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Presented by

Ngoni Conilius CHIRINDO

Development of a Sugarcane Crop Water Use Based Water Budgeting Calibration Tool for Catchment Water Management. Case Study: Zimbabwe's South-Eastern Lowveld

Defended on 03/09/2018 Before the Following Committee:

Chair	Dr. Latefa Sail	**Tlemcen University, Algeria**
Supervisor	Dr. Andrew Ako Ako	**Yaounde Hydrological Research Centre, Cameroon**
External Examiner	Prof. Thameur Chaibi	**National Institute for Research in Rural Engineering, Water and Forestry, Tunisia**
Internal Examiner	Prof. S. M. Chabane Sari	**Tlemcen University, Algeria**

Academic year: 2017/2018

DECLARATION OF INDEPENDENT WORK

I, Ngoni Conilius Chirindo, National Identity number: 47-168886 C 47 and student registration number PAUWES/2016/MWE08, do hereby declare that this design project submitted to the Pan African University Institute of Water and Energy Sciences (Inc. Climate Change), for the Master of Science Degree in Water Engineering, is my own independent work; and complies with the code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Pan African University, and has not been submitted before to any institution by myself or any other person in fulfillment of the requirements for the attainment of any qualification. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

Student Signature;  Date: 30/07/2018

SUPERVISOR'S CERTIFICATION

I hereby certify that this master thesis by **Ngoni Conilius CHIRINDO**, a Water Engineering Master student of Pan African University Institute of Water and Energy Sciences (including climate change) (PAUWES), Tlemcen, Algeria was carried out under my supervision.

Supervisor Signature:  Date: 31/07/2018

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DEDICATION

I dedicate this project to my beloved wife and my mother who ever gave me the much needed support.

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ABBREVIATIONS

CWU- Crop Water Use

CWM- Catchment Water Management

CWMA- Catchment Water Management Agency

CWR - Crop water requirement

ERF - Effective rainfall

ET – Evapotranspiration

ET_o – Reference Evapotranspiration

ET_c – Crop Evapotranspiration/ Crop Water

IR - Irrigation requirement

K_c- Crop Factor

ABSTRACT

Zimbabwe's Lowveld sugarcane farmers depends on at least 70 % irrigation for their crop production. Small scale sugarcane farmers (Out-growers) in the area are lacking technical capacities and finances to hire consultants to do their water budgeting predictions. They end up withdrawing unallocated water for their irrigation. This is posing a challenge to the supplier who ends up failing to supply water to deserving consumers. Conflict emerges among water users as they compete for the limited water resource.

Many water budgeting tools have been developed over the past years with different goals and approaches being used in the development of these tools. Many of these tools focus on irrigation water management and mainly depend on current weather data as input parameters for their operations. Those that are more into water budget predictions, are either locality based and only consider the pumping capacities and pumping duration as their bases for budgeting and they do not take into account the Crop Water Use (CWU)/ ET crop.

Due to the short comings of the existing tools, it was of paramount importance to develop a sugarcane CWU water budgeting tool for Catchment Water Management (CWM). Meteorological data from local weather stations and Satellite data for the past 14 years from 2003 to 2017 and 30 years from 1987 to 2017 respectively for the Lowveld area, incorporated with some formulas was used in determining CWU database in the calibration tool.

Through evaluation, the development of this tool resulted in 100 % time saving, 60 % improved water management strategies and 30 % efficient and effective utilization of water resources.

Key Words: Irrigation, Tool, Crop Water Use, Budgeting, Calibration

RESUME

Les producteurs de canne à sucre Lowveld du Zimbabwe dépendent d'au moins 70% d'irrigation pour leur production agricole. Les petits producteurs de canne à sucre (Out-growers) dans la région manquent de capacités techniques et de moyens financiers pour embaucher des consultants pour faire leurs prédictions sur le budget de l'eau. Ils finissent par retirer l'eau non allouée pour leur irrigation. Cela représente un défi pour le fournisseur qui finit par ne pas fournir de l'eau aux consommateurs méritants. Des conflits apparaissent parmi les utilisateurs d'eau alors qu'ils se font concurrence pour la ressource en eau limitée.

De nombreux outils de budgétisation de l'eau ont été développés au cours des dernières années avec différents objectifs et approches utilisés dans le développement de ces outils. Beaucoup de ces outils se concentrent sur la gestion de l'eau d'irrigation et dépendent principalement des données météorologiques actuelles comme paramètres d'entrée pour leurs opérations. Celles qui sont plus axées sur les prévisions du budget hydrique sont basées sur la localité et ne considèrent que les capacités de pompage et la durée de pompage comme base pour la budgétisation et ne tiennent pas compte de la culture d'utilisation des cultures (CWU) / ET.

En raison des lacunes des outils existants, il était primordial d'élaborer un outil de budgétisation de l'eau de la canne à sucre de la canne à sucre pour la gestion de l'eau du bassin versant (MCG). Les données météorologiques des stations météorologiques locales et des données satellitaires pour les 14 dernières années de 2003 à 2017 et 30 années de 1987 à 2017 pour la zone Lowveld, incorporées avec certaines formules, ont été utilisées pour déterminer la base de données CWU dans l'outil d'étalonnage.

Grâce à l'évaluation, le développement de cet outil a permis de gagner 100 % de temps, d'améliorer de 60 % les stratégies de gestion de l'eau et d'utiliser efficacement et à 30 % les ressources en eau.

Mots-clés: Irrigation, outil, utilisation de l'eau des cultures, budgétisation, étalonnage

DEFINITION OF TERMS

Irrigation- it is the application of controlled amounts of water to plants at needed intervals

Tool – A piece of software designed to do a particular task

Crop Water Use (ET crop) - is defined as the depth of water needed to meet the water loss through evapotranspiration.

Budgeting- an estimate of water for a given period in the future

Calibration- the action/ process of configuring an instrument to provide results for a sample within an acceptable range.

CHAPTER ONE: INTRODUCTION

1.0. Introduction

This chapter serves to introduce and state the focus of the study beginning with the background information concerning the problem leading to the need to develop a sugarcane crop water use based water budgeting calibration tool for Catchment Water Management (CWM). The Objectives, Problem statement, Justification of study, Research Questions and Working Hypothesis are also going to be found in this Chapter One.

1.1. Background of Study

Sugarcane is a high water-demanding crop (Eagri.org, 2018), with an average of 20 megalitres of water/ha (Silva *et al.*, 2013) which is equivalent to 1 500 mm depth. Zimbabwe's Lowveld sugarcane farmers depends on at least 70 % irrigation and at most 30 % rainfall water to meet up the 2 000 mm crop requirement (Maponga, 2016). The irrigation water is stored and managed by the Catchment Water Management Agency (CWMA) under the Zimbabwe Water Authority (ZINWA) who supplies water to the consumers based on needs.

Cooperation between the water consumer and supplier is therefore of utmost importance and any misjudgement on the required water from the consumer side has a great impact on both the consumer and suppliers. To the consumer side, inaccuracies on budgets induces pressure on the water resource use and subsequent stimulation of water stress and yield losses on sugarcane (Msibi et al., 2014). To the supplier side, failure of CWMA to have all consumer's advance monthly or yearly total water needs results in them failing to reserve enough water in reservoirs as in some cases water is released when consumers are not in need of it resulting in water being lost to the oceans.

In the case of bigger institutions in the South-Eastern Lowveld, consumer to supplier cooperation is better unlike with small scale farmers (Out-growers) who in most cases withdraw unallocated water disadvantaging a few individuals who requested their share which leads to conflict (Svubure *et al.*, 2010). Though with many shortcomings, these bigger institutions normally depends on billed water for the previous years to predict the water needs for the coming year.

Zimbabwe's Lowveld small scale sugarcane farmers are lacking technical capacities and finances to hire consultants to do their water budgeting. They end up withdrawing water for their irrigation as long as they see canals or rivers flowing. This is posing a challenge to the supplier who ends up failing to provide water to deserving consumers especially in times of critical water need. In the case of established Sugarcane Plantation Water Managers, the time that is supposed to be utilized in doing other beneficial activities in their respective Organizations is being wasted in doing water budgets also.

Uncertain water availability and a climate characterised by recurring droughts, provides strong motivation for the sugar industry in southern Africa to strive for continuous improvement in water management (Lecler, 2004). For example, the sugar industry in Zimbabwe which is totally reliant on irrigation, nearly collapsed as a result of crippling water shortages following the 1991/2 drought (Lecler, 2004). Concern over water for irrigation is growing in many countries where water supplies are limited and communities are becoming more sensible to the impact of irrigation on the environment and on the sustainability of their livelihoods (Inman-Bamber, 2004).

It is of significance to improve estimates of crop water use in order to advance irrigation design limitations and scheduling. Accurate estimates of crop water use are required to determine irrigation allocations and to improve management of both surface and underground water storages (Inman-bamber and Mcglinchey, 2003). Matching water supply and demand on a daily or weekly or monthly basis is essential for productivity and sustainability in any irrigation scheme (Inman-bamber and Mcglinchey, 2003). To help ensure the long term viability of irrigated industries, increased insight into the performance of the various water management and irrigation systems is needed, together with the development and adoption of strategies, tools and guidelines to improve performance (Lecler, 2004).

Many water budgeting/ management tools have been developed over the past years. These include ZIMsched (Lecler, 2000), ZIMsched 2.0 (Lecler, 2003) and Water Administration Systems (WAS) which was developed in 2006 (Benade, 2017). ZIMsched and ZIMsched 2.0 are currently popular amongst sugarcane farmers in the Zimbabwe’s Lowveld. Different goals and approaches have been adopted in the development of these tools with many of them focusing on the irrigation water management or irrigation scheduling and mainly depend on daily weather data as their main input parameters for their operations. Those that are more into water budget predictions only consider the pumping capacities and pumping duration as their bases for budgeting.

Contrary to the already developed tools, the sugarcane CWU water budgeting calibration tool for CWM in Zimbabwe’s Lowveld makes use of historical climatic database which makes it easier for a farmer who does not have access to either daily, weekly, monthly, yearly or historical weather data to use in the tool to do their water budget predictions. The tool makes use of the crop water requirements as the bases to predict what should be supplied by the CWM. This proposed tool act as an updated version of the already developed tools as it will have a provision to bypass the database in the event that current data needs to be used in case unpredicted rainfall is received and an immediate water budget is required or irrigation scheduling needs to be done.

Due to the stated problems and opportunities cited above, it was of paramount importance to develop a sugarcane CWU water budgeting calibration tool for Catchment water management to save time, improve on water management strategies and utilize water resources efficiently and effectively.

1.2. Objectives

1.2.1. Main objective

To develop a sugarcane crop water use based water budgeting calibration tool for Catchment Water Management (CWM).

1.2.2. Specific Objectives

i. To create a climatic database based on historical data for the Zimbabwe's Lowveld.
ii. To compute and create a database of crop water demands based on the climatic data.
iii. To develop a water budgeting tool based on climatic database to compute daily, monthly and yearly water budgeting (demand).
iv. To use water judiciously with a view to optimizing benefits in a context of climate variability, erratic rainfall and possible drought.

1.3. Problem Statement

Zimbabwe's small scale sugarcane farmers lack technical capacities and financial resources to hire consultants to do their water budgeting predictions. They end up withdrawing water for their irrigation as long as they see supply canals or rivers flowing. This poses a challenge to the CWMA who end up failing to supply water to deserving consumers especially in times of critical water need. As a result of this water shortage, conflict is arising between farmers resulting in compromising their social relationships (Svubure *et al.*, 2010).

This lack of cooperation between the water consumer and supplier is resulting in adverse impacts to both the water consumer and supplier. To the consumer side, inaccuracies on budgets induces pressure on the water resource use and subsequent stimulation of water stress and yield losses on sugarcane (Msibi et al., 2014). To the supplier side, failure of CWMA to have all consumer's advance daily, weekly, monthly or yearly total water needs results in them failing to reserve enough water in reservoirs as in some cases water is released when consumers are not in need of it resulting in water being lost to the oceans.

Already existing water budgeting tools have different goals and approaches with many of them focusing on the irrigation water management or irrigation scheduling and mainly depend on current weather data as their main input parameters for their operations. Those that are more into water budget predictions are either site specific or only consider the pumping capacities and pumping duration as their bases for budgeting.

Due to the cited problems above, it was of paramount importance to carry this design to save time in doing water budgets, improve on water management strategies and utilize water resources efficiently and effectively. This design therefore aimed at developing a sugarcane CWU water budgeting calibration tool for CWM in Zimbabwe's South-Eastern Lowveld.

1.4. Justification of study

Majority of the existing water budgeting tools exist in the form of irrigation scheduling or irrigation water management tools which do not compute or predict the future total water needs. These tools depend on daily weather data which makes them not fit to compute the future water budgeting predictions unlike the sugarcane CWU water budgeting tool which depends on historical climatic data. This developed tool makes it easier for the remotely located farmers who do not have access to daily climatic data to do their own budgets. Those that go further in doing the water budgeting are either locality based, expensive to acquire, require many input data or they do not cater much for the crop water needs as they depend on the pump flow rates and pumping durations for their budgeting.

Apart from focusing only on addressing the short-comings of the already existing water budgeting tools, the developed sugarcane CWU water budgeting tool incorporates the basic functions of the already existing tools making it an updated version of the existing tools. It also takes into account the effects of climate change since historical climatic data was used. This tool also helps Sugarcane Plantation Water Managers in doing their water budgeting predictions in no time which results in them diverting effort to other duties in their respective Organisations thereby increasing the Organisations' outputs.

To the CWMA, this developed water budgeting tool cements cooperation between them and the consumers as it helps in making the CWMA a very important stakeholder who can be able to guide farmers on whether or not they can expand based on the availability of water in the storage reserves. Last but not least, the developed water budgeting tool can be used to measure if the crop is being over or under irrigated through measuring the actual water applied against the predicted from the budgeting tool.

1.5. Research Questions and Working Hypothesis

1.5.1. Questions

1. How is the tool helping in saving time?
2. How is the tool helping in improving water management strategies?
3. How is the tool helping in utilizing water resources efficiently and effectively?
4. How is the tool different from already existing budgeting tools?
5. How is the tool combating conflict among water users?

1.5.2. Hypothesis

Failure by farmers to predict their future water needs has a great impact in managing water at Catchment level.

1.6. Conclusion

In Zimbabwe, small holder sugarcane farmers are financially and technologically constrained so they do not have the capacity to do their water budgets or hire consultants to do their water budgeting needs. Those that have the capacity to do their water budgeting needs, they take a long time to do so resulting in loss of time which is supposed to be directed to other productive activities. This study seeks to develop a sugarcane Crop Water Use (CWU) water budgeting tool for Catchment Water Management (CWM). This development result in time saving, improved water management strategies, efficient and effective utilization of water resources.

CHAPTER TWO: LITERATURE REVIEW

2.0. Introduction

This chapter provides a comprehensive review of literature related to the problem under investigation. This among other things include: the importance of the crop under study, already existing water management tools and relevant information that the researcher came across that is in relation to achieving the above stated objectives.

2.1. Importance of Determining Water Needs

All plants need water to grow and produce good yields. When plants are water stressed they close their stomata (the small holes in the leaf surface) and cannot photosynthesise effectively. Best growth can be achieved only if plants have a suitable balance of water and air in their root zones (Lecler, 2000). Some stages in the growth of a crop are particularly sensitive to moisture stress.

Water shortages that are sufficient to hinder crop growth can occur without producing obvious wilting of foliage, while waterlogging can cause large yield reductions too (Inman-Bamber and Smith, 2005). The grower must therefore rely on some other methods of determining the water needs of the crop to avoid production or quality losses. This requires an understanding of the movement and storage of water in the root zone of the crop and the rate of water use by the crop (Inman-Bamber and Smith, 2005).

2.2. Sugarcane Crop Water requirement

Sugarcane is a high water-demanding crop (Eagri.org, 2018), with an average of 20 megalitres of water/ha (Silva et al., 2013) which is equivalent to 2 000 mm depth.

Water requirement is the total amount of water needed for raising a crop successfully (Shrivastava et al., 2011). In the case of all crops, it comprises the quantity of water for meeting the losses during application of water, water needed for land preparation as pre-planting irrigation and the needs of evapotranspiration and metabolic activities. Water loss from the soil takes place through surface evaporation, transpiration by plants and deep percolation beyond the root zone.

Under field conditions, water requirements are met effectively by rainfall, contribution from groundwater (if the water table is within the reach of the root system) and irrigation (Shrivastava et al., 2011). It varies from place to place depending on weather conditions, texture of soil, and growth and development stage of the crop.

It is in the interests of irrigators, environmental managers and the community in general to ensure that crop production remains profitable while water is used more sparingly and drainage and runoff are reduced to a minimum (Inman-Bamber and Smith, 2005).

2.3. Water Budgeting

A water budget is a plan for managing water use and saving. It tracks planned water use versus actual water use. Watershed Organisation Trust (2017) conceptualizes Water Budgeting as being geared towards ensuring optimum and most efficient use of water. This involves gaining an understanding of water availability, community's existing needs and requirements of water, crop-planning based on water availability, optimizing irrigation, equitable sharing of excess water, and considered decisions on groundwater withdrawals (See Figure 2-1 below for further illustration).

Source: (Water Organisation Trust, 2017)

Figure 2-1: Community Based Water Budgeting

This kind of integrated approach and exercises help the community understand the implications of the different patterns of water use that are prevalent in their area. By obtaining community level water availability data (from the rainfall data, etc), people are able to assess water available at their disposal for the coming months, plan judicious uses of water and decide on the crops accordingly, after taking into consideration the needs of households and livestock.

This consideration of various local claims on water resources in the community provide a strong basis for making decisions regarding the different and appropriate cropping patterns, area to be taken for cultivation, the method of application of irrigation water, imposition of water use charges (if any), that arrives at not only equitable sharing of water but also optimizing output per drop of water (Water Organisation Trust, 2017).

According to Swanson and Fipps (2013), water budgeting is usually an estimate of the amount of water to allocate to landscape irrigation used for the determination of:

- Maximum applied water allowance which is set by a regulatory agent as measured by a water meter

- Estimate applied water budgets for a worst case scenario (zero rain), expected use basis (normal rainfall) and maximum water conservation
- Water use tracking to compare actual monthly water use ton one or more of the above

Also Mayer et al. (2008) defines water budget as the volumetric allotments of water to customers based on customer-specific characteristics and conservative resource standards. A water budget helps in managing costs and improves site maintenance and efficiency. Mayer et al. (2008) further explains water budgets in respect to how other stakeholders define it like where water providers tend to define water budgets in more specific terms so that their customers can easily understand how the budget (or allocation as it is often called) applies, for example, the city of Boulder, Colombia which defines the concept for its customers as follows: “A water budget is the amount of water you are expected to need for a specific month. Each customer’s water budget will be different based on their water needs. Water budgets may vary monthly based on seasonal outdoor watering needs.”

Water-Budgeting exercise brings to light water availability within a village. Agro-advisories help in better planning and making better crop decisions (Water Organisation Trust, 2017).

A landscape and crop water use based water budget is the most common form of a water budget. This water budget is typically a volume of water that is calculated from two parameters which are the landscape size (usually in Hectares) and the water requirement of plants in that geographic area, which is usually represented by the evapotranspiration (ET) rate.

Unlike the focus of this thesis which is based on Crop Water Use, indoor water budgets are typically a fixed volume provided each month based on the historical use of the customer class or a calculated volume based on the anticipated needs of the customer.

Water budgeting may be for an irrigation system planned by irrigation engineers; may be for a canal or for an area (block) or may be for a farm according to the need and plan by responsible persons who plan the irrigation efficiency.

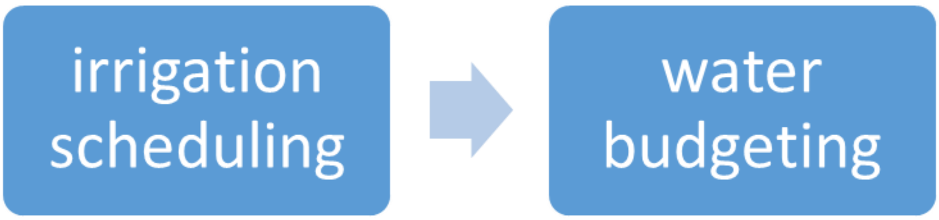
2.3.1. Importance of Water Budgeting

- To reduce excess irrigation and losses caused thereby
- Efficient utilization of available water and bringing more area under irrigation.
- To increase cropping intensity of a region / farm
- To increase the productivity of a region / farm.
- To avoid run off losses
- To tide over some dry-spells

2.4. Water budgeting Versus Irrigation Scheduling

Water budgeting calculations can be simple or complicated as is needed and also are usually based on a monthly or annual analysis whereas irrigation scheduling calculations can be complicated and are usually based on running a daily balance on ET, soil, moisture levels and other factors (Swanson and Fipps, 2013).

In general, Irrigation scheduling is the forerunner to water budgeting (Swanson and Fipps, 2013), see Figure 2-2 below.



Source: (Swanson and Fipps, 2013)

Figure 2-2: Relationship between Irrigation Scheduling and Water Budgeting

2.5. Irrigation scheduling

Irrigation scheduling is defined as the frequency with which water is applied to the crops based on needs and soil nature. Irrigation scheduling is nothing but the number of irrigations and their frequency required to meet the crop water requirement (Eagri.org, 2018).

It is a daily or weekly detailed water balance analysis to determine the amount of water needed to optimize plant growth and quality, maintain plants/ landscapes at a desired level and ensure survival of plants. Irrigation scheduling may also be defined as scientific management techniques of allocating irrigation water based on the individual crop water requirement (ET_c) under different soil and climatic condition, with an aim to achieve maximum crop production per unit of water applied over a unit area in unit time (Allen *et al.*, 1998). Last but not least, irrigation scheduling as according to the Author, is a decision making process repeated many times in each month or year involving when to irrigate and how much of water to apply?

However, Irrigation scheduling has its own importance according to the nature of the work as stated below (Eagri.org, 2018).

For irrigation Engineers: Irrigation scheduling is important to effectively and efficiently cover more area with available quantity of water.

For soil scientists: It is important that the field should not be over irrigated or under irrigated as both will spoil the chemical and physical equilibrium of the soil.

