m^3)	Total supplemental water (m^3)
0 L Cistern	Time based	226.69	5459.31
	Soil moisture	244.67	907.84
	ET	224.01	446.84
	Control	287.18	5459.31
208 L Cistern	Time based	163.67	5010.96
	Soil moisture	212.97	756.72
	ET	203.25	299.98
	Control	287.18	5459.31
416 L Cistern	Time based	112.58	4785.16
	Soil moisture	187.17	639.68
	ET	183.09	242.73
	Control	287.18	5459.31
624 L Cistern	Time based	76.58	4668.51
	Soil moisture	169.78	553.82
	ET	166.76	206.74
	Control	287.18	5459.31
833 L Cistern	Time based	53.97	4589.60
	Soil moisture	158.61	487.42
	ET	155.30	179.85
	Control	287.18	5459.31

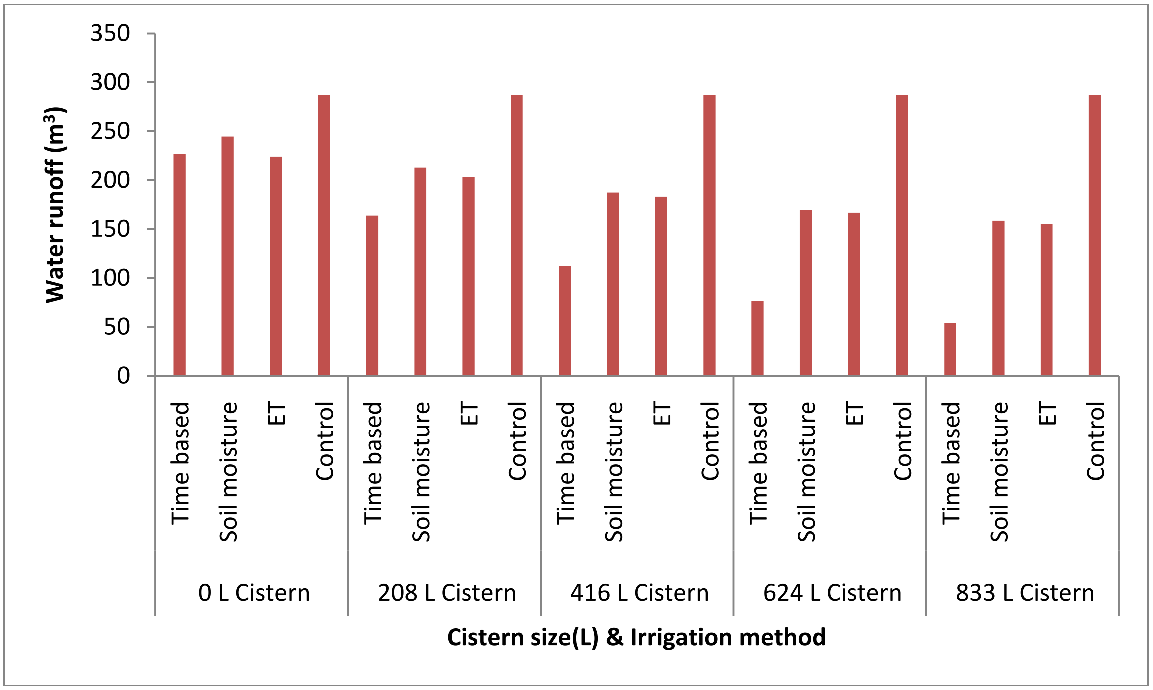

Figure F-1. Comparison between different irrigation methods and total water runoff by utilizing different cistern sizes.

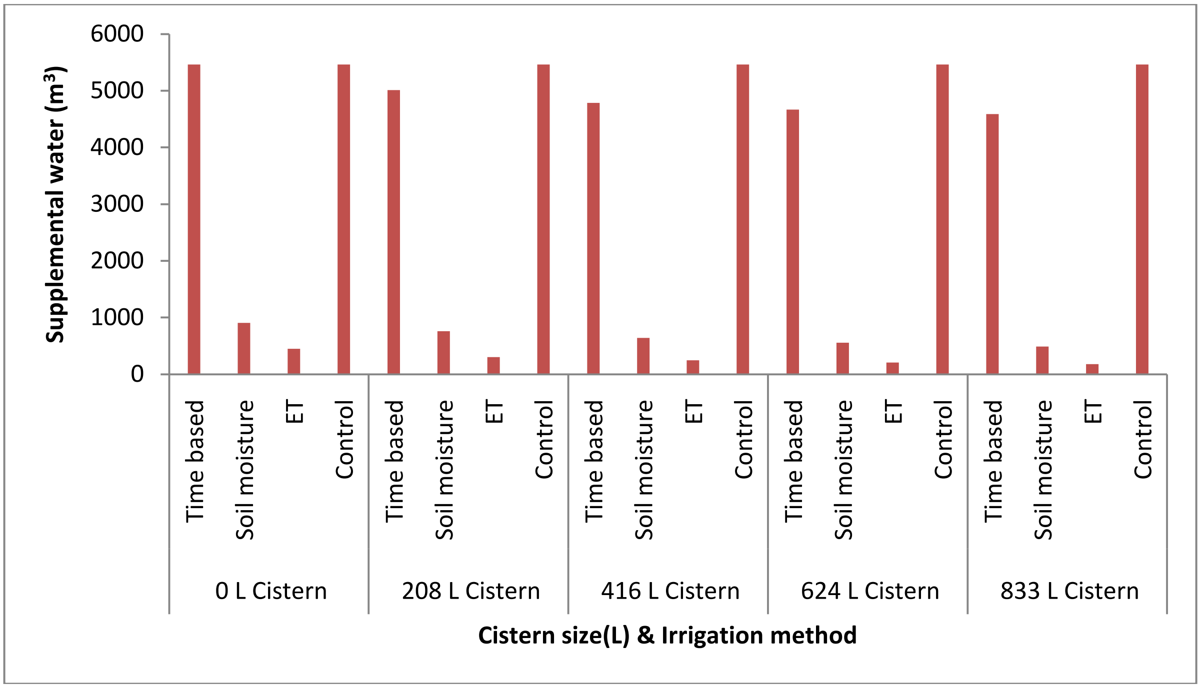

Figure F-2. Comparison between different irrigation methods and total supplemental water by utilizing different cistern sizes.