For Agronomists: It is very much important to get higher yield per unit quantity of water in normal situations and to protect the crop to get as much as possible yield under drought situation by means on supplying water in optimum ratio and minimizing all field losses.

Mathematically irrigation scheduling or irrigation requirement is shown in Equation 2-1 (Eagri.org, 2018):

Irrigation requirement (IR) = Crop water requirement (CWR) – Effective rainfall (ERF). It can be expressed either in mm/day/ or mm/month **Equation 2-1**

Practical considerations in irrigation scheduling

If the crop water requirement of a particular crop is 5 mm per day, it means every day we have to give 5 mm of water to the crop to compensate for the water lost through ET. Practically it is not possible since it is time consuming and laborious. Hence, it is necessary to schedule the water supply by means of sometime intervals and quantity (Swanson and Fipps, 2013). For example the water requirement of 5 mm/ day can be scheduled as 20 mm for every 4 days or 30 mm/for every 6 days or 35 mm/for every 7 days depending upon the soil type and climatic conditions prevailing in that particular place. While doing so we must be very cautions that the interval should not allow the crop to suffer from water stress (Eagri.org, 2018).

Before scheduling irrigation in a farm or field or a command, the following factors should be taken care for efficient scheduling (Eagri.org, 2018).

Water Delivery System: It consists of Well and river or canal irrigation. Under well irrigation, the individual's decision is final whereas under river irrigation or canal irrigation, it is a public distribution system where scheduling is arranged based on the decision made by public and is based on the availability of resource (Eagri.org, 2018).

Crop factors (K_c): When crops are young and small, actual ET is only about 1/3 of ET_o because the small plants do not transpire much and soil surfaces typically dry out quite less between irrigations (there is very little evaporation off a dry soil surface) (Asi.ucdavis.edu, 2018). When a crop is full sized and still green, actual ET will be closer to ET_o and is often actually slightly greater than ET_o. The "Crop Coefficient" (K_c) quantifies the ratio between actual ET and ET_o. K_c tends to increase with the size of the plant (in the case of annual crops) or the amount of foliage (in the case of deciduous perennials) (Asi.ucdavis.edu, 2018).

Methods of Irrigation Used: Include Furrow Irrigation method which allows for less infiltration due to less wetting surface which needs less water and short interval in irrigation frequency, Flooding Irrigation method which allows for more infiltration through more wetting surface area which in turn needs more water and long interval in irrigation frequency, Basin Irrigation method which allows more infiltration through more wetting surface area which in turn needs more water and long interval in irrigation frequency, Sprinkler Irrigation method which needs less water and more frequency, Drip Irrigation method which needs less water and more frequency and Centre Pivot Irrigation method which needs less water and more frequency (Eagri.org, 2018).

Soil Type: An example of two soils is elaborated. Under clay soils, long frequency of irrigation and more quantity of water is required and under sandy soils, short frequency of irrigation and less quantity of water is required.

Salinity Issues: To maintain favorable salt balance, excess water application may be required to leach the excess salts through deep percolation rather than ET requirement of the crop.

Irrigation Interval: The extension of irrigation interval does not always save water. The interval has to be optimized based on the agro climatic situation of the area.

Minimum spreadable depth: We cannot reduce the depth based on the water requirement of the crop alone. The depth should be fixed based on the soil type, rooting nature of the crop and irrigation method used. The minimum depth should be so as to achieve uniformity of application and to get uniform distribution over the entire field.

2.5.1. Effects of applying excess amount of water

- It wastes water below root zone and also causes erosion through runoff
- It results in leaching of fertilizer nutrients resulting in the pollution of ground water
- It causes water stagnation resulting in poor aeration and salinity
- Ultimately it damages the crops

2.6. Water Budgets and Drought Response

Water budgets and water budget rate structures offer water utilities powerful tools for reducing demand during drought and for monitoring customer compliance with drought restrictions (Mayer *et al.*, 2008). Unlike nowadays, historically, drought has been considered an unpredictable natural disaster. In response to drought, Water System Managers have usually relied on foreseeable response mechanisms.

Water managers have viewed droughts as low-water supply events of unknowable and uncontrollable duration (Mayer *et al*., 2008). In response, water utilities typically invoke some form of water use restrictions on customers that limit outdoor use, often using somewhat arbitrary baselines such as the previous year's use. The strategy for drought management has been expanded in recent years to put more emphasis on drought planning instead of mere drought response (Billingsley, 2002). Drought management plans may vary from place to place, but progressive drought plans generally include four main elements which are listed below (Inman-Bamber, 2004). Each of the four elements contains sub-elements that must be taken into account in order to formulate a successful drought response plan:

- An analysis of how water supplies are likely to vary for a range of droughts;
- An understanding of local water requirements as well as the ability to reduce them;
- Established measures for reducing demands in an equitable manner;
- Creation of a modern system designed for flexibility to match the conditions of the drought.

A water budget rate structure is a sword that cuts both ways during drought (Inman-Bamber, 2004). Initially, it establishes an empirical and quantifiable limit to the amount of water that a customer is entitled to use at a given price from a given tap. Also, it supposedly reserves a volume of water for the customer to use as he/ she sees fit. Water budgets have the potential to protect the utility from overuse and to protect the customer from having his or her water allocated to other uses or micromanaged by the utility. In time of shortages, water budgets allow a water provider to quickly and easily identify excess use and even penalize it if necessary.

By summing all water budgets, utilities can quickly understand the amount of water likely to be required to meet customer demands in any given month. During a drought, water budgets have the potential to assist water utilities in more fairly apportioning demand reductions among customers with different needs and among different customer classes (Mayer et al., 2008). This is because the reference point for reductions is based on the water required by each customer in normal times. Archeologically, when customers are asked to reduce their use from the previous year, justified complaints arise from those who are already conserving and don't have as much room for additional limitations.

The water budget rate structure, along with its billing system, informs all customers on a regular basis of the required use reductions. The water bill can show customers how much water they are allocated during a drought. This information can be developed well before a drought occurs as part of the budgeting process. This is a far more reliable and effective way to implement drought-related conservation because it is preplanned rather than improvised (Mayer et al., 2008).

The billing system is already in place, and the bills can provide the public with the information needed to respond to the drought. Another way that water budget rate structures aid with drought plan implementation is in the enforcement of mandatory demand limitation.

In each billing period, a simple query of the billing database can tell the utility which customers have complied with drought restrictions and remained within budget and those who have not. If the higher water rates being charged are not sufficient to elicit cooperation, then additional fines and penalties can be considered (Mayer et al., 2008).

This is a highly reliable system. Unlike the “water cop” approach in which customers are ticketed if they happen to be observed violating the drought restrictions, a water budget drought enforcement program automatically identifies every customer who is not complying. This enables fair and uniform enforcement. Water enforcement patrols are costly and can only catch violators “in the act” of violating a watering restriction. A water budget, however, provides a regular and automatic check on which customers are in or out of compliance with drought response (Mayer et al., 2008).

2.7. Overview of Already Existing Water Budgeting/ Management Tools

2.7.1. Cropwat

Cropwat is a pilot initiative that helps the farmers make decisions about when and how much to irrigate their fields based on the crops planted (Water Organisation Trust, 2017).

Cropwat is a decision support tool developed by the Land and Water Development Division of FAO (FAO, 2018). Cropwat for Windows is a computer program based on the previous Disk Operating System (DOS) versions for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns (FAO, 2018). Cropwat can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rain fed and irrigated conditions.

All calculation procedures used in Cropwat are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 "Crop Evapotranspiration - Guidelines for computing crop water requirements" and No. 33 titled "Yield response to water" (FAO, 2018).

As a starting point, and only to be used when local data are not available, Cropwat includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5,000 stations worldwide from Climwat, the associated climatic database (FAO, 2018).

The development of irrigation schedules in Cropwat is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern defined by the user, which can include up to 20 crops (FAO, 2018).

Apart from a completely redesigned user interface, Cropwat for Windows includes a host of updated and new features that includes (FAO, 2018):

- Monthly, decade and daily input of climatic data for calculation of reference evapotranspiration (ET_o)
- Backward compatibility to allow use of data from Climwat database possibility to estimate climatic data in the absence of measured values for decades

- Daily calculation of crop water requirements based on updated calculation algorithms including adjustment of crop-coefficient values calculation of crop water requirements and irrigation scheduling for paddy & upland rice
- Using a newly developed procedure to calculate water requirements including the land preparation period interactive user adjustable irrigation schedules daily soil water balance output tables easy saving and retrieval of sessions and of user-defined irrigation schedules graphical presentations of input data
- Crop water requirements and irrigation schedules easy import/export of data and graphics through clipboard or ASCII text files extensive printing routines, supporting all windows-based printers context-sensitive help system

With all the information and how useful is the Cropwat software, a gap was observed. Cropwat is not a user friendly software and requires real time weather data to compute the daily water needs. It is an irrigation scheduling software hence it does not compute or predict the water quantities required by the crop in the coming future.

2.7.2. ZIMsched

According to Lecler (2000), ZIMsched is a robust, scientifically sound and yet simple irrigation management and yield forecasting tool. Spreadsheets were selected as the basis for developing ZIMsched because they are familiar to many people and have very powerful in-built functionality. Use of ZIMsched irrigation scheduling tool was shown to have potential to facilitate up to 20 % savings in annual irrigation water requirements in many cases (Griffiths and Lecler, 2001).

The irrigation management tool has been accepted by farmers due to its simplicity, less time-consuming and easy to operate. When using ZIMsched for determination of irrigation water applications, a user simply enters recorded daily values for maximum and minimum temperature, A-pan evaporation, Total Available Moisture (TAM) of the soil for the field in question, the saturated drainage coefficient, rainfall and irrigation water applications and observes changes to the estimated soil water status and the date when the estimated soil water is expected to reach a level at which an irrigation water application is needed (Lecler, 2000).

ZIMsched concepts and algorithms which are used to account for the major components of the water budget and the crop yield estimates include evaporation which takes into account crop coefficient, Atmospheric Evaporative Demand (AED), rooting characteristics and Evaporation Under Conditions of Soil Water Stress, Surface Runoff, drainage, effective rainfall and Crop Yield Estimates parameters.

Though ZIMsched is an irrigation management tool and mainly depends on daily climatic data, some of its concepts and algorithms forms the bases for the development of sugarcane CWU water budgeting tool for CWM in Zimbabwe's Lowveld which will be making use of historical climatic database.

2.7.3. ZIMsched 2.0

The spreadsheet-based irrigation scheduling and crop yield forecasting tool ZIMsched (Lecler, 2000), was refined to a deterministic crop and irrigation systems simulation model, ZIMsched 2.0 (Lecler, 2003). The refinements to the ZIMsched 2.0 model were developed in order to estimate how water management, different irrigation system characteristics and the infield measures of irrigation systems performance indices derived by the Mobile Irrigation Performance Unit (MIPU) impacted on potential crop yields, irrigation water requirements and water losses (Lecler, 2003). The main refinements to the original ZIMsched model developed by Lecler (2000) and their validity is described below.

2.7.3.1. Evaporation from the soil and plant (transpiration)

In ZIMsched 2.0, evaporation from the soil and the crop were determined separately, based largely on the algorithms described in the Food and Agriculture Organisation of the United Nations (FAO) Irrigation and Drainage Paper No. 56, by Allen et al., (1998) (Lecler, 2003). According to Lecler (2003), it was very important to separate the processes because prior to the development of significant canopy cover, water losses are dominated by evaporation from the soil surface. This evaporative loss can be very variable because different types of irrigation systems wet different fractions of the soil and there are also variations in wetting frequencies. Effective early season water losses and associated crop coefficients can thus vary significantly, depending on the type of irrigation system and its operation (Lecler, 2003).

The main modification to the algorithms given in FAO 56 (Allen et al., 1998) involved the incorporation of a relationship between the rate of canopy development and thermal time (Lecler, 2000), and small refinements to the procedures used to calculate the soil surface water evaporation coefficient (K_e). The rate of canopy development is mainly dependent on temperature and therefore, the concept of relating canopy development to thermal time was superior to relating it to calendar days. This is because variations in the rate of canopy development that are associated with different planting/ ratooning times (early, mid, late season), and seasonal temperature variations can be automatically accounted for (Lecler, 2003).

The FAO 56 coefficient, K_e, describes the potential evaporation of water from the soil surface, which can be assumed to take place in two stages (Allen *et al.*, 1998). In the first stage, when the topsoil is wet following irrigation or rainfall, K_e is maximal. In the second stage, after a certain amount of water has evaporated, the soil surface is drier and Ke reduces, eventually reaching zero when there is minimal water near the soil surface for evaporation (Allen *et al.*, 1998).

In FAO 56, the effects of shading are accounted for through the fraction of the soil surface covered by vegetation, f_c (Allen *et al.*, 1998). In ZIMsched 2.0, f_c is determined using thermal time (TT), as given in Equation 2-2 (Lecler, 2003):

$f_c = Grd_{ini}$ for $TTA < 340$ **Equation 2-2**

$f_c = \max(Grd_{ini}, \min(0.99, ((TT-340)/(1000-340))0.99)$ for $TTA > 340$

Where

Grd_{ini} = initial ground cover, e.g. due to surface mulching

TTA = accumulated thermal time (degree days)

= (Tmax + Tmin)/2 - 12ºC

T_{max} = daily maximum temperature (ºC)

T_{min} = daily minimum temperature (ºC)

Where 'max' and 'min' select the maximum or minimum of the terms in brackets which are separated by commas. The numerical values '340' and '1000' were based on analysis of leaf area index (LAI) versus thermal time (unpublished data) (Lecler, 2003).

Determination of K_e requires a daily water balance computation in order to calculate the cumulative depletion, D_e, for the surface layer from a wet condition. In ZIMsched 2.0, the depth of the surface layer was taken as 0.1 m (Lecler, 2003). The daily soil water balance equation for the exposed and wetted soil fraction, f_{ew}, of the surface layer (Allen *et al.*, 1998) is as shown in Equation 2-3 below:

$$D_{e,i} = D_{e,i}\text{-}1 - (P_i - RO_i) - I_i/f_w + E_i/f_{ew} + T_{ew,i} + DP_{e,i}$$ **Equation 2-3**

Where

$D_{e,i}\text{-}1$ = cumulative depth of evaporation following complete wetting from the exposed and wetted fraction of the topsoil at the end of day i-1 (mm)

$D_{e\,i}$ = cumulative depth of evaporation following complete wetting from the exposed and wetted fraction of the topsoil at the end of day i (mm)

P_i = rainfall on day i (mm)

RO_i = stormflow/ runoff from the soil surface on day i (mm)

I_i = irrigation depth on day i that infiltrates the soil (mm)

E_i = evaporation from the soil surface on day i (mm)

$T_{ew,i}$ = depth of transpiration from the exposed and wetted soil surface layer on day i (mm)

$DP_{e,i}$ = deep percolation from the topsoil layer on day i if soil water content exceeds field capacity (mm) (Note: for the determination of K_e, $DP_{e,\,i}$ is always assumed equal to zero as although the surface layer may be draining, in such a state the surface will likely be wet and evaporation from the surface uninhibited)

f_w = fraction of the soil surface wetted by irrigation (0.01 - 1)

f_{ew} = exposed and wetted soil fraction (0.01 - 1)

With limits 0. $D_{e,\,i}$ .TEW

$TEW = 1000(2_{dul} - 0.52_{pwp})\ Z_e$

TEW = total evaporable water from the top soil (mm)

2_{dul} = soil water content at the drained upper limit (field capacity) (m^3/m^3)

2_{pwp} = soil water content at permanent wilting point (m^3/m^3)

Z_e = depth of the surface soil layer that is subject to drying by way of evaporation, taken as 0.1 m in ZIMsched 2.0.

Use of Equation 2-4 is simplified in FAO 56 where it is assumed that all water infiltrates, i.e. zero runoff (RO) and that transpiration from the surface layer that contributes to E_i is negligible.

In ZIMsched 2.0, however:

- Stormflow/ RO is not assumed to be zero, but is calculated using the modified SCS stormflow equation (Schulze, 1995).
- Transpiration, (T_{ew}), from the soil layer contributing to E_i is also not assumed to be zero. The proportion of the actual transpiration for a day that is extracted from the topsoil layer is given in Equation 2-5 below:

$F_{T,\,i} = \max\,(0,\ 0.1/(R_{fac}\ .\ S_{dep}).(TAM_{10} - D_{e,\,i}\text{-}1)/TAM_{10})$

Where

$F_{T,\,i}$ = fraction of actual transpiration on day i that is extracted from the topsoil layer

R_{fac} = proportion of total soil depth that is penetrated by roots

= 0.4 for TTA < 340

= min (1, 0.6(TTA-340)/(980-340) + 0.4) for TTA .340

Note: it is assumed that maximum rooting depth coincides with the development of full canopy cover (Jensen *et al*., 1990)

TTA = accumulated thermal time (degree days)

S_{dep} = total soil depth (m)

TAM_{10} = Total available water in the topsoil layer of 0.1 m, viz. (2dul - 2pwp)

0.1

2_{dul} = soil water content at the drained upper limit (field capacity) (m^3/m^3)

2_{pwp} = soil water content at permanent wilting point (m^3/m^3)

$D_{e,\,i}$-1 = cumulative depth of evaporation following complete wetting from the exposed and wetted fraction of the topsoil at the end of day i-1 (mm)

Thus, based mainly on the algorithms given in FAO 56, the evaporation losses associated with different types of irrigation systems, the effects of planting/ratooning in different months and the effects of hot or cold intra-seasonal conditions on the rate of canopy development and associated water use were accounted for in ZIMsched 2.0 (Lecler, 2003).

2.7.3.2. Atmospheric evaporative demand (AED)

ZIMsched 2.0 uses the evaporation measured using a class A-pan to represent AED. In Zimbabwe, most of the research involving sugarcane crop water use has been undertaken using the evaporation from A-pans as the reference evaporation. Nevertheless, the correlation between the evaporation from an A-pan and the evaporation from a cropped surface can be markedly different in summer and winter, and also under adjective conditions or when there are wide variations in wind and humidity (Allen *et al.*, 1998).

For this reason, relationships between:

- the FAO Penman-Monteith reference evaporation,
- evaporation from a class A-pan, and
- evaporation from a relatively simple atmometer device that may better represent a plant,

were investigated for possible incorporation into ZIMsched 2.0. However, Griffiths and Lecler (2001) showed that there was very little difference between using A-pan data with appropriate pan factors and the Penman-Monteith equation with data from an automatic weather station (AWS), especially when the data is averaged over a five day period, which is equivalent to a typical irrigation cycle. As the data from the AWS were only collected beginning in 1998, A-pan data were used as the default option in ZIMsched 2.0.

2.7.3.3. Rooting characteristics

In ZIMsched 2.0, the root zone which delimits the volume of soil from which water is available to the crop is dynamic in order to account for root growth (Lecler, 2003). The depth of the zone from which water uptake can occur, R_z, is calculated by assuming that maximum rooting depth coincides with the development of full canopy, which in ZIMsched 2.0 is predicted from a relationship with TT as shown in Equation 2-4 below (Lecler, 2003):

$R_z = R_{fac} \cdot TAM$ **Equation 2-4**

Where

R_{fac} = proportion of total soil depth that is penetrated by roots

= 0.4 for TTA < 340

= min (1, 0.6 (TT-340)/(980-340) + 0.4) for TT_A . 340

TT_A = accumulated thermal time

2.7.3.4. Transpiration under conditions of soil water stress, runoff, drainage and effective rainfall

The procedures used in ZIMsched 2.0 for the calculation of:

- Transpiration if the soils are too wet or too dry,
- Surface runoff (or stormflow),
- Drainage or deep percolation, and
- Effective rainfall,

were unchanged from the algorithms used in the original crop yield and irrigation scheduling tool, ZIMsched. These procedures are described by Lecler (2000).

ZIMsched 2.0 was developed to help ensure the long term viability of the sugarcane industry by increasing insight into the performance of the various water management and irrigation systems together with the development and adoption of strategies to improve performance (Lecler, 2003).

2.7.3.5. Irrigation systems uniformity

To account for the effects of irrigation uniformity on systems performance, the water budget and yield estimate in ZIMsched 2.0 was based on the average of three equal areas each receiving different amounts of water at each irrigation application (Lecler, 2003). The simulated amount of water on each of the three areas was varied, dependent on the uniformity measure of the irrigation system.

One third of the area was simulated to receive the mean irrigation water application, one third received the mean water application plus a percentage (D %) of the mean and one third received the mean minus a percentage (D %) of the mean (Lecler, 2003).

Assuming normally distributed irrigation water applications, Equations 2-5, 2-6 and 2-7 were derived to relate the percentage deviation (D %) corresponding to a given coefficient of uniformity (CU), statistical uniformity (SU) or distribution uniformity (DU) respectively (Lecler, 2003). For example, if the mean application for a furrow irrigation event is 50 mm, and the DU was equal to 60, one third of the area would receive an average of 50 mm, one third would receive an average of 69 mm and one third would receive an average of 31 mm at each irrigation water application (Lecler, 2003).

$$D\% = 96.48 - 96.50.\ (DU/100) \qquad \textbf{Equation 2-5}$$

$$D\% = 122.49 - 122.49.\ (SU/100) \qquad \textbf{Equation 2-6}$$

$$D\% = 149.97 - 149.96.\ (CU/100) \qquad \textbf{Equation 2-7}$$

Where

D% = percentage of mean application to be added and subtracted from the mean to determine irrigation application amounts

DU = Distribution Uniformity

SU = Statistical Uniformity

CU = Christiansen’s Coefficient of Uniformity

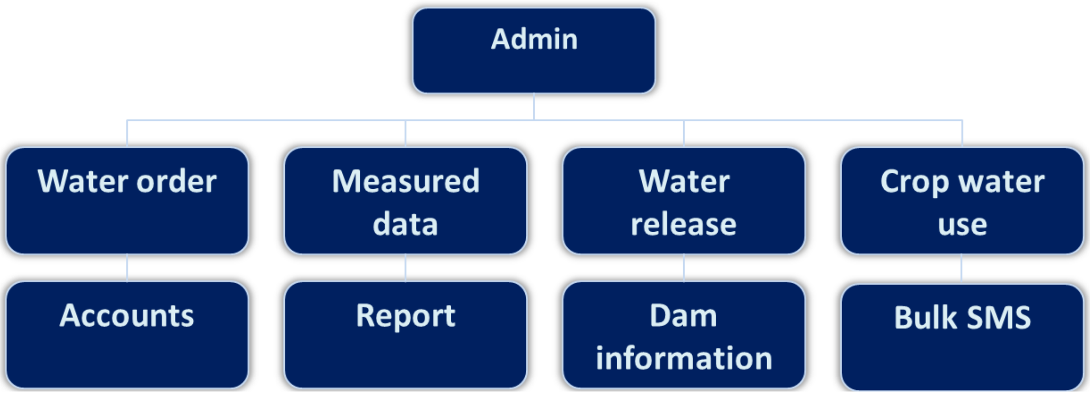
Since the ZIMsched 2.0 was developed to improve the accuracy of ZIMsched, it still did not cover the future water budget predictions which is the main focus for this study.

2.7.4. Water Administration System (WAS)

According to Benade (2017), the Water Administration System (WAS) which was developed in 2006 is an integrated management tool for irrigation schemes that delivers water on demand through canal networks, pipelines and rivers. WAS is used for water distribution management and for the calculation of canal and dam operating procedures for a given down-stream demand.

WAS program is currently in use at all the major irrigation schemes and a number of smaller irrigation boards throughout South Africa (Benade, 2017). The main benefits of using the WAS information system according to Benade (2017) are as follows: minimizing of water distribution losses, improved control of water orders, releases, distribution and usage per Farmer, management of date and time related flow data collected from electronic loggers or mechanical chart recorders, integrates with the Zednet platform on the Internet which is used to automate the import of data from multiple measuring stations into the WAS database, availability of an extensive list of water reports on a farm and scheme level, increased productivity of scheme management personnel, reliance on an integrated accounting system that improves debit management and Improvement of the overall water management on irrigation schemes.

The program makes use of nine modules, as shown in Figure 2-3 below, which are fully integrated, making it possible to cross-reference relevant data and information.



Source: (Benade, 2017)

Figure 2-3: WAS Modules

These modules can be implemented partially or as a whole, depending on the requirements of the user. The WAS program saves all information in a Firebird (SQL) database that can be installed on a single PC or on a server for use over a network. This makes it possible for the manager, accounts personnel and water office personnel to access the database from PC's in their own offices. What makes the WAS program unique is the fact that it is an integrated system that includes the water allocations, water use, water distribution, water measurement, crop water use, billing information and a bulk SMS system (Benade, 2017).

Of all these nine modules, the researchers' interest in this project proposal is the water order, water release and crop water use modules. The water order module is based on flow rate and duration, the Water release module links with the Water administration and Water order modules and lastly the crop water use module which is used to calculate the water required for a specified period for all planted crops is based on the plant date, area planted and the crop water use information. The information needed is the Days After Planting (DAP) and the corresponding water use per day (mm/day) apart from the plant date and area planted in the crop water use module (Benade, 2017).

With all the information pertaining to how these modules operate, a gap was observed on these three modules. In irrigation design, the crop water needs determine the water discharge but in this case, the water order module is being defined by the pump flow rate and pumping duration. This makes the water order module more biased towards the billing purposes only not for the supply of adequate crop water needs as the water supply is determined by the abstraction capacity therefore there is no room for expansion to meet the crop water needs for increased production. In the case of the crop water use module, that one is more biased towards irrigation crop water needs as only the date after planting which defines the crop factors and daily water use are used.

2.7.5. Water Sense Water Budget Tool

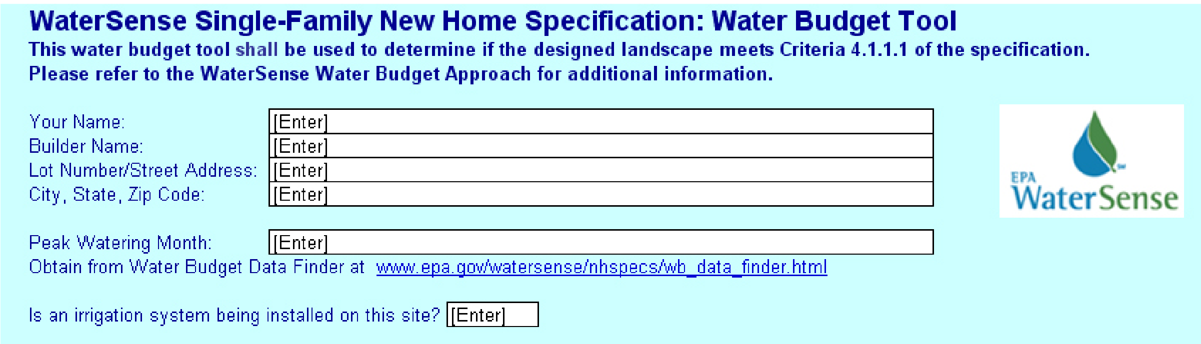
Water Sense created the Water Budget Tool as one option to help builders, landscape professionals, and Water Sense irrigation partners meet the criteria for the 2009 Water Sense Single-Family New Home Specification (WaterSense, 2010).

According to WaterSense (2010), the water budget tool is comprised of three sections (Part 1, Part 2, and Part 3), each on its own worksheet and works as follows:

Part 1: Baseline & LWA- Collects basic information and calculates the landscape water allowance (LWA).

Basic Information

A. Fill in the information for the landscape in the white boxes at the top of the sheet as shown in Figure 2-4 below:



WaterSense Single-Family New Home Specification: Water Budget Tool
This water budget tool shall be used to determine if the designed landscape meets Criteria 4.1.1.1 of the specification.
Please refer to the WaterSense Water Budget Approach for additional information.

Your Name: [Enter]
Builder Name: [Enter]
Lot Number/Street Address: [Enter]
City, State, Zip Code: [Enter]

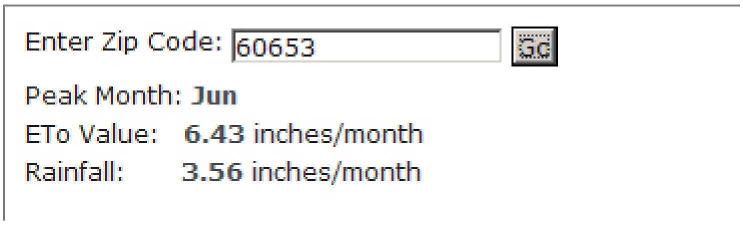
Peak Watering Month: [Enter]
Obtain from Water Budget Data Finder at www.epa.gov/watersense/nhspecs/wb_data_finder.html

Is an irrigation system being installed on this site? [Enter]

Source: (WaterSense, 2010)

Figure 2-4: Basic information data input on a Water Sense Water Budgeting Tool

B. To get the peak watering month, evapotranspiration (ET_o) value, and rainfall, One has to visit the Water Budget Data Finder on the Water Sense website. Enter the zip code where the landscape is located and click the “Go” icon. The tool will give you three pieces of information: peak watering month, evapotranspiration (ET_o) value, and rainfall as shown in Figure 2-5 below. Enter the peak month (June in the example) in the water budget tool in the white box labeled “peak watering month." Record and save the other pieces of information (ET_o and Rainfall) as you will need these later in the tool.



Source: (WaterSense, 2010)

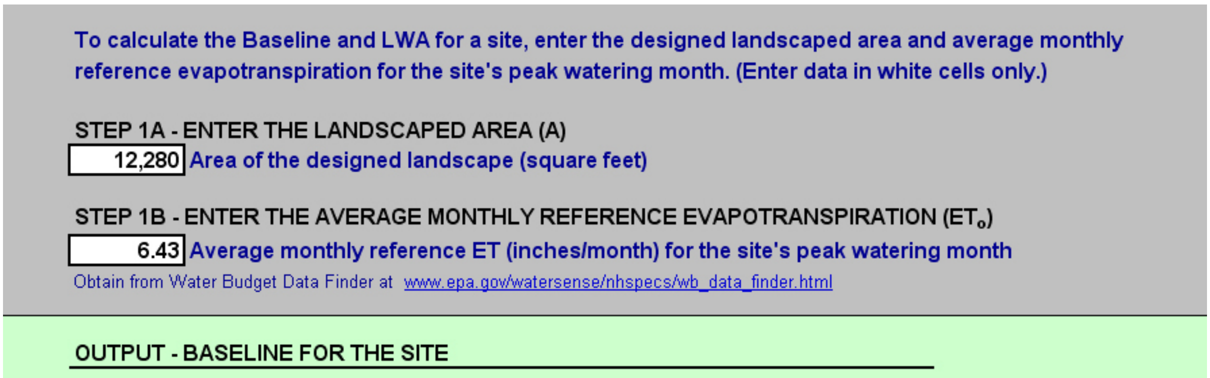
Figure 2-5: Water Budget Data Finder showing peak watering month, evapotranspiration (ETo) value, and rainfall

C. The drop down menu is used to select whether or not an irrigation system is installed on this site.

This information will populate automatically throughout the tool, and you will not have to enter it again. Now, proceed through the following steps.

Step 1

Step 1A: Determine and input the area of the landscape as shown in Figure 2-6 below:



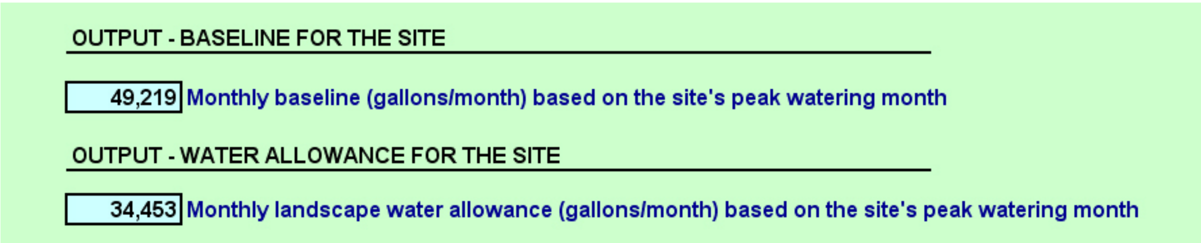
Source: (WaterSense, 2010)

Figure 2-6: Window for inputting the area on Water Sense Water Budgeting Tool

Step 1B: Enter the ET_o Value obtained from the Water Budget Data Finder in the box above and in this case 6.43 was used as an example (refer to Figure 2-6 above).

The tool will automatically generate two “output” values once you have completed Step 1. They are:

Output 1: The monthly baseline which is the amount of water a typical landscape would use during the peak watering month e.g. 49,219 gallons/month as shown in Figure 2-7 below.



Source: (WaterSense, 2010)

Figure 2-7: Window for output values on Water Sense Water Budgeting Tool

Output 2: The monthly landscape water allowance which represents an efficient allotment of water that the landscape may be designed to use during the location’s peak watering month e.g. 34,453 gallons/ month as shown in Figure 2-7 above.

Part 2: LWR- Calculates the landscape water requirement (LWR) or how much water the landscape will need.

In Part 2, entering of more specific information about the landscape will be done. The Water Budget Tool will calculate the amount of water the landscape will require during the location’s peak watering month.

Step 2

Step 2A: Entering the value received from the Water Budget Data Finder for rainfall is done as shown in Figure 2-8 below.

To calculate the LWR for the site, enter the information requested below for the site's peak watering month. (Enter data in white cells only.)

STEP 2A - ENTER THE AVERAGE MONTHLY RAINFALL (R) AT THE SITE FOR THE PEAK WATERING MONTH IDENTIFIED IN PART 1

3.56 Average monthly rainfall (inches/month) for the site's peak watering month

Obtain from Water Budget Data Finder at www.epa.gov/watersense/nhspecs/wb_data_finder.html

Source: (WaterSense, 2010)

Figure 2-8: Window for inputting rainfall values on Water Sense Water Budgeting Tool

Step 2B: Enter details about the landscape in Figure 2-9 below. This will enable the tool to estimate the landscape water requirement, or how much water the landscape will actually require during the peak watering month.

Zone	Hydrozone/Landscape Feature Area (sq. ft.)	Plant Type or Landscape Feature	Landscape Coefficient (K_L)	Irrigation Type	Distribution Uniformity (DU_{LQ})	LWR_H (gal/month)
1	7,150	Turfgrass - High water requirement	0.8	Fixed Spray	65%	29,168
2	2,200	Shrubs - Medium water requirement	0.5	Drip - Standard	70%	4,555
3	2,030	Groundcover - Low water requirement	0.2	Drip - Standard	70%	716
4	900	Nonvegetated Softscape		No Irrigation	NA	-
5						-
6						-
7						-
8						-
9						-
10						-
11						-
12						-
13						-
14						-
15						-
Total Area =	12,280	Landscape Water Requirement for the Site (gal/month)				34,439

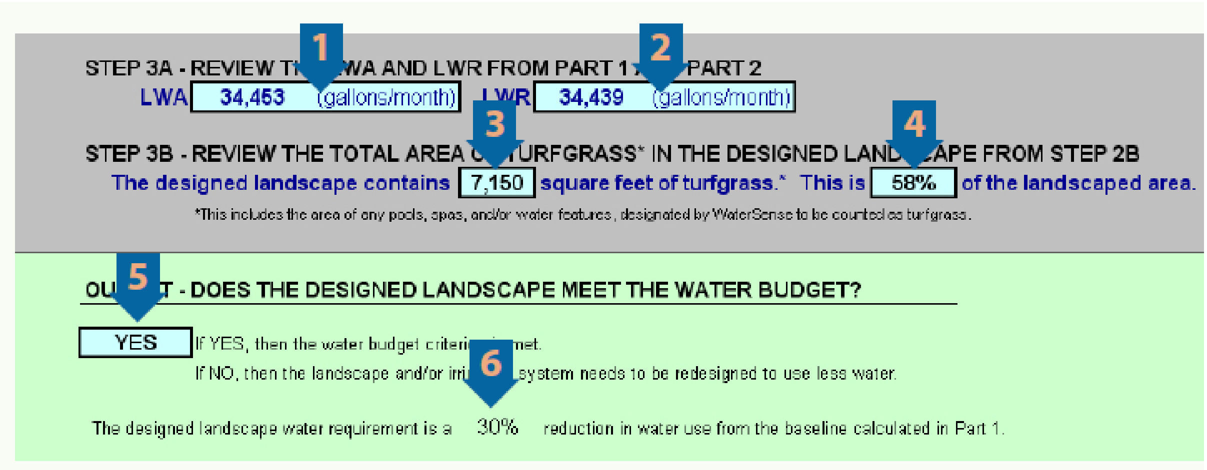
Source: (WaterSense, 2010)

Figure 2-9: Window showing how landscape details are inputted on Water Sense Water Budgeting Tool

As shown in column 2, for each hydrozone, or group of plantings that have similar watering needs, the area in square feet that it covers is entered. In column 3, the plant type or feature from the list that best describes each hydrozone is selected. If an irrigation system is installed, select the type of irrigation being used on each hydrozone as shown in column 4.

Output: As it is shown at the lower right corner of the above Figure 2-9, the tool automatically calculates the amount of water your landscape will require during the peak watering month and in this case is 34,439 gallons.

Part 3: Results-Displays the results of the tool as shown in Figure 2-10 below and requires no new information to be entered.



Source: (WaterSense, 2010)

Figure 2-10: Final results window on Water Sense Water Budgeting Tool.

According to Figure 2-10 above, the description of the numbers in the window is as below:

1. The LWA (landscape water allowance) is the amount of water the landscape is permitted under section 4.1.1.1 of the 2009 Water Sense Single-Family New Home Specification.
2. The LWR (landscape water requirement) is the amount of water the landscape would need during the peak watering month for your location.
3. Displays the total area of turf grass in the landscape.

4. Displays the percent of the total landscape that is comprised of turf grass.
5. If the output shows:

"YES" - Congratulations! You have met the criteria.

"NO" - You will need to make adjustments to your planned landscape of Part 2 reducing the size of the hydrozones with highest water requirements (LWR_H) or changing to lower water use plants are good places to start.

6. Shows the expected reduction in water use during the peak watering month for the landscape when compared to the landscape of a typical single-family new home.

Unlike the Water Sense water budgeting tool which relies on satellite data and can only budget for a peak watering month, the CWU based water budgeting tool is based on historical daily data which enables it to predict daily, monthly or yearly water requirements in offline mode.

2.8. Summary of already existing tools versus the newly developed tool

The summary of the already existing tools versus the newly developed water budgeting tool is as shown in Table 2-1 below.

Table 2-1: Summary of already existing tools versus the newly developed tool

1. Cropwat (FAO, 2018)	**Water Budgeting Calibration Tool For Catchment Water Management**
➢ Not a user friendly tool ➢ Requires real time weather data to compute the daily water needs. ➢ It is an irrigation scheduling tool hence it does not compute or predict the water quantities required by the crop in the coming future.	➢ User friendly tool ➢ Requires historical weather data to compute monthly and yearly water needs ➢ Future water needs prediction tool
2. ZIMsched (Lecler, 2000)	**Water Budgeting Calibration Tool For Catchment Water Management**

➢ Irrigation scheduling tool ➢ Requires real time weather data to compute the daily water needs. ➢ Forms the bases of the budgeting tool	➢ Future water needs prediction tool ➢ Requires historical weather data to compute monthly and yearly water needs
3. ZIMsched 2.0 (Lecler, 2003)	**Water Budgeting Calibration Tool For Catchment Water Management**
➢ Developed to improve the accuracy of ZIMsched, it still did not cover the future water budget predictions which is the main focus for this study. ➢	➢ Future water needs prediction tool ➢ Requires historical weather data to compute monthly and yearly water needs
4. Water Administrative System (WAS) (Benade, 2017)	**Water Budgeting Calibration Tool For Catchment Water Management**
➢ The pump flow rate and pumping duration determine water to be supplied. ➢ Irrigation scheduling tool	➢ Crop water needs determine water to be supplied. ➢ Future water needs prediction tool
5. Water Sense Water Budget Tool (WaterSense, 2010)	**Water Budgeting Calibration Tool For Catchment Water Management**
➢ Relies on real time satellite data and can only budget for a peak watering month	➢ based on historical daily data which enables it to predict daily, monthly or yearly water requirements in offline mode

2.9. Institutional Arrangements for Water Management and Allocation

Apart from the use of Tools, Institutional arrangements which provide positive incentives to use water more effectively are also a key to successful uptake and implementation of best water management practices which, in turn, will lead to higher productivity, increased and sustained profits, and a healthy environment both now and in the future. Since the irrigated agricultural sector often uses the major portion of the available water resources, facilitating gains in efficiency in this sector is a vital strategic issue. There are at least two contrasting options by which water allocations can be instituted by Water Management Authorities (WMA), namely (Lecler, 2004):

- Volume per unit time water allocations, issued at an estimated level of assurance.
- Fractional water allocations and capacity sharing (FWACS).

2.9.1. Volumetric water allocations and priority-based reservoir and river operating rules (VWA-PRROR)

Most of the water planning and allocation decision support tools procedures which have been developed, and traditionally used in southern Africa, have been based on VWA-PRROR. For example, an irrigation water allocation of 10000m^3 ha^{-1} annum^{-1} may be issued and expected to be available, say, eight years out of ten (Lecler, 2004). If VWA-PRROR are instituted and the flow in a given river or the level of a dam is low, users have their access limited relative to other users, according to a priority structure. Since licenses are based on a volume entitlement, upstream users may pump a river dry in low flow periods even although the amount pumped may be less than their license entitlements thereby causing serious conflicts and problems for downstream users and the WMA (Lecler, 2004).

Apart from the potential for recurrent conflicts, the major problem with VWA-PRROR, is that there is little, if any, incentive for individual water use sectors to implement effective water conservation and demand management strategies (Lecler, 2004). This is because with VWA-PRROR individual users have very limited or no control as to when in the future their water abstractions may be reduced. Therefore, whilst water is available, the motivation is for users to abstract it. Also, if a user's water is stored in a shared multi-purpose reservoir, there is the risk that any water savings made by an individual and 'left' (stored) in the storage reservoir, may, at a later stage, be ceded to another user deemed to have a higher priority of use, even if this previously saved or unused water had been paid for (Lecler, 2004). The outcome of the 'use it or lose it' mindset which becomes inherent in such a system is that with the diminished incentive to save water, the number and duration of water shortage periods is likely to increase and the overall water use productivity is likely to decrease.

An example of the potentially catastrophic results such an allocation and licensing option has had, happened in the Runde River catchment in Zimbabwe. Between 1980 and 1992 the available water reserves in the Runde catchment were severely depleted culminating, *inter alia*, in the near collapse of the country's sugar industry. The VWA-PRROR institutional arrangements and water allocation system which, during the 12 years preceding 1992, led many users to take as much water as they could, when it was available, played a major role in this catastrophe (Lecler, 2004).

2.9.2. Fractional water allocations and capacity sharing (FWACS)

Under a FWACS allocation and water management system, water allocations/ licenses do not reflect a volume, but rather entitlement to a percentage or fraction of the total available river flow (Lecler, 2004). The rate at which water can be extracted for use or storage by any given user, is then dependent on the flow in a defined river section at any given time multiplied by the licensed allocation fraction (Lecler, 2004). The weekly or monthly volumes available for potential abstraction will vary significantly with the climate of the season.

The practical challenge of measuring and monitoring flows, water abstractions, and successfully implementation of FWACS was achieved in practice in the Mazowe catchment in Zimbabwe according to Doertenbach (1998) (Lecler, 2004). In 1984, eleven commercial farmers formed Zimbabwe's first "Combined Irrigation Scheme" (CIS). Each of the CIS members subscribed to a defined percentage of the cost of construction of a dam and its related infrastructure and members further agreed that each of them would be entitled to the same defined percentage or "fraction" of the annual new storage capacity of the dam to which the CIS was entitled (Lecler, 2004). This practice allowed members to manage their own percentage share of the stored water and manage their own risk (of failure of supply) independently. However, a management system was needed to ensure its success.

The water in the reservoir was treated like money in a bank. Each of the participants was given a separate account, with a facility for both deposits and withdrawals. The new water to which the parent Water Right was entitled each month was quantified, separated into the appropriate percentages or fractions and deposited into each individual account. According to Lecler (2004), Doertenbach (1998) explained that the normal river flow coming into the reservoir was also quantified and deposited into the account of the river itself, or the system as it was called.