Total water runoff and total supplemental water vs. cistern size

Increasing cistern size contributed in decreasing total amount of runoff and total potable water used for irrigation (supplemental water) estimates.

Table F-2. Comparison between total water runoff (m^3) and total potable water used for irrigation (supplemental water) by utilizing different cistern sizes.

	0 L cistern	208 L cistern	416 L cistern	624L cistern	833 L cistern
Total Runoff (m^3)	982.58	867.09	770.02	700.31	655.07
Total Supplemental water(m^3)	12273.31	11526.99	11126.89	10888.38	10716.19

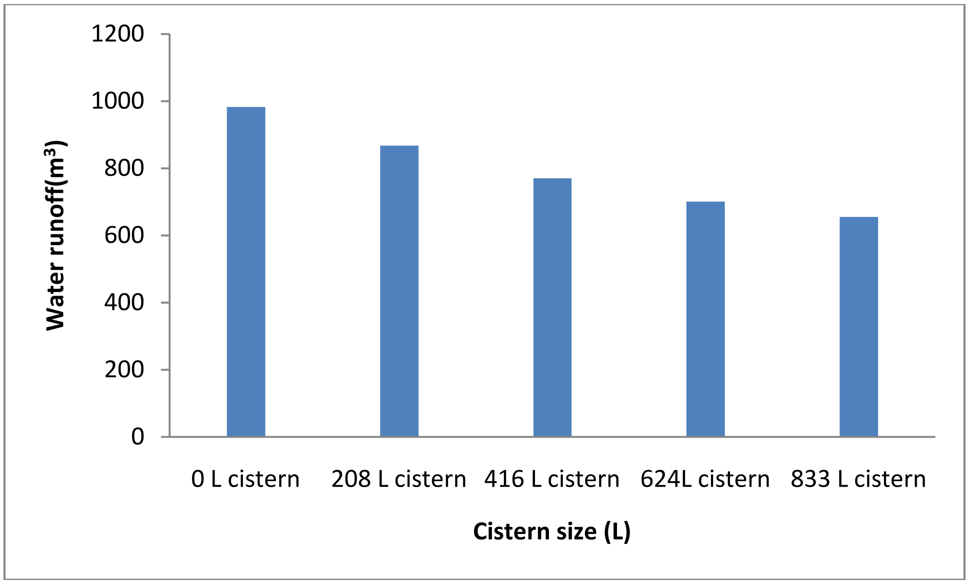

Figure F-3. Comparison between different cistern sizes and total water runoff.

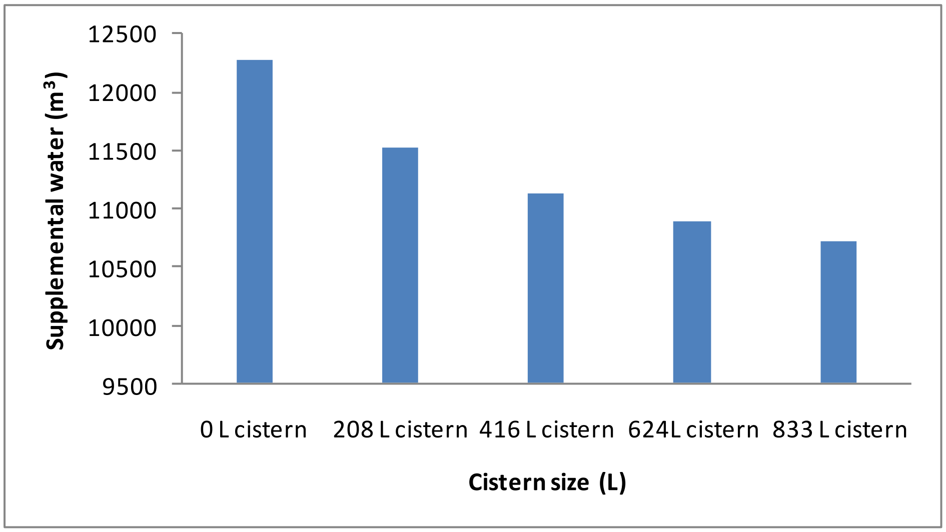

Figure F-4. Comparison between different cistern sizes and total supplemental water.

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Experience:

Monitoring and Evaluation Coordinator at Mercy Corps organization, Oct 2006 – Aug2008
Designated responsibilities in projects which include; the design and analysis of a monitoring and evaluation system with indicators related to the projects activities, facilitated project start-up logistics, procurement and administrative tasks including liaison with government ministries.

Research Assistant at University of Jordan, **Aug 2005 - Oct 2006**
Conducted chemical and physical assessments in researches that study the effect of treated water and water quality in general on the sensory, chemical and physical criteria of foods.

Agricultural Engineer at Center of Strategic Studies June2003-July2004
Designed, installed and evaluated irrigation networks for different agricultural projects that aim to develop and enhance water utilization practices for farmers in the Jordan valley area.