Flow measuring devices were installed at each pump and canal off take so that withdrawals could be accurately measured and debited to each account. Monthly evaporation losses were calculated and debited to each account in proportion to the account holder's percentage of total storage in the reservoir that month. At the end of each month, the reservoir's assets were reconciled in the same manner as the accounts in a bank, to confirm that the total of all accounts matched the amount of water in the reservoir. Bank statements were produced monthly for each account, showing deposits, withdrawals and a month-end balance. These calculations, whilst difficult to manage manually, were easy, quick and accurate to make when computers and spreadsheets became readily available, thus according to Doertenbach (1998) (Lecler, 2004).

The same management methods were applied to water that was released from the reservoir. This water was a mixture of natural river flow (which belonged to "the system" account) and stored water released for transmission to account holders downstream. The amount of water released (deposited) into the river was measured, as was the amount abstracted (withdrawn) by all those abstracting water downstream of the reservoir. According to Lecler (2004), Doertenbach (1998) noted that not all downstream abstractors were members of the CIS and both members and non-members also had Rights to river flow (or system water) which was passed through the reservoir. At a point downstream of the last CIS participant, the amount of water flowing downstream was also measured. The section of river between the dam and the downstream measuring weir was then "reconciled" in the same manner as the reservoir.

Each month, the reconciliation of the river section between the dam and the downstream measuring weir produced a significant surplus or a small loss. The surplus in the downstream river section was assumed to be a combination of irrigation return flow and natural river accretions, and was called generation. Gains and losses in the reservoir itself were assumed to be due to normal inconsistencies in the smoothed surface area/capacity curves for the reservoir and/or natural generation from the section of the river submerged by the reservoir. In order to prevent the possibility of prejudice to other Right holders, the generation in both the reservoir and the section of river below the reservoir was quantified and deposited into the account of the system" so it could be withdrawn by those with Rights to river flow.

The new management system received broad approval from both the CIS members and non-member Right holders, as according to Doertenbach (1998) (Lecler, 2004). It was simple to calculate, easy to understand, mathematically verifiable, and transparent. Released storage could be mixed with natural river flow and safely transported downstream without suspicion or prejudice. Natural river flow was quantified more accurately than ever before and readily available to those with Rights to river flow.

The management system also satisfied the original requirements of the CIS participants, all of whom were free to manage their own stored water and risk of failure as their individual financial circumstances required, just as if they were owners of individual private reservoirs.

According to Lecler (2004), Apart from being implemented in practice successfully, FWACS has also been:

- Assessed in terms of equity and efficiency by Natsa *et al*. (2000),
- Assessed in terms of environmental water releases by Symphorian *et al*., (2002), and

- The principles underlying FWACS have been reported on in an Australian context by Dudley and Musgrave (1988) and Dudley (1990).

The main advantages of FWACS include:

It is relatively easy to audit and regulate water use. This is because because the rate (weekly / monthly / annual volume) which individual users are allowed to abstract at any given time can be determined from actual flow measurements and reconciliation (Lecler, 2004). Whilst presenting some practical implementation challenges, flow measurement and monitoring is a non-negotiable requirement if water is to be managed equitably under any system (Zagona and Carron, 2010).

The license conditions allow upstream and downstream users to be managed in an integrated fashion, as opposed to a license based on a volume entitlement which may result in upstream users pumping a river dry in low flow periods, even though the amount pumped may be less than their license entitlements, thereby causing serious conflicts and problems for downstream users and the WMA (Lecler, 2004).

Periods of high or low flows affect all users in a predictable, equal fashion. Most importantly, users are empowered to manage their water supply status/ security, and can receive direct benefits from any water savings they make. There is, therefore, a positive incentive to institute WCDM strategies.

There is also a framework to facilitate ‘win-win’ water trades. The associated transfer of water to more productive users, can therefore, take place transparently and with minimal administrative complications (Zagona and Carron, 2010). In addition, optimizing strategies such as deficit irrigation will be facilitated (English, 1990; Lecler, 1999). The overall result should be a significant improvement in the productive use of water and few conflicts.

Individual stakeholders will be confident that water savings resulting from investments can be stored and saved for use (or trade) at a later stage, for example, during droughts, rather than taken and possibly wasted in high rainfall seasons. This is a key aspect of FWACS, the significance of which should not be underestimated (Lecler, 2003).

2.10. Barriers to Implementation of Water Budgets

Water budget are undoubtedly not for everyone. Understanding potential barriers to implementation can be helpful when developing a strategy for moving forward with a new water budgeting concept. Some of the perceived barriers to adopting and implementing a water budget-based rate structure include (Mayer et al., 2008):

- Data requirements
- Software requirements
- Complexity
- Equity concerns
- Revenue requirements
- Lack of local precedent
- Political resistance
- Institutional resistance
- Cost of service concerns

In some cases these barricades can be overcome, in other cases they cannot.

2.11. Conclusion

Many water budgeting/ management tools have been developed over the past years. Different goals and approaches have been adopted in the development of these tools with many of them focusing on the irrigation water management or irrigation scheduling and mainly depend on daily weather data as their main input parameters for their operations. Those that are more into water budget predictions only consider the pumping capacities and pumping duration as their bases for budgeting. All these developments were made to ensure the saving of the precious water resource at all cost.

Contrary to the already developed tools, the developed sugarcane CWU water budgeting tool for CWM have potential to give accurate water budget predictions as it makes use of historical climatic database which is easy to update, and also a farmer who does not have access to either daily, weekly, monthly, yearly or historical weather data can easily use the tool to do their water budget predictions. This tool act as an updated version of the already developed tools as it will have a provision to bypass the database in the event current data needs to be used in case unpredicted rainfall is received and an immediate water budget is required. It has also a provision for the water billing.

CHAPTER THREE: RESEARCH DESIGN AND PROCEDURE

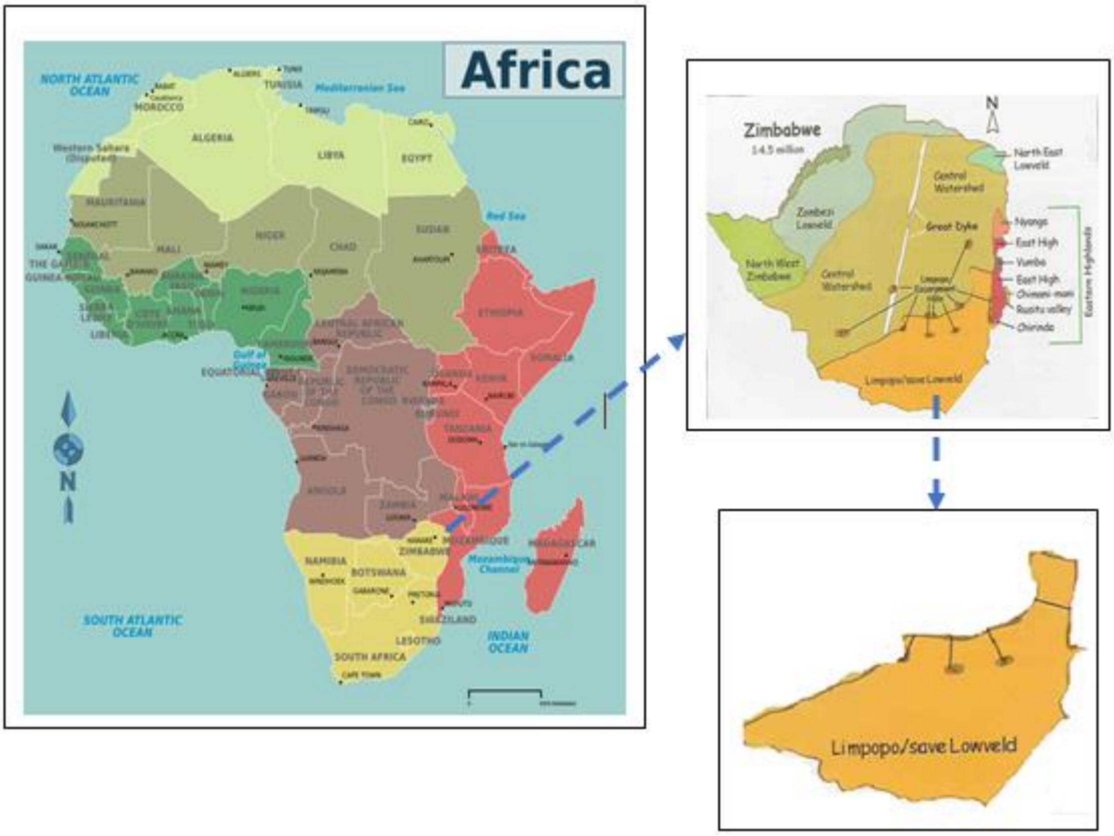
3.0. Introduction

This chapter highlights the design specifications used by the designer for the development of the water budgeting tool, from which the conceptual designs were developed. Criteria and selection used to choose the most suitable solution by the designer are clearly shown in this chapter.

3.1. Description of study area

Zimbabwe South–Eastern Lowveld is situated at an average longitude of -20.5° and latitude of 31.8˚C with an average altitude of 434 m above sea level (World Climate Home, 2018; World Weather Online, 2018). The area is hot and dry and it covers at least 20 % of Zimbabwe's total surface area (Lowveld Rhino Trust Zimbabwe, 2018).

Currently about 70 000 Ha in the South–Eastern Lowveld area is covered by sugarcane plantations for both ethanol and sugar production. The 70 000 Ha sugarcane plantations is distributed among Middle Sabi (3 000 Ha), Chisumbanje (7000 Ha) and Chiredzi (60 000). The Chiredzi area consists of Triangle and Hippo Valley Estates and several Out-growers. A map of the Zimbabwe south eastern Lowveld is shown in Figure 3-1 below:



Source: (Lowveld Rhino Trust Zimbabwe, 2018).

Figure 3-1: Zimbabwe map showing the Limpopo/ Save Lowveld

The rainfall regime is modal with mean annual rainfall of about 450 mm (450 litres/m^2) which normally occurs during summer season between October and April (World Climate Home, 2018; World Weather Online, 2018).

The area has mean annual min temperature of 18˚C in winter and mean max temperature of 37˚C in summer. Water supply for irrigation is from the Save River for the Middle Sabi and Chisumbanje areas and Mutirikwi River for the Chiredzi area.

3.2. Approach

Meteorological data from local Weather Stations for the past 14 years from 2003 to 2017 for the Lowveld area was used in determining crop water use/requirements. Canopy factors for different sugarcane growth stages, month of the year, and irrigation systems used for each individual field was integrated with a historical Class

A pan evaporation (Ep) and effective rainfall data to predict an average sugarcane daily, weekly, monthly and annual water and irrigation requirements.

As a way of validating the crop water requirements obtained from Weather Stations, a 30 year (1987 – 2017) time series Satellite data for longitude, latitude, elevation, max and min temperatures, precipitation, wind speed, relative humidity and solar for the Lowveld area was assimilated and analysed using Instat software to determine the reference evapotranspiration (ETo) for the area which was then multiplied by the canopy factor values. The Weather Station and Satellite reference evapotranspiration was used in determining sugarcane CWU for the period.

Irrigation water required which is to be supplied by the Catchment Water Management Agency is obtained from deducting effective rainfall from the total crop water requirements.

3.2.1. Crop Evapotranspiration (ET_c) Determination

ET_c was determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ET_o and the crop characteristics into the Crop coefficient (K_c) (Allen *et al.*, 1998). The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient. The K_c incorporates crop characteristics and averaged effects of evaporation from the soil (Allen *et al.*, 1998). The ET_c / water requirements for each day from the period 2003 to 2017 was therefore in this case determined using the relationship in the given Equation 3-1 below (Allen et al., 1998**;** Swanson and Fipps, 2013):

$$ET_c = K_c \times ET_o \qquad \text{Equation 3-1}$$

Where: K_c = Crop coefficient, crop or canopy factor for either Plant or Ratoon crop obtained from Msibi et al., (2014).

ET_o = reference evapotranspiration obtained from class A evaporation pan

Canopy factors for Plant and Ratoon Cane

Canopy/ Crop factor (K_c) used for plant cane are as shown in Table 3-1 below:

Table 3-1: K_c for plant cane

April	May	June	July	August	September	October	November	December	January	February	March
Plant	0.45	0.65	0.8	0.9	1	1	1	1	1	1	1
1	Plant	0.45	0.65	0.8	0.9	1	1	1	1	1	1
1	1	Plant	0.45	0.55	0.75	0.9	1	1	1	1	1
1	1	1	Plant	0.45	0.55	0.75	0.9	1	1	1	1
1	1	1	1	Plant	0.45	0.55	0.75	0.9	1	1	1
1	1	1	1	1	Plant	0.45	0.55	0.75	0.9	1	1
1	1	1	1	1	1	Plant	0.45	0.55	0.75	0.9	1
1	1	1	1	1	1	1	Plant	0.45	0.55	0.75	0.9
1	1	1	1	1	1	1	1	Plant	0.45	0.7	0.9
1	1	1	1	1	1	1	1	1	Plant	0.45	0.7
0.9	1	1	1	1	1	1	1	1	1	Plant	0.45
0.7	0.9	1	1	1	1	1	1	1	1	1	0.45
0.45	0.65	0.8	0.9	1	1	1	1	1	1	1	Plant

Source: (Msibi et al., 2014)

Canopy/ Crop factor (K_c) used for ratoon cane are as shown in Table 3-2 below:

Table 3-2: K_c values for ratoon cane

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
APRIL CUT - c/f	0.40	0.45	0.60	0.70	0.85	0.95	1.00	1.00	1.00	1.00	1.00	1.00
MAY CUT - c/f	1.00	0.40	0.45	0.60	0.75	0.90	1.00	1.00	1.00	1.00	1.00	1.00
JUNE CUT - c/f	1.00	1.00	0.40	0.45	0.65	0.85	1.00	1.00	1.00	1.00	1.00	1.00
JULY CUT - c/f	1.00	1.00	1.00	0.40	0.45	0.70	0.90	1.00	1.00	1.00	1.00	1.00
AUGUST CUT - c/f	1.00	1.00	1.00	1.00	0.40	0.50	0.75	0.95	1.00	1.00	1.00	1.00
SEPTEMBER CUT - c/f	1.00	1.00	1.00	1.00	1.00	0.40	0.55	0.75	0.95	1.00	1.00	1.00
OCTOBER CUT - c/f	1.00	1.00	1.00	1.00	1.00	1.00	0.40	0.55	0.80	1.00	1.00	1.00
NOVEMBER CUT - c/f	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.40	0.55	0.80	1.00	1.00
DECEMBER CUT - c/f	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.40	0.55	0.70	1.00

Source: (Msibi et al., 2014)

A canopy factor of 1 was selected by the Researcher for full canopy crop to cater for maximum possible water needs though in the Lowveld of Zimbabwe a $K_c \leq 0.85$ for a full canopy crop is recommended based on the analysis of irrigation trial data from the Zimbabwe Sugar Association Experiment Station (ZSAES) as according to Lecler (2000).

3.2.2. Effective Rainfall/ Precipitation Determination

Effective rainfall was defined as that amount of rainfall that enters into the soil profile and is available for use by the crop (Lecler, 2000; Farmwest.com, 2018).

During drier periods less than 5mm of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before soaking into the ground. In addition, only 75% of the rainfall over 5mm is considered to be effective precipitation (Farmwest.com, 2018). According to Farmwest.com (2018), the equation used to determine effective precipitation is shown in Equation 3-2 below:

Effective Precipitation (mm) = (Rainfall - 5) x 0.75 Equation 3-2

The effective precipitation was multiplied by all the rainfall received for the period 2003 to 2017 in the database.
The area under sugarcane, sugarcane growth stage/ age, month of the year and Irrigation system used are the input parameters for the water budgeting tool for it to compute the total water required for a certain day, month or year. A simple excel tool was developed to assist farmers determine cane ages based on their ratoons.

Net crop water demand is calculated in line with harvest dates of the individual blocks. For ease of interpreting results, metric units are used for all calculations. Excel Spreadsheets was used as the basis for developing this water budgeting tool because they are familiar to many people and have very powerful in-built functionality (Lecler, 2000).

3.2.3. General formula Used for Irrigation Water Requirement

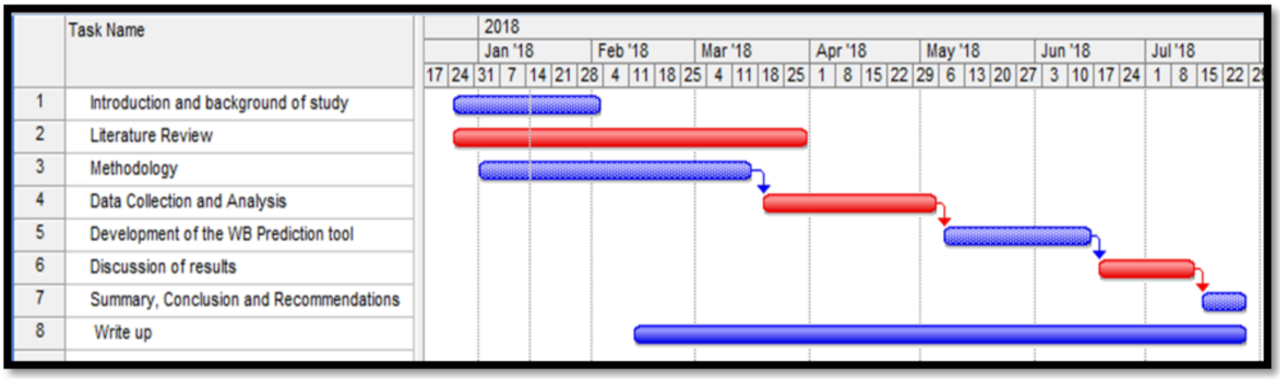
The below Equation 3-3 was used in the computation of the total crop water needs in m3 per each Hectare.

Irrigation Requirement (IR) = ((Historical monthly Crop Water Requirement (CWR) – Historical Effective rainfall)/30 x (Area (Ha) x 10 000)) + (((Historical monthly Crop water requirement (CWR) – Historical Effective rainfall)/30 x (Area (Ha) x 10 000)) * (1 – Irrigation Application Efficiency)). **Equation 3-3**

3.3. Timeframe and Milestones

3.3.1. Duration

The duration for the thesis was presented in the form of a Gantt chart as shown in the Figure 3-2 below.



Source: (Author, 2018)

Figure 3-2: Gantt chart showing thesis duration

Internship for data collection

- 1 and ½ months

Thesis

- 7 months from January 2018 to July 2018.

3.4. Budget

The costs incurred during the course of the project are as shown in the Table 3-3 below.

Table 3-3: Costs Incurred During the Course of the Project

DESCRIPTION	UNITS	QNTY	UNIT COSTS (US$)	TOTAL COSTS (US$)
Secondary Data	Yearly rainfall and ET data sets	14	$130.00	$1,820.00
Flight ticket	Round Trip	1	$1,180.00	$1,180.00
				$3,000.00

Source: (Author, 2018)

3.5. Evaluation

A questionnaire was prepared and distributed amongst the farmers and the CWMA in the lowveld area who are the sole beneficiary of the tool. A sample of 100 farmers, which is approx. 10 % of the sugarcane farmers in the area (Scoones et al, 2017), and three representatives from the CWMA were randomly selected to individually answer the questionnaire. The calibration tool was distributed amongst the farmers and the CWMA, and were taught on how to use the tool before answering the questionnaire. For a sample of the questionnaire, see Appendix 1 attached at the end of the document.

3.6. Technology Transfer and/ or Commercialization Plan

Since the sustainability of the government water management body lies within the revenues they get from the water consumers, the government will be of great importance in enforcing the use of the water budgeting tool. The water management body acquires its revenue from selling water so releasing water which is not used by the consumer is a loss on their part. On the other hand, by providing the Sugarcane farmers with information about their future water needs, water will be supplied or stored in adequate quantities, therefore, they will not lose their crop due to shortage of water. The farmers can also be guided on how far they can expand production based on the availability of water in the Catchment's reserves.

Last but not least, if the tool is to be used effectively, time will be saved and they will be an improvement on water management strategies and efficient and effective utilization of water resources.

3.7. Conclusion

Methods and procedures to be used to design the calibration tool were clearly stated in this chapter. Formulas to be used in the designing and evaluation method of the tool were also stated.

CHAPTER FOUR: DATA PROCESSING AND ANALYSIS

4.0. Introduction

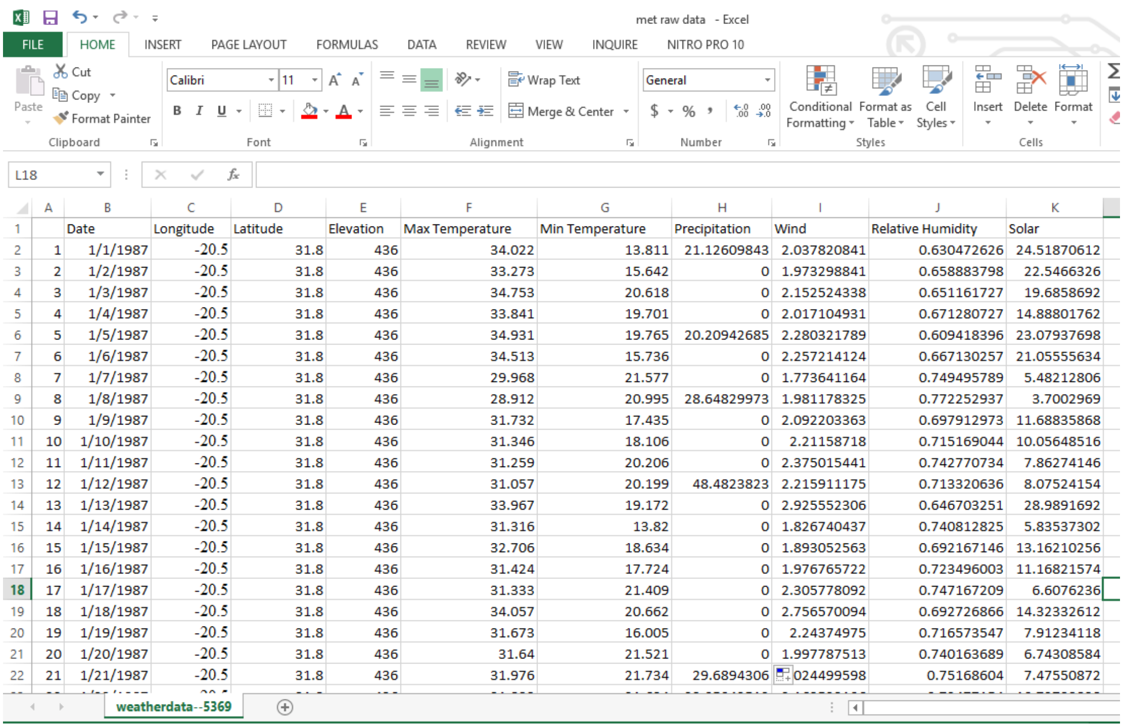
In this Chapter, the processes followed in capturing and analyzing the data that was used is clearly elaborated. Satellite data and data from the Zimbabwe Meteorological Services Department (ZMSD) for the named area are processed to create a climatic database and the tool itself was developed in this Chapter. A Reset Button programming with VBA is also done in this Chapter.

4.1. Satellite Data Processing

4.1.1. Input Data Gathering

The required raw input data which comprise of Temperature, Precipitation, Wind, Relative Humidity, Solar radiation, latitude, longitude and elevation was obtained from the internet through requesting the link from eco.web@tamu.edu. The data was downloaded in the excel format, see Table 4-1 below:

Table 4-1: Collected raw data format



	A	B	C	D	E	F	G	H	I	J	K
1		Date	Longitude	Latitude	Elevation	Max Temperature	Min Temperature	Precipitation	Wind	Relative Humidity	Solar
2	1	1/1/1987	-20.5	31.8	436	34.022	13.811	21.12609843	2.037820841	0.630472626	24.51870612
3	2	1/2/1987	-20.5	31.8	436	33.273	15.642	0	1.973298841	0.658883798	22.5466326
4	3	1/3/1987	-20.5	31.8	436	34.753	20.618	0	2.152524338	0.651161727	19.6858692
5	4	1/4/1987	-20.5	31.8	436	33.841	19.701	0	2.017104931	0.671280727	14.88801762
6	5	1/5/1987	-20.5	31.8	436	34.931	19.765	20.20942685	2.280321789	0.609418396	23.07937698
7	6	1/6/1987	-20.5	31.8	436	34.513	15.736	0	2.257214124	0.667130257	21.05555634
8	7	1/7/1987	-20.5	31.8	436	29.968	21.577	0	1.773641164	0.749495789	5.48212806
9	8	1/8/1987	-20.5	31.8	436	28.912	20.995	28.64829973	1.981178325	0.772252937	3.7002969
10	9	1/9/1987	-20.5	31.8	436	31.732	17.435	0	2.092203363	0.697912973	11.68835868
11	10	1/10/1987	-20.5	31.8	436	31.346	18.106	0	2.21158718	0.715169044	10.05648516
12	11	1/11/1987	-20.5	31.8	436	31.259	20.206	0	2.375015441	0.742770734	7.86274146
13	12	1/12/1987	-20.5	31.8	436	31.057	20.199	48.4823823	2.215911175	0.713320636	8.07524154
14	13	1/13/1987	-20.5	31.8	436	33.967	19.172	0	2.925552306	0.646703251	28.9891692
15	14	1/14/1987	-20.5	31.8	436	31.316	13.82	0	1.826740437	0.740812825	5.83537302
16	15	1/15/1987	-20.5	31.8	436	32.706	18.634	0	1.893052563	0.692167146	13.16210256
17	16	1/16/1987	-20.5	31.8	436	31.424	17.724	0	1.976765722	0.723496003	11.16821574
18	17	1/17/1987	-20.5	31.8	436	31.333	21.409	0	2.305778092	0.747167209	6.6076236
19	18	1/18/1987	-20.5	31.8	436	34.057	20.662	0	2.756570094	0.692726866	14.32332612
20	19	1/19/1987	-20.5	31.8	436	31.673	16.005	0	2.24374975	0.716573547	7.91234118
21	20	1/20/1987	-20.5	31.8	436	31.64	21.521	0	1.997787513	0.740163689	6.74308584
22	21	1/21/1987	-20.5	31.8	436	31.976	21.734	29.6894306	024499598	0.75168604	7.47550872

Source: (Author, 2018)

Data from 1/1/1987 to 31/12/2017 was collected. A warm-up period of one year from 1987-1988 was selected to eliminate some initial errors.

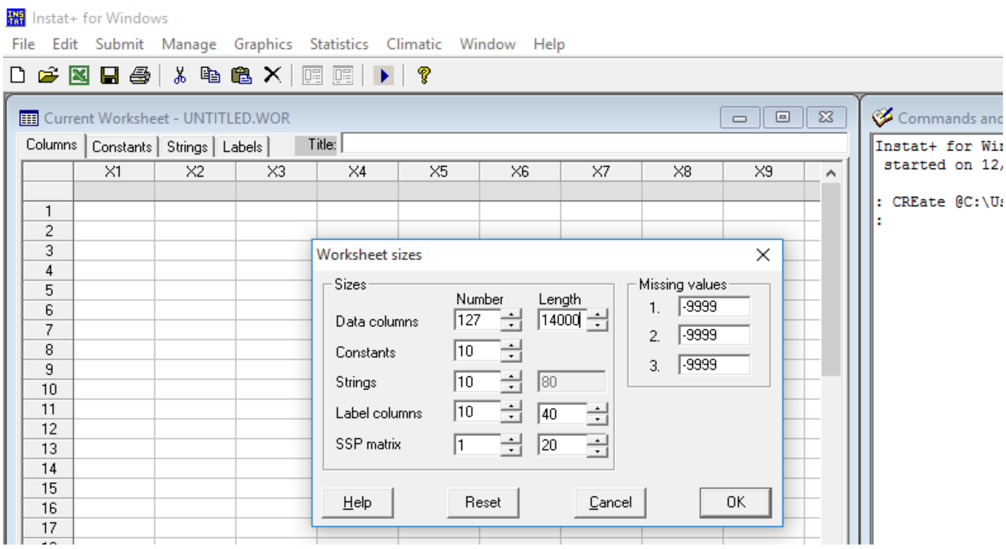
4.1.2. Input Data Processing

Data from the downloaded excel file was first analysed for errors. Some missing data was added so that we can have consistent flow of data. The gaps which were created by adding the missing dates were removed by inserting -99 which can be read by Instat Software.

4.1.3. Evapotranspiration in Instat

Evapotranspiration (ET_o) was calculated using the Instat software. The inputs for the Instat were Temperature, Wind speed, Relative Humidity, Solar Radiation, Latitude and Altitude/ Elevation for it to calibrate ET_o.

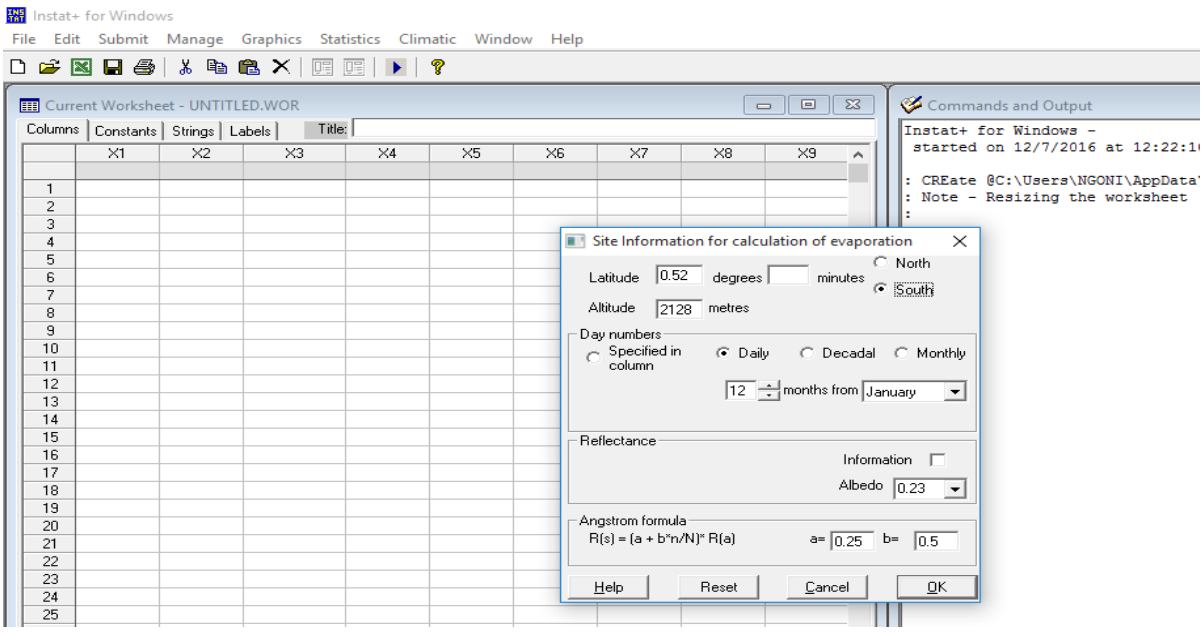
The first step before inputting data in the Instat Plus was to resize the worksheet by going to the Manage tab > Resizing Worksheet so that our data from 1/1/87 - 31/12/2017 can be able to fit, See Figure 4-1 below:



Source: (Author, 2018)

Figure 4-1: Resizing the Instat Worksheet

The second step was to set the location detail by going to the Climate tab > Evaporation > Site and Latitude and Altitude data was imputed, see Figure 4-2 below

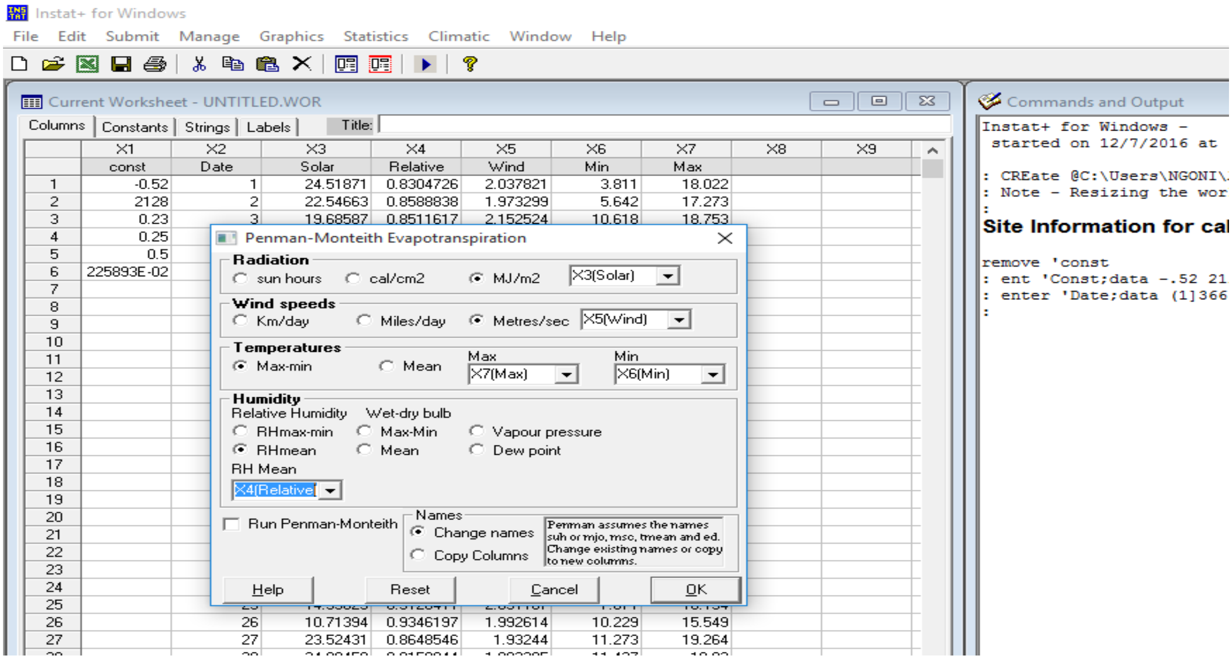


Source: (Author, 2018)

Figure 4-2: Location Inputting in Instat

The third step was to replace the date column that is always automatically inserted after visiting the Site by inserting days which can cover the whole of our data in 1-365 days/ year intervals.

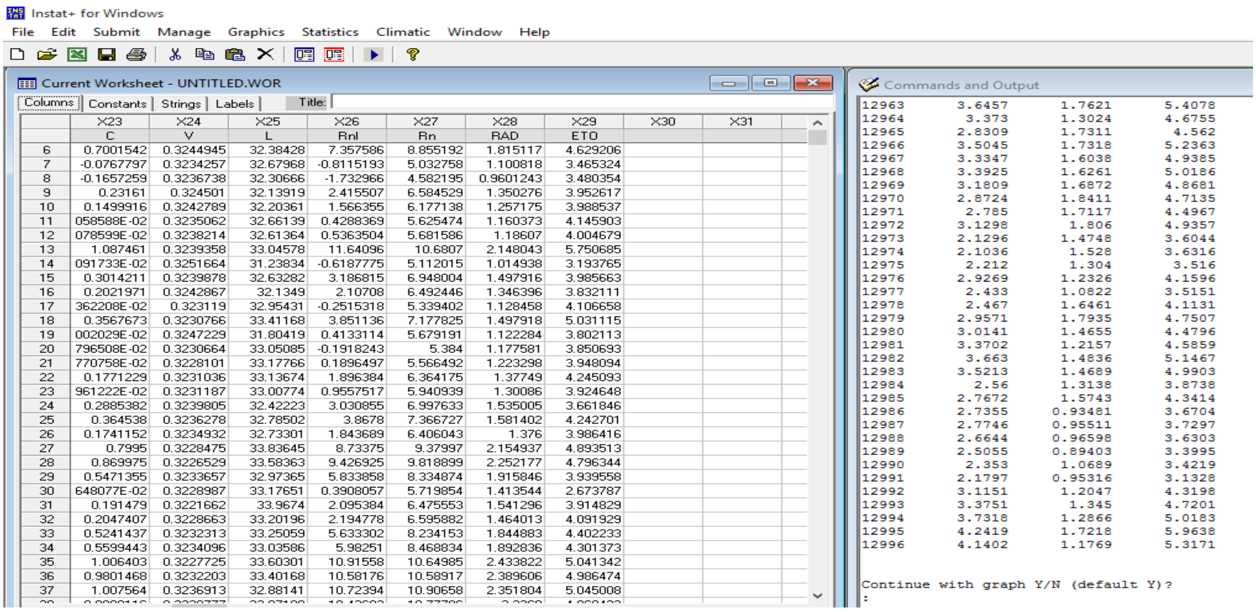
After this third step, the rest of the data was inputted in to the Instat software. After inputting, you go again to the Climate tab > Evapotranspiration > Penman so that the inputted data can be linked to the provided cells for ET_o to be calculated, see Figure 4-3 below:



Source: (Author, 2018)

Figure 4-3: Final stage for ET_o Calibration

After linking the columns to the cells in the Penman- Monteith equation, Ok was pressed and ET_o was calibrated, see Figure 4-4 below:

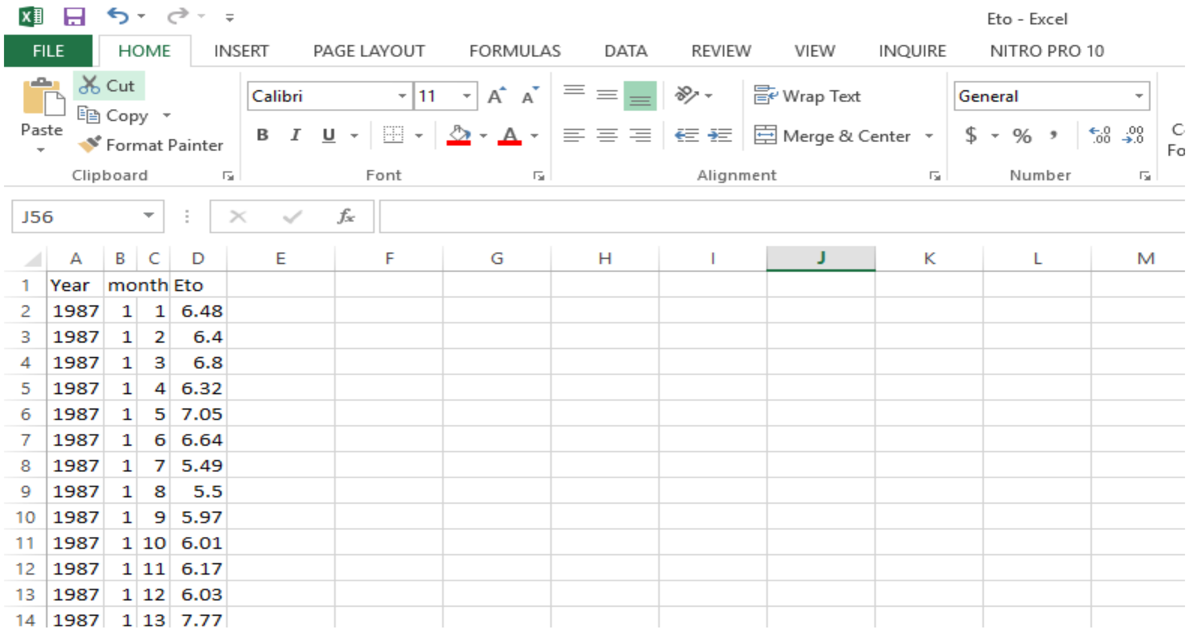


Source: (Author, 2018)

Figure 4-4: Calibrated ET_o

The calibrated ET_o was exported from Instat to excel for further processing as shown in the Table 4-2 below.

Table 4-2: Instat plus Calibrated ET_o in Excel format



Year	month		Eto
1987	1	1	6.48
1987	1	2	6.4
1987	1	3	6.8
1987	1	4	6.32
1987	1	5	7.05
1987	1	6	6.64
1987	1	7	5.49
1987	1	8	5.5
1987	1	9	5.97
1987	1	10	6.01
1987	1	11	6.17
1987	1	12	6.03
1987	1	13	7.77

Source: (Author, 2018)

These ETo values from Satellite data will be later linked with the ETo values from the Meteorological stations to get an average reference evapotranspiration for the area.

4.2. Meteorological Data Processing

The required raw input data which comprise of Precipitation and daily ET_o was obtained from the Zimbabwe Meteorological Services Department in excel format for the period 2003 to 2017. The monthly averages for the ET_o and rainfall as shown in the Table 4-3 below were compiled by the Author for ease of use of the data:

Table 4-3: ZMSD Monthly averages for the ET_o and rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. Max °C	33.1	32.6	32.7	29.9	28.0	25.9	25.7	24.4	27.1	31.4	32.1	31.8
Av. Min °C	21.0	21.2	20.5	17.7	13.9	11.5	11.1	10.9	13.4	18.4	20.4	20.0
Av. Evap (mm)	4.8	5.0	4.2	4.1	3.3	2.5	3.0	4.6	6.0	7.0	5.7	4.8
Av. Evap (m)	0.0048	0.0050	0.0042	0.0041	0.0033	0.0025	0.0030	0.0046	0.0060	0.0070	0.0057	0.0048
Rainfall (mm)	134.8	61.0	56.2	31.9	10.2	2.1	2.9	0.0	6.0	13.5	49.0	102.0
Rainfall (m)	0.1348	0.0610	0.0562	0.0319	0.0102	0.0021	0.0029	0.0000	0.0060	0.0135	0.0490	0.1020

Source: (Author, 2018)

4.3. Database Processing

The above weather data was analysed and incorporated with some formulas which are highlighted in Chapter 3 to determine the effective rainfall for the area as shown in Table 4-4 below.

Table 4-4: Monthly ET_o and Eff. Rainfall Quantities

	Daily Eto (m)	Total Monthly Eto (m)	Total Monthly rainfall (m)	Effective Monthly Rainfall (m)
Jan	0.004824	0.1495	0.1348	0.0974
Feb	0.004985	0.1396	0.0610	0.0420
Mar	0.004218	0.1308	0.0562	0.0384
Apr	0.004065	0.1219	0.0319	0.0202
May	0.003273	0.1015	0.0102	0.0039
Jun	0.002532	0.0759	0.0021	0.0000
Jul	0.003013	0.0934	0.0029	0.0000
Aug	0.004599	0.1426	0.0000	0.0000
Sep	0.006011	0.1803	0.0060	0.0008
Oct	0.007042	0.2183	0.0135	0.0064
Nov	0.005694	0.1708	0.0490	0.0330
Dec	0.004847	0.1503	0.1020	0.0727

Source: (Author, 2018)

These monthly ET_0 and Eff. Rainfall was then incorporated by the crop factors for the Ratoon and Plant crop to determine the Ratoon and Plant crop water needs respectively as shown in the following Table 4-5 and Table 4-6 below:

Ratoon Crop Database

Table 4-5 below is the database showing the values that were used for the ratoon crop.

Table 4-5: Ratoon Crop Database

Ratoon Crop Database

Crop Type	Ratoon	Apr Cut		May Cut		June Cut		July Cut		Aug Cut		Sep Cut		Oct Cut		Nov Cut		Dec Cut	
Ratoon	April___Cut	May c/f -0.45	0.00135	Jun c/f -0.45	0.0012	Jul c/f -0.45	0.0014	Aug c/f -0.45	0.0022	Sep c/f -0.5	0.0030	Oct c/f -	0.0037	Nov c/f -0.	0.0020	Dec c/f -0.55	0.0003	Jan c/f -0.55	-0
Plant	May___Cut	Jun c/f -0.6	0.00159	Jul c/f -0.6	0.0019	Aug c/f -0.65	0.0031	Sep c/f -0.7	0.0042	Oct c/f -0.75	0.0051	Nov c/f	0.0032	Dec c/f -0.8	0.0015	Jan c/f -0.8	0.0007	Feb c/f -0.7	0
	June___Cut	Jul c/f -0.7	0.00216	Aug c/f -0.75	0.0036	Sep c/f -0.85	0.0051	Oct c/f -0.9	0.0061	Nov c/f -0.9	0.0043	Dec c/f -	0.0023	Jan c/f -1	0.0017	Feb c/f -1	0.0035	Mar c/f -1	0
	July___Cut	Aug c/f -0.85	0.00403	Sep c/f -0.9	0.0054	Oct c/f -1	0.0068	Nov c/f -1	0.0046	Dec c/f -1	0.0025	Jan c/f -	0.0017	Feb c/f -1	0.0033	Mar c/f -1	0.0030	Apr c/f -1	0
	Aug___Cut	Sep c/f 0.95	0.00568	Oct c/f -1	0.0068	Nov c/f -1	0.0046	Dec c/f -1	0.0025	Jan c/f -1	0.0017	Feb c/f -	0.0035	Mar c/f -1	0.0030	Apr c/f -1	0.0034	May c/f -1	0
	Sep___Cut	Oct c/f -1	0.00684	Nov c/f -1	0.0046	Dec c/f -1	0.0025	Jan c/f -1	0.0017	Feb c/f -1	0.0035	Mar c/f	0.0030	Apr c/f -1	0.0034	May c/f -1	0.0031	Jun c/f -1	0
	Oct___Cut	Nov c/f -1	0.00459	Dec c/f -1	0.0025	Jan c/f -1	0.0017	Feb c/f -1	0.0035	Mar c/f -1	0.0030	Apr c/f -	0.0034	May c/f -1	0.0031	Jun c/f -1	0.0026	Jul c/f -1	0
	Nov___Cut	Dec c/f -1	0.00250	Jan c/f -1	0.0017	Feb c/f -1	0.0035	Mar c/f -1	0.0030	Apr c/f -1	0.0034	May c/f	0.0031	Jun c/f -1	0.0026	Jul c/f -1	0.0031	Aug c/f -1	0
	Dec___Cut	Jan c/f -1	0.00314	Feb c/f -1	0.0035	Mar c/f -1	0.0030	Apr c/f -1	0.0034	May c/f -1	0.0031	Jun c/f -	0.0026	Jul c/f -1	0.0031	Aug c/f -1	0.0047	Sep c/f -1	0
		Feb c/f -1	0.00150	Mar c/f -1	0.0030	Apr c/f -1	0.0034	May c/f -1	0.0031	Jun c/f -1	0.0026	Jul c/f -1	0.0031	Aug c/f -1	0.0047	Sep c/f -1	0.0060	Oct c/f -1	0
		Mar c/f -1	0.00124	Apr c/f -1	0.0034	May c/f -1	0.0031	Jun c/f -1	0.0026	Jul c/f -1	0.0031	Aug c/f -	0.0047	Sep c/f -1	0.0060	Oct c/f -1	0.0068	Nov c/f -1	0

May c/f	0.45	Jun c/f	0.45	Jul c/f	0.45	Aug c/f	0.45	Sep c/f	0.5	Oct c/f	0.55	Nov c/f	0.55	Dec c/f	0.55	Jan c/f	
Jun c/f	0.60	Jul c/f	0.6	Aug c/f	0.65	Sep c/f	0.7	Oct c/f	0.75	Nov c/f	0.75	Dec c/f	0.8	Jan c/f	0.8	Feb c/f	
Jul c/f	0.70	Aug c/f	0.75	Sep c/f	0.85	Oct c/f	0.9	Nov c/f	0.95	Dec c/f	0.95	Jan c/f	1	Feb c/f	1	Mar c/f	
Aug c/f	0.85	Sep c/f	0.9	Oct c/f	1	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	
Sep c/f	0.95	Oct c/f	1	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	
Oct c/f	1.00	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	
Nov c/f	1.00	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	
Dec c/f	1.00	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	
Jan c/f	1.00	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	
Feb c/f	1.00	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	1	Oct c/f	
Mar c/f	1.00	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	1	Oct c/f	1	Nov c/f	

Callibration Tool | Database 1 | Database 2 | Database 3

Source: (Author, 2018)

Plant Crop Database

Table 4-6 below is the database showing the values that were used for the plant crop.

Table 4-6: Plant Crop Database

Plant Crop Database

Plant	Apr Plant		May Plant		June Plant		July Plant		Aug Plant		Sep Plant		Oct Plant		Nov Plant		Dec Plant		
April__Plant	May c/f -0.45	0.0013	Jun c/f -0.45	0.0012	Jul c/f -0.45	0.001	Aug c/f -0.45	0.002	Sep c/f -0.45	0.003	Oct c/f -	0.003	Nov c/f -0.	0.0015	Dec c/f -0.45	-2E-04	Jan c/f -0.45	-0.0010	Feb
May__Plant	Jun c/f -0.65	0.0017	Jul c/f -0.65	0.0020	Aug c/f -0.55	0.003	Sep c/f -0.55	0.003	Oct c/f -0.55	0.004	Nov c/f	0.002	Dec c/f -0.	0.0003	Jan c/f -0.55	-5E-04	Feb c/f -0.7	0.0020	Ma
June__Plant	Jul c/f -0.8	0.0025	Aug c/f -0.8	0.0038	Sep c/f -0.75	0.004	Oct c/f -0.75	0.005	Nov c/f -0.7	0.003	Dec c/f -	0.001	Jan c/f -0.7	0.0005	Feb c/f -0.75	0.002	Mar c/f -0.9	0.0026	Apr
July__Plant	Aug c/f -0.9	0.0043	Sep c/f -0.9	0.0054	Oct c/f -0.9	0.006	Nov c/f -0.9	0.004	Dec c/f -0.9	0.002	Jan c/f -	0.001	Feb c/f -0.	0.0030	Mar c/f -0.9	0.003	Apr c/f -1	0.0034	Ma
Aug__Plant	Sep c/f -1	0.006	Oct c/f -1	0.0068	Nov c/f -1	0.005	Dec c/f -1	0.003	Jan c/f -1	0.002	Feb c/f -	0.003	Mar c/f -1	0.0030	Apr c/f -1	0.003	May c/f -1	0.0031	Jun
Sep__Plant	Oct c/f -1	0.0068	Nov c/f -1	0.0046	Dec c/f -1	0.003	Jan c/f -1	0.002	Feb c/f -1	0.003	Mar c/f	0.003	Apr c/f -1	0.0036	May c/f -1	0.003	Jun c/f -1	0.0026	Jul
Oct__Plant	Nov c/f -1	0.0046	Dec c/f -1	0.0025	Jan c/f -1	0.002	Feb c/f -1	0.003	Mar c/f -1	0.003	Apr c/f -	0.003	May c/f -1	0.0031	Jun c/f -1	0.003	Jul c/f -1	0.0031	Aug
Nov__Plant	Dec c/f -1	0.0025	Jan c/f -1	0.0017	Feb c/f -1	0.003	Mar c/f -1	0.003	Apr c/f -1	0.003	May c/f	0.003	Jun c/f -1	0.0028	Jul c/f -1	0.003	Aug c/f -1	0.0047	Sep
Dec__Plant	Jan c/f -1	0.0017	Feb c/f -1	0.0035	Mar c/f -1	0.003	Apr c/f -1	0.003	May c/f -1	0.003	Jun c/f -	0.003	Jul c/f -1	0.0031	Aug c/f -1	0.005	Sep c/f -1	0.0060	Oct
Jan__Plant	Feb c/f -1	0.0035	Mar c/f -1	0.0030	Apr c/f -1	0.003	May c/f -1	0.003	Jun c/f -1	0.003	Jul c/f -	0.003	Aug c/f -1	0.0047	Sep c/f -1	0.006	Oct c/f -1	0.0068	Nov
Feb__Plant	Mar c/f -1	0.003	Apr c/f -1	0.0034	May c/f -1	0.003	Jun c/f -1	0.003	Jul c/f -1	0.003	Aug c/f	0.005	Sep c/f -1	0.0064	Oct c/f -1	0.007	Nov c/f -1	0.0046	Dec
March__Plant																			
	May c/f	0.45	Jun c/f	0.45	Jul c/f	0.45	Aug c/f	0.45	Sep c/f	0.45	Oct c/f	0.45	Nov c/f	0.45	Dec c/f	0.45	Jan c/f	0.45	Feb
	Jun c/f	0.65	Jul c/f	0.65	Aug c/f	0.55	Sep c/f	0.55	Oct c/f	0.55	Nov c/f	0.55	Dec c/f	0.55	Jan c/f	0.55	Feb c/f	0.7	Ma
	Jul c/f	0.8	Aug c/f	0.8	Sep c/f	0.75	Oct c/f	0.75	Nov c/f	0.75	Dec c/f	0.75	Jan c/f	0.75	Feb c/f	0.75	Mar c/f	0.9	Apr
	Aug c/f	0.9	Sep c/f	0.9	Oct c/f	0.9	Nov c/f	0.9	Dec c/f	0.9	Jan c/f	0.9	Feb c/f	0.9	Mar c/f	0.9	Apr c/f	1	Ma
	Sep c/f	1	Oct c/f	1	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun
	Oct c/f	1	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul
	Nov c/f	1	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug
	Dec c/f	1	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep
	Jan c/f	1	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	1	Oct
	Feb c/f	1	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	1	Oct c/f	1	Nov
	Mar c/f	1	Apr c/f	1	May c/f	1	Jun c/f	1	Jul c/f	1	Aug c/f	1	Sep c/f	1	Oct c/f	1	Nov c/f	1	Dec

Callibration Tool | Database 1 | Database 2 | Database 3

Source: (Author, 2018)

The values that are displayed in Table 4-5 and Table 4-6 above came as a result of various formulas that link what is being displayed to what is in other databases.

These crop factor values were then linked with various Irrigation system application efficiency database which is shown in the Table 4-7 below.

Table 4-7: Irrigation System Efficiency Database

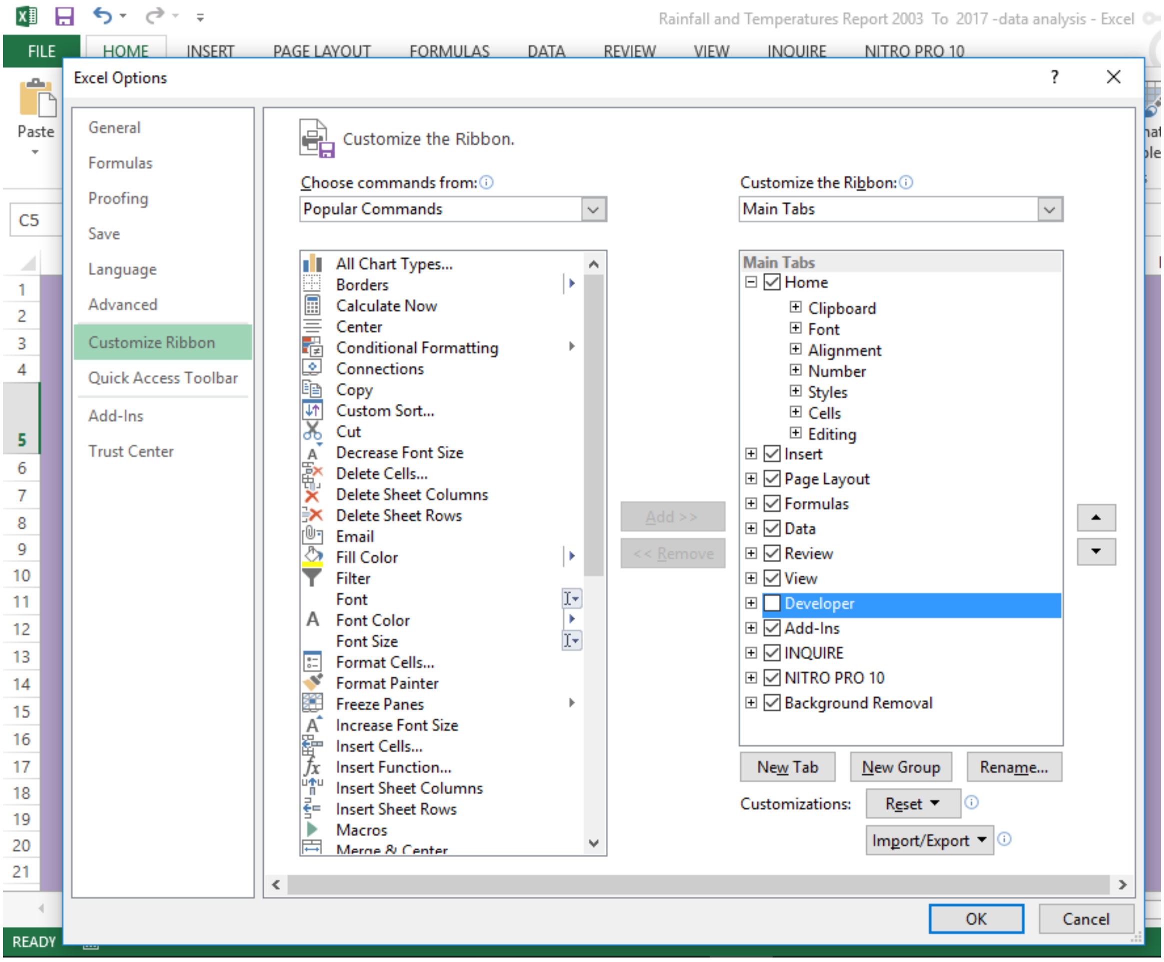
	System Efficiencies			
Irrigation System	**Flooding**	**Furrow**	**Sprinkler**	**Centre Pivot**
Flooding	0.55	0.6	0.65	0.8
Furrow				
Sprinkler				
Centre_Pivot				

Source: (University of Wyoming, 2018)

Even though these application efficiencies can be argued since in most instances, the efficiency of a system depends on infield parameters such as terrain, management, etc., for progress sake and referencing, the above efficiencies had to be used. This database was created to enable a reduction in water wastages as each irrigation system application efficiency has an effect on water consumption.

4.4. Reset Button Programming

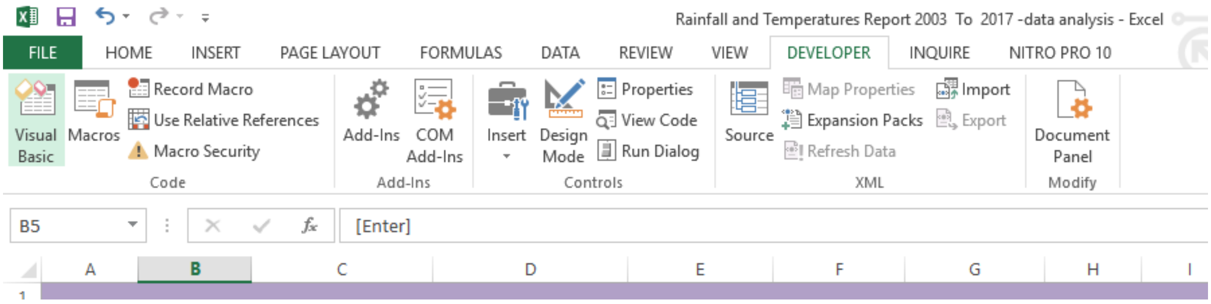
A reset button was created using the VBA programming options to make sure that after every calibration, all previous data entry is cleared to allow for new data entry. The reset button was created as follows: Under the excel spreadsheet, you first start by unlocking the Developer Tab through going to File > Options > Customize Ribbon > Developer. Tick on the box and click OK and shown in the Figure 4-5 below:



Source: (Author, 2018)

Figure 4-5: Unlocking the Developer Tab

This was done to allow for the VBA programming options that are to be used in programming the reset button to come out, see the Developer Tab in Figure 4-7 below.



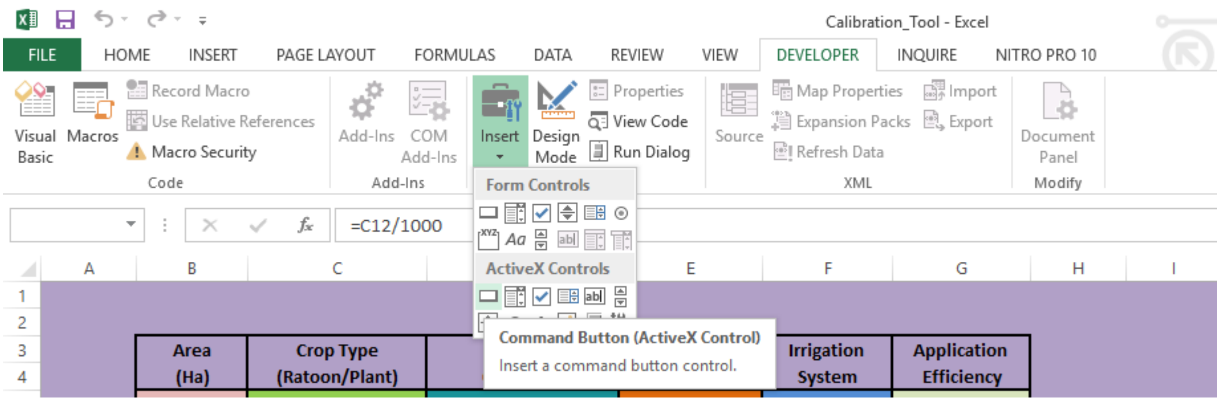
Source: (Author, 2018)

Figure 4-6: Developer Tab showing VBA programming Options

4.4.1. VBA Programme for the Reset Button

After having the Developer Tab on the excel spreadsheet, the following processes were followed in inserting the Reset Button and the programme:

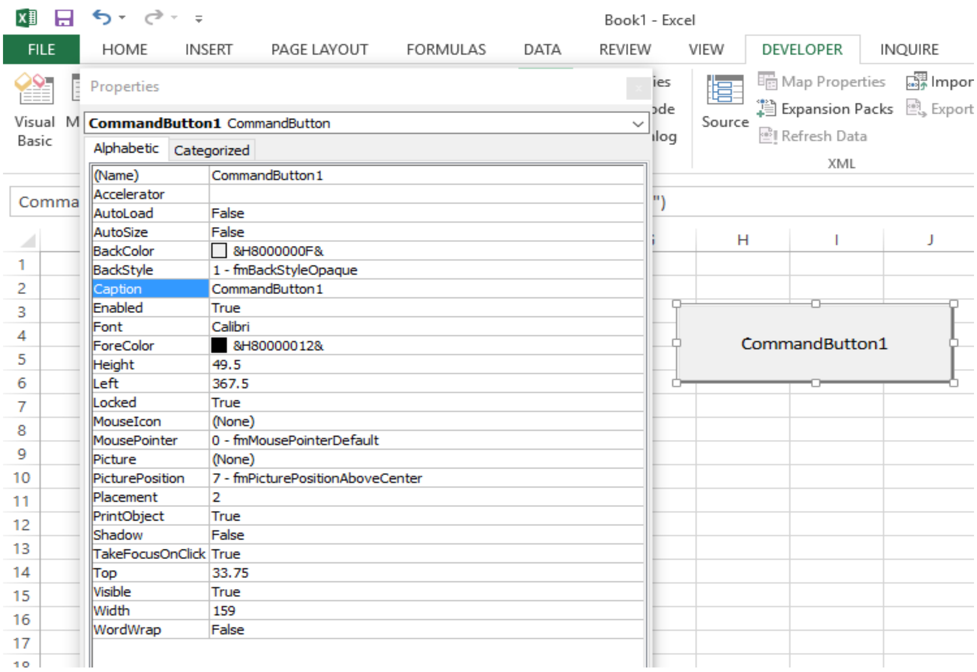
The first step was to go to the Developer Tab then to the Insert Options. Under the ActiveX Controls in the Insert Options, a Command Button was selected as shown in Figure 4-8 below:



Source: (Author, 2018)

Figure 4-7: Command Button Creation- First Step in Developing a Reset Button

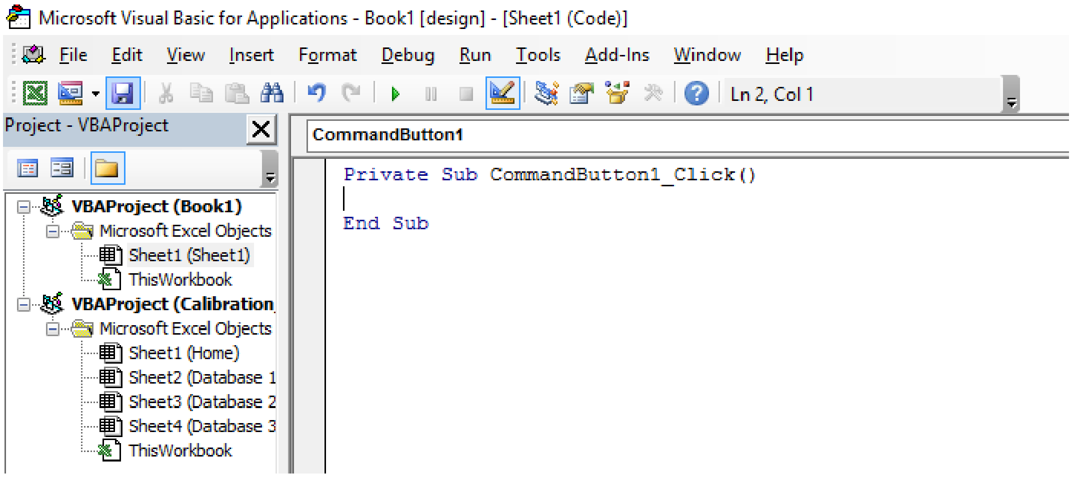
Upon clicking the Command Button, you are taken to the Spreadsheet where you are to draw the command button. Since we are creating the Reset Button, the command button is renamed from ‘CommandButton1’ to Reset Button by right clicking on the Button then go to properties. A properties window will then come out with options that can enable you to personalize the button as shown in the Figure 4-9 below:



Source: (Author, 2018)

Figure 4-8: Personalization of the Command Button

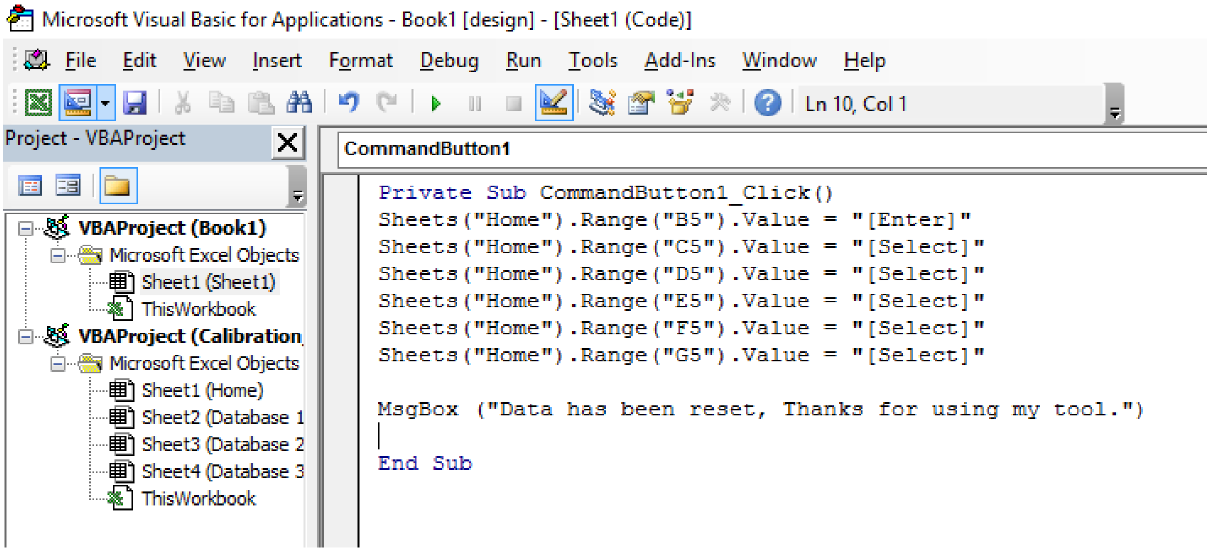
Under this window, the button name, colour, font size, etc. can be changed. After the personalization of the Command Button which is now our Reset Button, you exit the properties window and double click on the button to open the VBA programming window (See Figure 4-10 below).



Source: (Author, 2018)

Figure 4-9: VBA Programming Window

In between the Private and the End Sub, a VBA programme was wrote as shown in the Figure 4-11 below which enables the clearing of the ‘named cells’ e.g. B5 to G5, to allow for new entries.



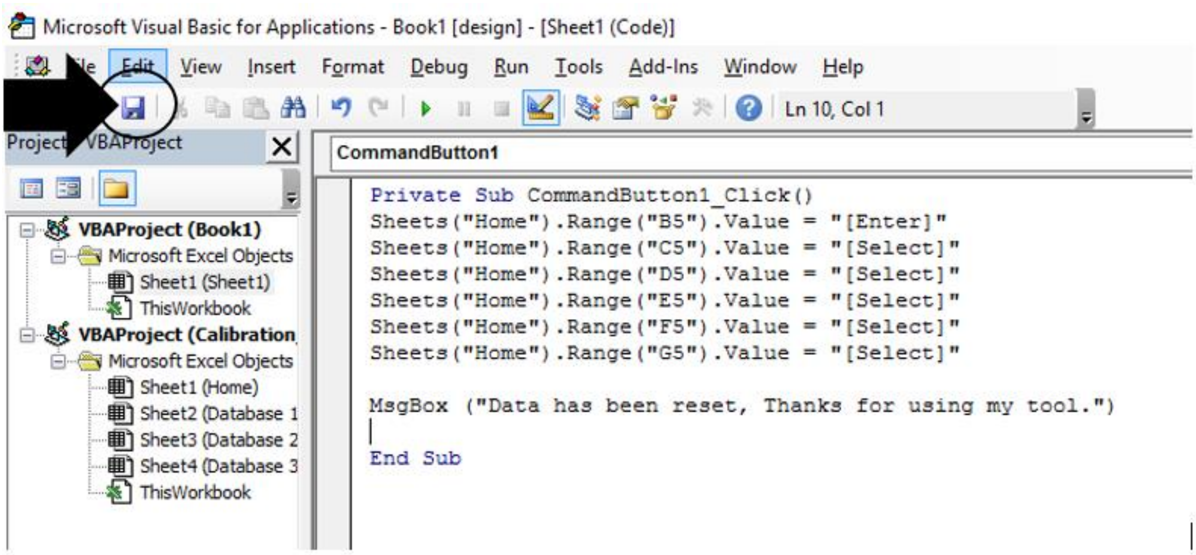
Source: (Author, 2018)

Figure 4-10: VBA programme for the Reset Button

The Sheets (“ … ”) Command was put to allow for the programme to know that it will be working with the spreadsheet. Since the spreadsheet where the programme is supposed to work on is named 'Home' , home was put in Sheet Command to allow for the programme to pick cells in that Home spreadsheet for resetting. The Range (" … ") command was put to give a directive of the cells that are supposed to be worked on. In this case, each cell is being worked independently of other cells. In other cases where many cells are to be reset at once, a Range (" ... : … ") Command is used. The Value = " … " Command is put to give the cell result after the Reset Button is pressed.

If the cell is supposed to be left blank, a Value = "" command is used. In this case, the cells are supposed to be left either with an [Enter] option where the farmer is required to insert a value or with a [Select] option where the farmer is supposed to select a value from the given options hence the Value = "[Enter]" and Value = "[Select]" Commands were used respectively. The MsgBox (" .") Command was put to allow for a notification after a Reset Button is pressed.

After programming, you are required to save the programme by clicking 'Save' option which is found on the VBA window as shown in the Figure 4-12 below:

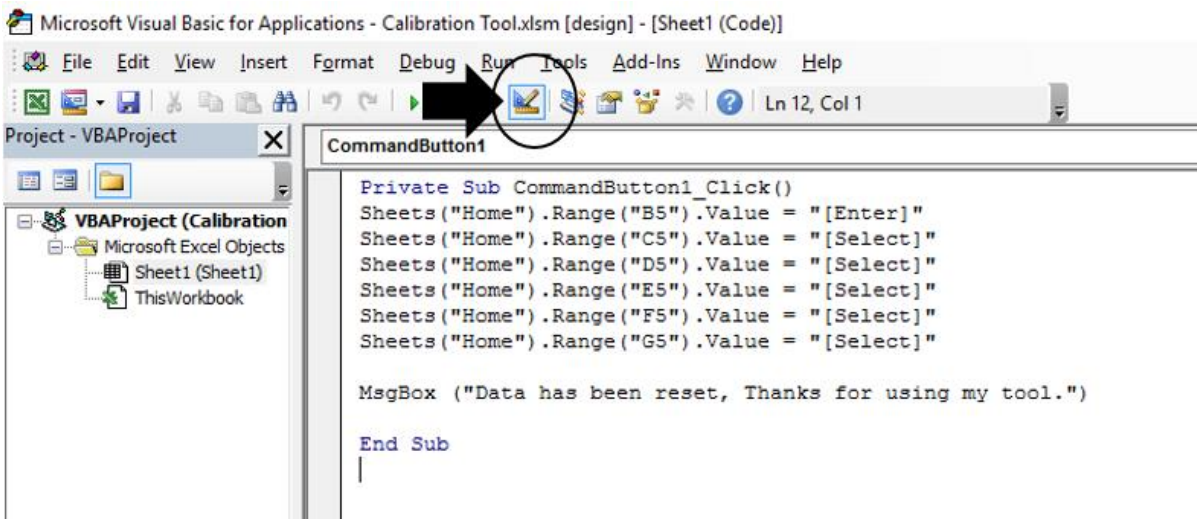


Source: (Author, 2018)

Figure 4-11: Saving the VBA programme

After clicking Save, the below processes will follow. You are required to give a name to the Excel workbook and save it as Excel Macro- Enabled Workbook then click Ok.

After saving the VBA programme, you are required to exit the Design Mode to enable the Reset Button to function, See Figure 4-13 below:



Source: (Author, 2018)

Figure 4-12: Exiting the Design Mode

Below is the programme in word format to allow for any editing if required:

```
Private Sub CommandButton1_Click()

Sheets("Home").Range("B5").Value = "[Enter]"

Sheets("Home").Range("C5").Value = "[Select]"

Sheets("Home").Range("D5").Value = "[Select]"

Sheets("Home").Range("E5").Value = "[Select]"

Sheets("Home").Range("F5").Value = "[Select]"

Sheets("Home").Range("G5").Value = "[Select]"

MsgBox ("Data has been reset, Thanks for using my tool.")

End Sub
```

4.5. Conclusion

To increase the accuracy of the weather data obtained from the Zimbabwe Meteorological Services Department (ZMSD) for the area under study, satellite data was analysed using Instat Software and ETo was obtained. The obtained satellite daily ETo was then averaged with the daily ETo from the ZMSD. The new value of ETo was incorporated into the Tool's database and is the one which was used in calculating the daily CWU for the area. A Reset Button was also wrote to allow for easy use of the tool.

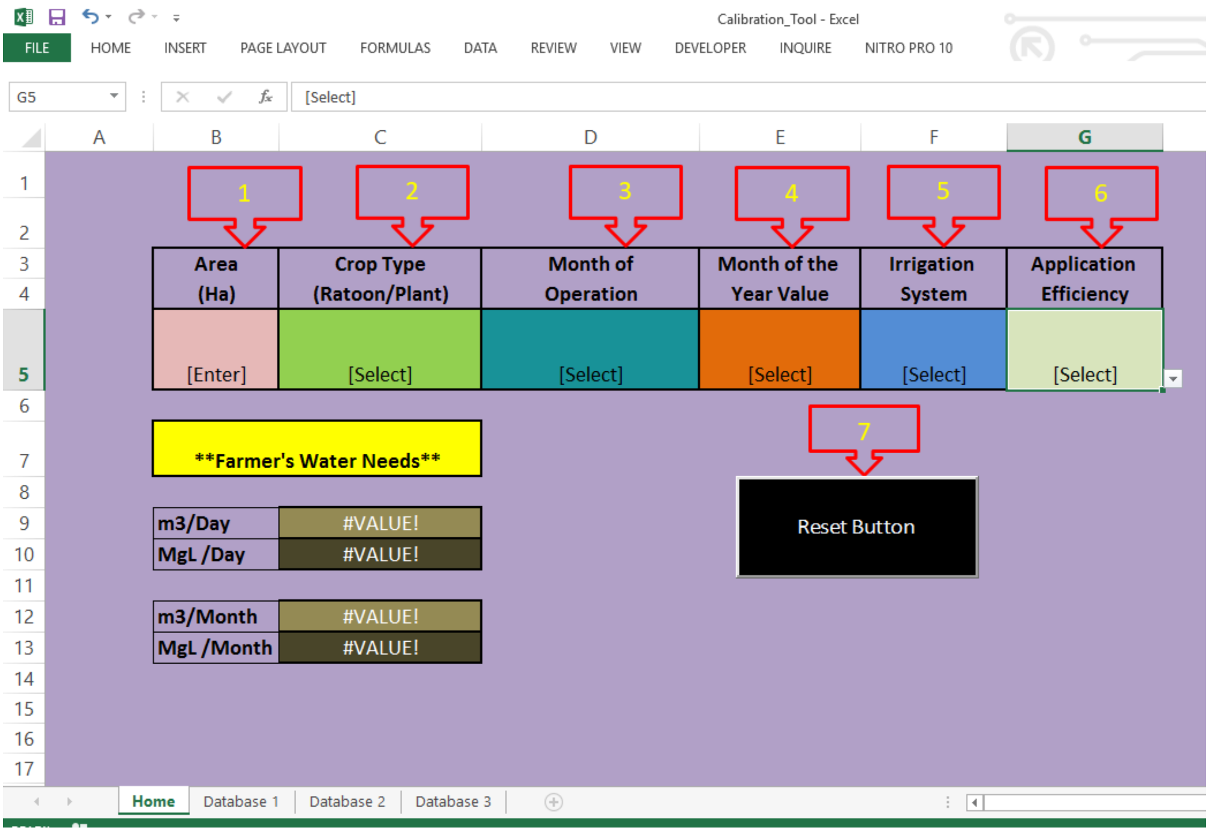
CHAPTER FIVE: RESULTS AND RESULTS DISCUSSION

5.0. Introduction

After the Satellite data and Meteorological Services Department data are analysed, the Crop Water Use based water budgeting calibration tool is developed. In this Chapter, the principle of operation of the tool is shown.

5.1. Interface of the Calibration Tool

The interface of the Calibration tool which shows where the User is supposed to input or select values based on in-farm information, the results and the Reset Button is shown in the Figure 5-1 below.

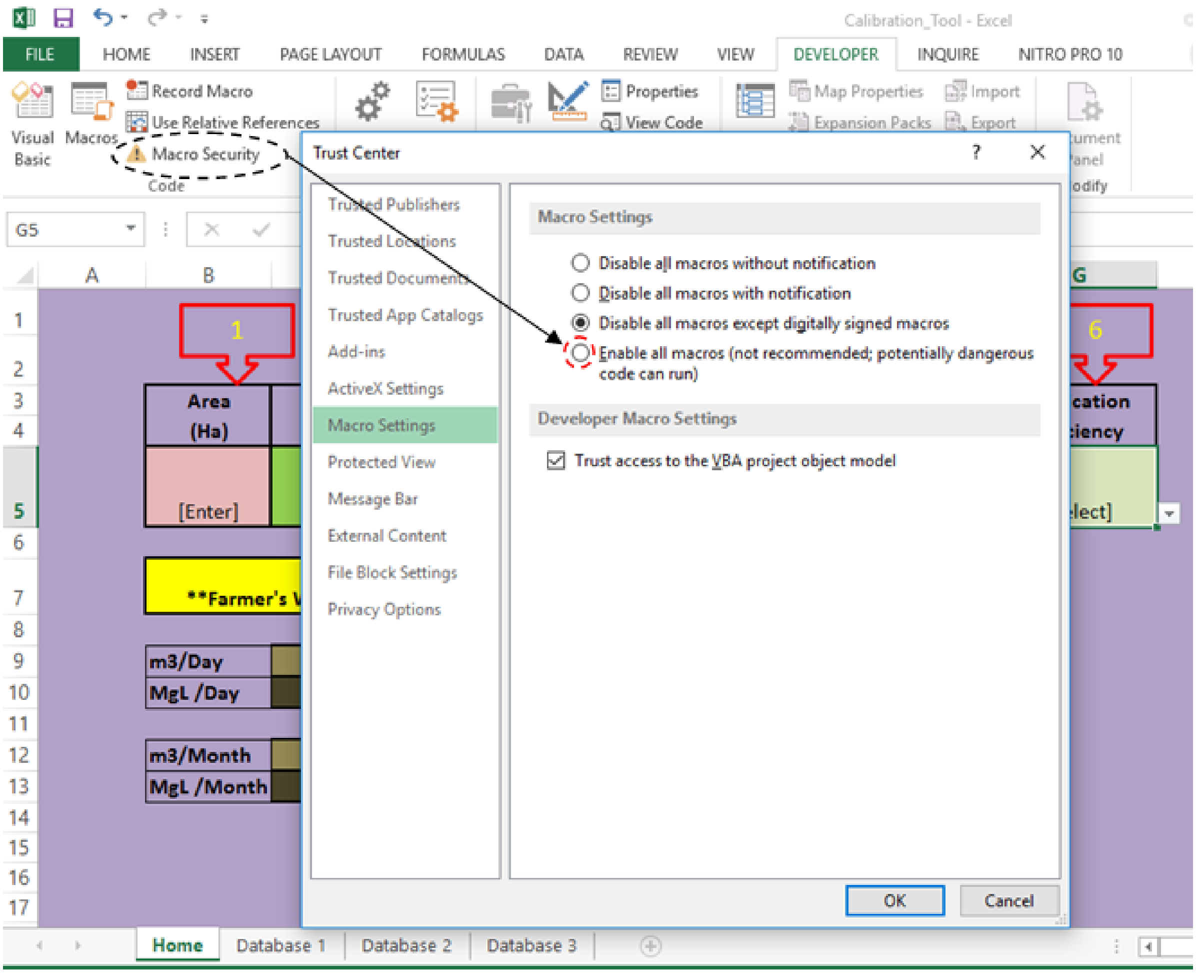


Source: (Author, 2018)

Figure 5-1: Interface of the Water Budgeting Tool

5.2. Activation of the VBA project/ Excel Macro-Enabled Workbook

The first step after opening the excel file which is macro-enabled is to activate some security features in the User's excel by clicking on the Developer Tab and then Macro Security. After clicking the Macro Security, a window with options to activate/ enable the security features is displayed as shown in the Figure 5-2 Below.



Source: (Author, 2018)

Figure 5-2: Enabling macros in excel

On the Macro Setting window, the User has to click on the circle as highlighted in the Figure 5-2 above to enable all macros / VBA programmes to run.

5.3. Principle of operation of the Tool

A typical example is used in elaborating the principle of operation of the Water Budget Calibration Tool.

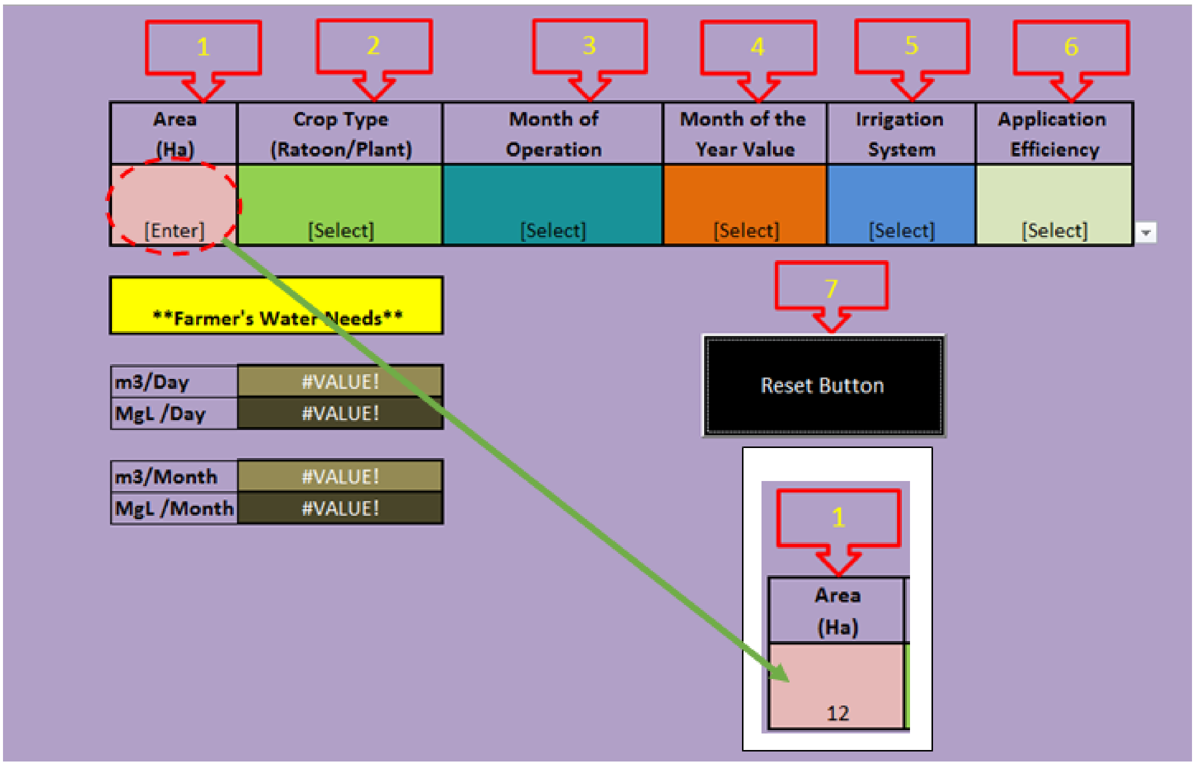
The example to be used is as follows:

It is assumed that a farmer has a **12 Ha** piece of land under the sugarcane crop in the Lowveld area of Zimbabwe. The crop that the farmer wants to get his/her water budget for is a **'Plant Crop'** (Crop growing from first planting operations and has never been harvested) as opposed to a 'Ratoon Crop' (Crop that has grown from shooting after every harvesting). This Plant Crop is assumed to have been planted in the month of **November** (Current year)**.** For this November plant, the farmer wants to get the water budget for the month of **February** (Next year). At this farm, the Farmer makes use of a **Sprinkler** Irrigation System which has an application efficiency of **0.65** as according to (Lecler, 2000).

With this given information above, the procedure in inputting this information in the Tool is shown below.

5.3.1. Inputting the Landscape Area

Step 1: Based on the in-farm information, the farmer is required to input the Area (in Hectares) under sugarcane in which he/she wants to get the water needs for. Since our farmers are well versed in Hectares, a conversion from Square meters to Hectares was made in the Tool's database to allow for farmers to input their landscape area in Ha. A window showing the circled position where the Farmer/ User is supposed to input the Landscape Area is as shown in the Figure 5-3 below.



Source: (Author, 2018)

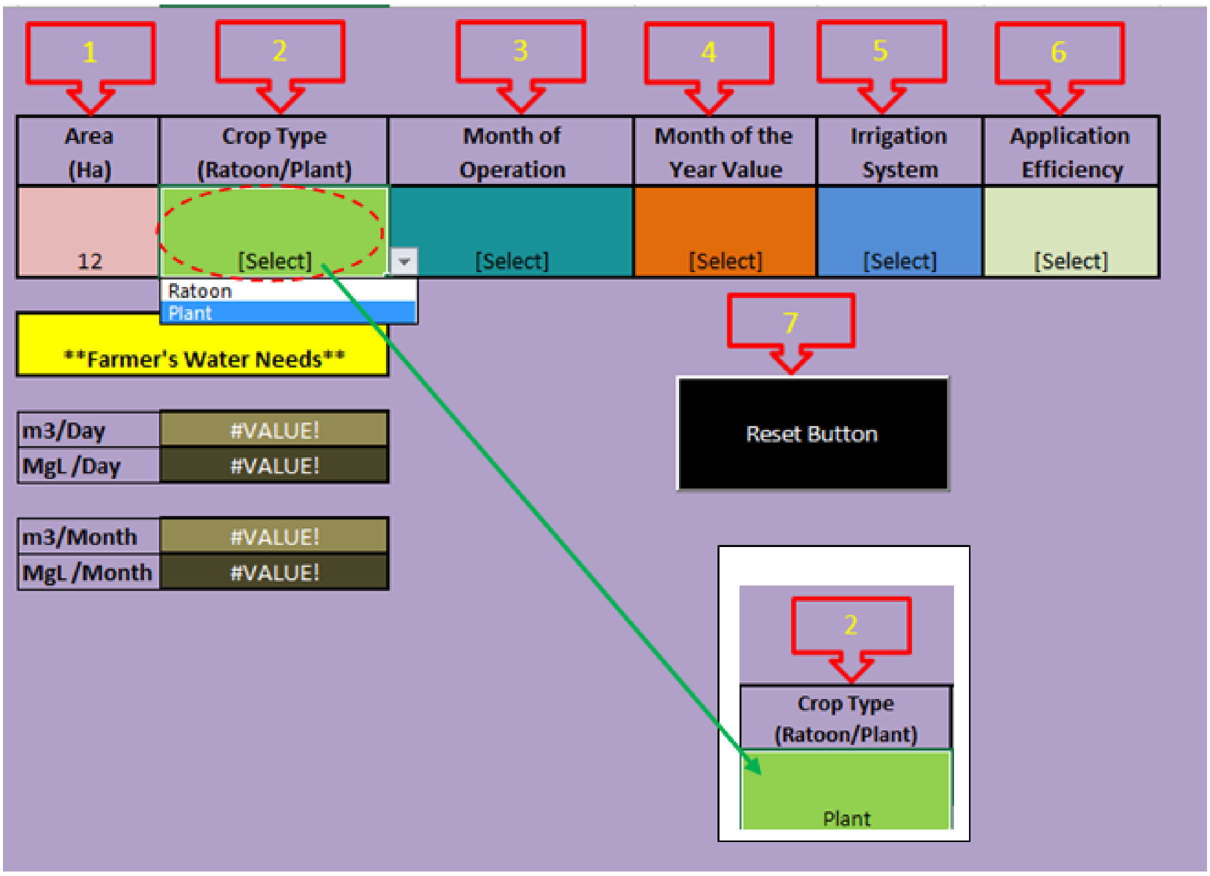
Figure 5-3: Cell for Inputting the Landscape Area

In the case above, an example of a farmer with a 12 Ha piece of land was used. This is just but an imaginary value to allow for a practical calibration to take effect after we have completed inputting the In-farm information.

5.3.2. Inputting the Crop Details in the Calibration Tool

Step 2: A drop down list was created to allow for the User to select an option from the given options based on his/ her in-farm situation. Under the Crop Type Drop down list, we have two options of whether the crop is a Plant Crop (Crop growing from first planting operations and has never been harvested) or a Ratoon Crop (Crop that has grown from shooting after every harvesting). Based on what is on the farm, the farmer only needs to select the option that best fits what is there on the farm.

To be able to select the needed option, the Farmer needs to click on the circled box with a [Select] which is under the Crop Type Box (See Figure 5-4 below). An arrow will come out and the user is required to click on the arrow to view the options in the drop down list. When options come out, click on the option that best fit your crop condition as shown in the Figure 5-4 below:



Source: (Author, 2018)

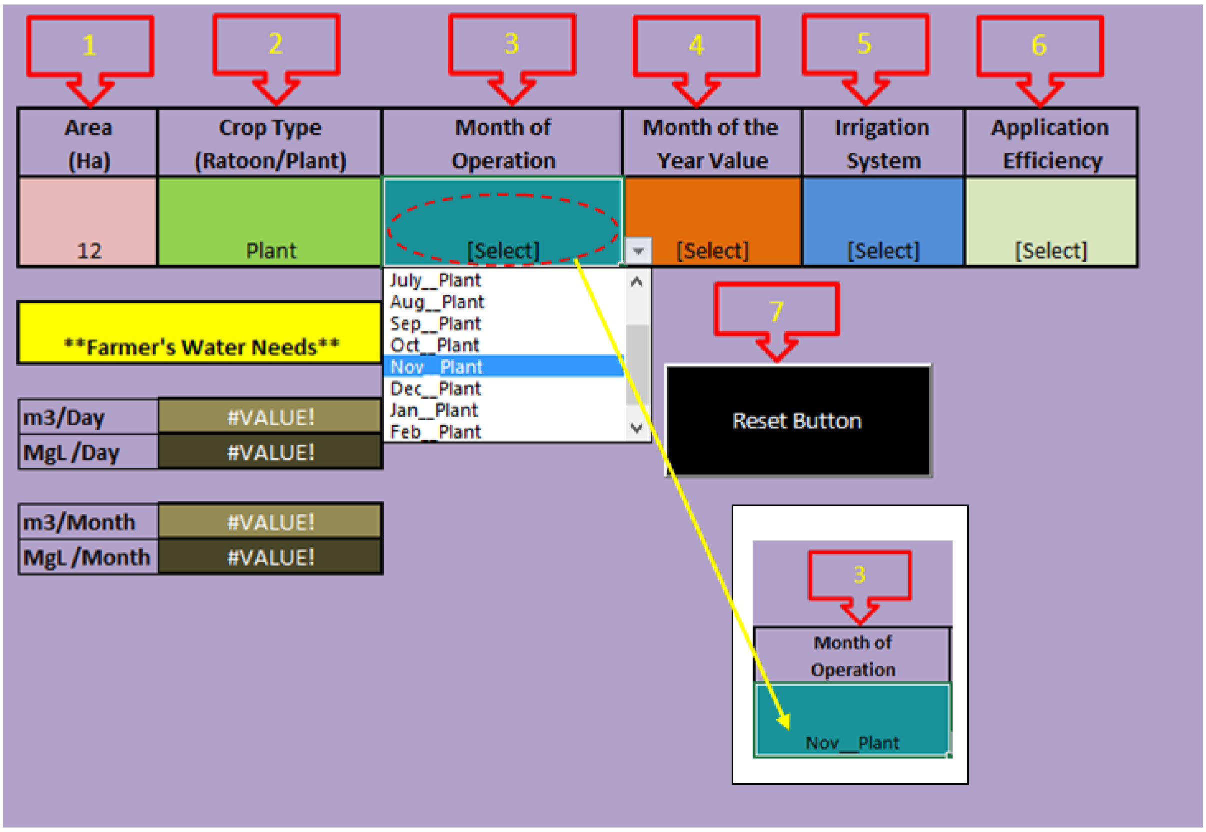
Figure 5-4: Process involved in Inputting Crop Type Details

In this calibration process, it was assumed that the farmer has grown his/ her sugarcane crop for the first time hence the selection of a 'Plant' option. Without this step 2, option 3 cannot be opened as this stage acts as its predecessor.

5.3.3. Month of Operation

Step 3: After Step 2, Step 3 is automatically opened. In this Step 3, a drop down list was created that is directly linked to step 2 and allows the User to select an option from the given options. Under the Month of Operation Dropdown list, we have two scenarios of Plant Crop options or Ratoon Crop options.

Under the Plant Crop option, we have a dropdown showing months in which the crop was planted and under the Ratoon Crop option, we have a dropdown showing months in which the crop was cut. By selecting either the Plant or Ratoon Crop option in Step 2, the options related to either of the two is automatically extracted in step 3. In this case, a Plant Crop was selected so the options for the Plant Crop are shown. See Figure 5-5 below for more clarity:



Source: (Author, 2018)

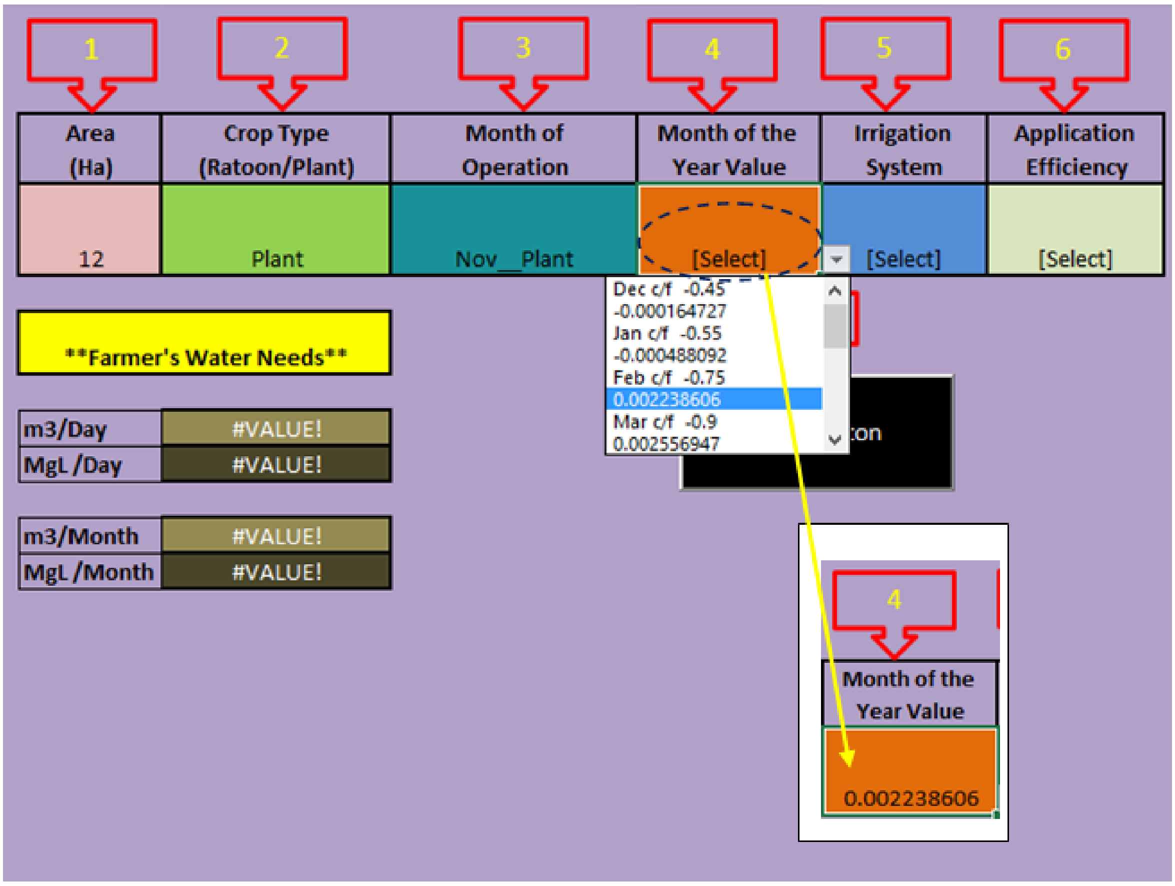
Figure 5-5: Process involved in inputting the Month of Operation Details

In this case, it is assumed that the farmer planted his/ her crop in the month of November hence the November option was selected from the drop down list. This step 3 automatically opens the step 4 options that are specifically aligned to a crop that was planted in November.

5.3.4. Month of the Year Value

Step 4: Under this Step, a drop down list showing options that are specifically aligned to the predecessor option in step 3 are presented. As briefed above, since November was selected in Step 3, this has automatically opened Step 4 options that are specifically aligned to a crop that was planted in November.

Since it is assumed that the crop was planted in November, options that start from December (current year) to October (following year) comes out with a Crop Factor value which was used for each month attached to it. A value that is in **'decimal'** comes out '**below'** the '**month'** in which the User/ Farmer wants to get his/ her Crop Water Needs for. That value incorporates Crop Factor values, Effective Rainfall and all other formulas that enabled the tool to compute the actual depth of water in meters used by the crop. See Figure 5-6 below:



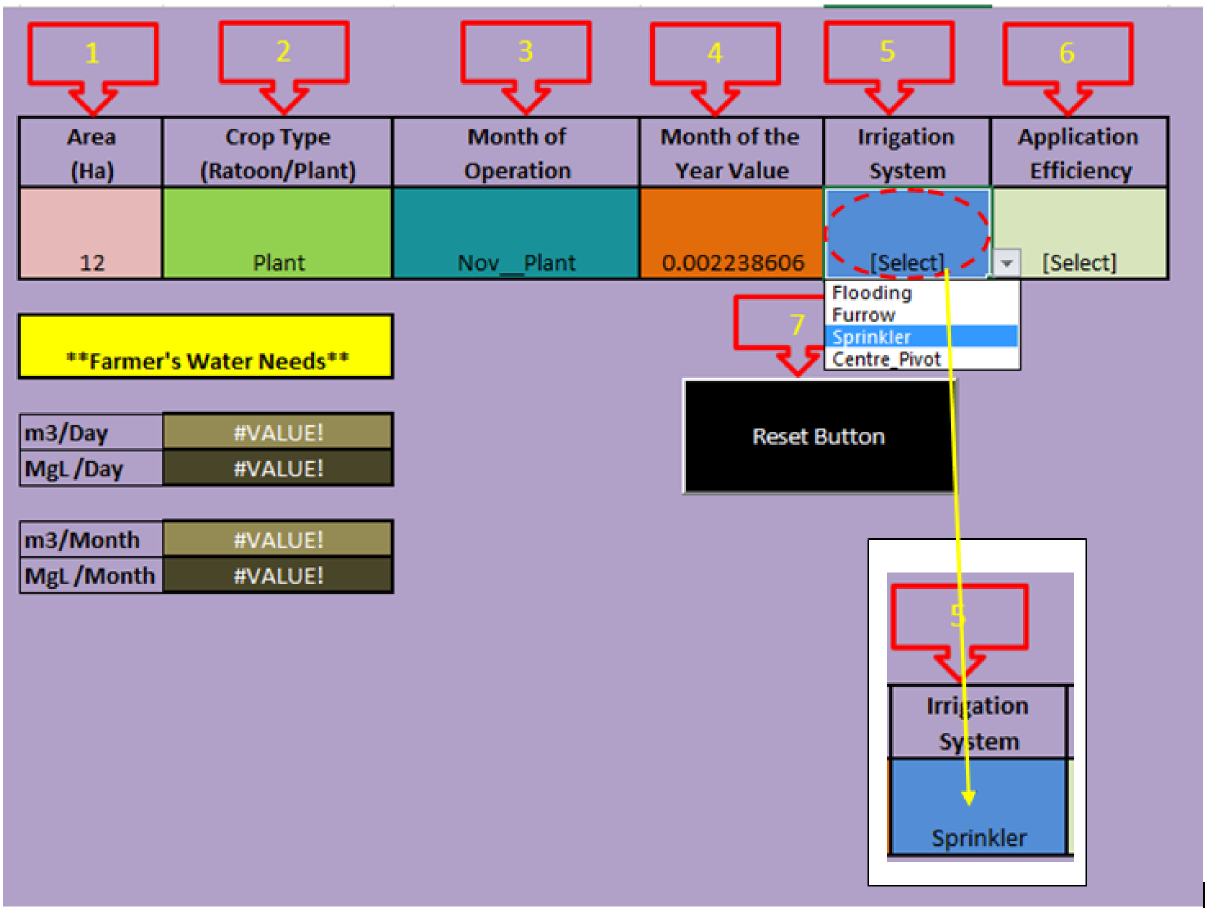
Source: (Author, 2018)

Figure 5-6: Process involved in inputting the Month of the Year Value

In the case shown in the above Figure, the User/ Farmer want to get the water budget for the month of February next year for this imaginary crop which was planted in November. A value that comes out below February (in Decimal) is selected. If you happen to fail to click on the month instead of the value 'in decimal' below the month, you get an error in the results.

5.3.5. Irrigation System Option

Step 5: In this step, irrigation options that are commonly used by farmers in the Lowveld area are incorporated in a drop down list. The User/ Farmer only needs to select the irrigation system that is being used to irrigate the crop, See Figure 5-7 below.



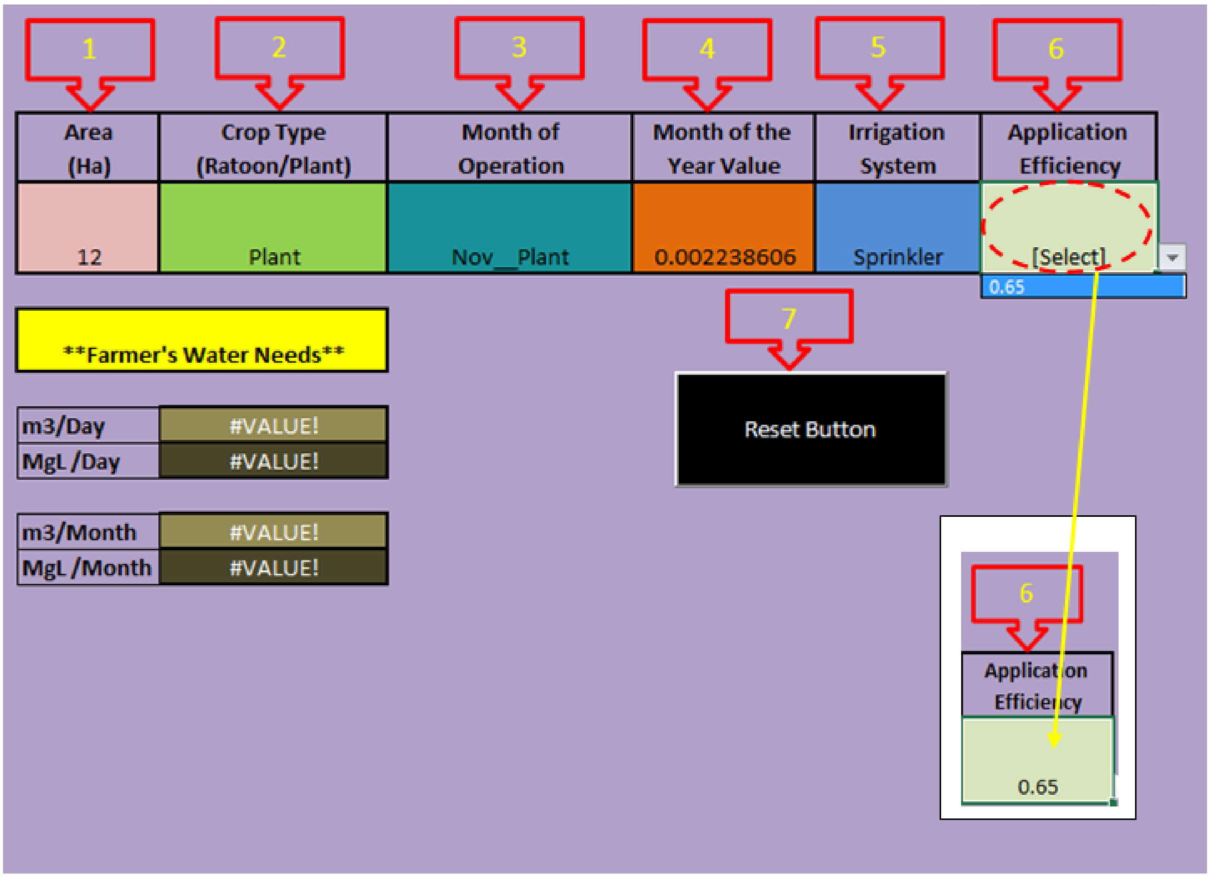
Source: (Author, 2018)

Figure 5-7: Process involved in inputting the Irrigation System Option

In the case above, it is assumed that the farmer is using sprinkler irrigation system to irrigate his/ her crops hence the sprinkler option was selected. This step 5 act as a predecessor to step 6.

5.3.6. Application Efficiency

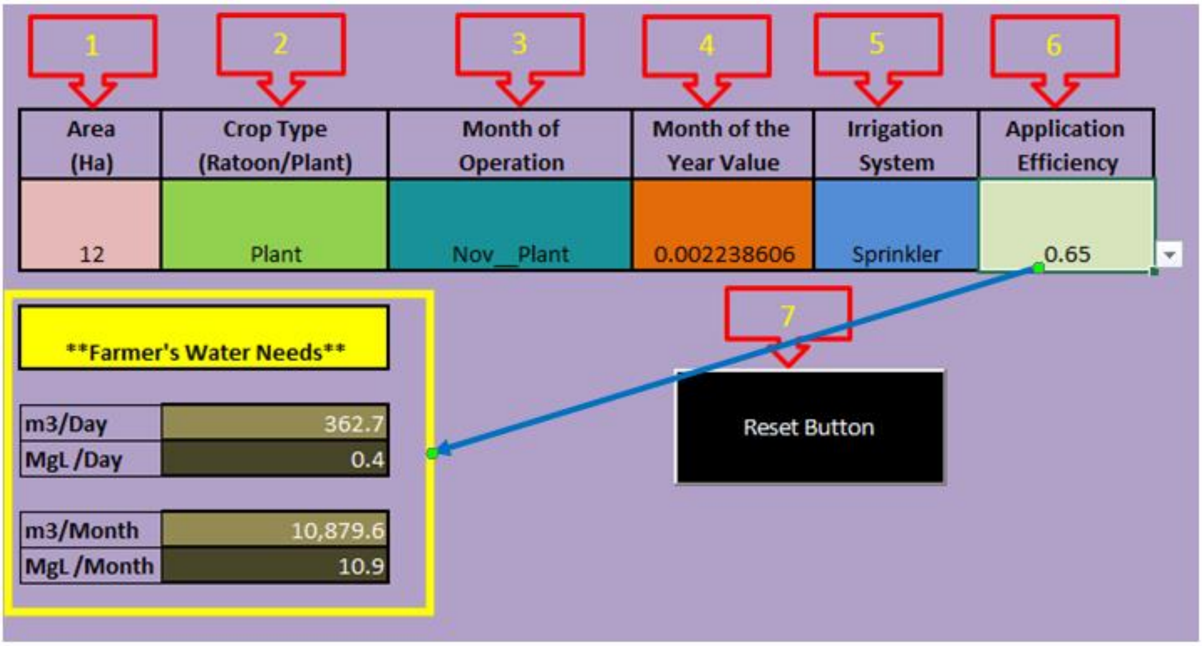
Step 6: In this step, irrigation application efficiencies for the selected irrigation systems are given in a dropdown list. After completing step 5, only the application efficiency for the selected irrigation system will be extracted for selection in step 6. The User/ Farmer only needs to click on the irrigation system application efficiency that comes out after clicking the drop down list arrow, See Figure 5-8 below.



Source: (Author, 2018)

Figure 5-8: Process involved in inputting the Irrigation System Option

In the Figure 5-8 above, an irrigation system application efficiency for sprinkler irrigation was used. Upon giving a value on the irrigation system application efficiency cell, results are automatically computed as shown in the Figure 5-9 below.



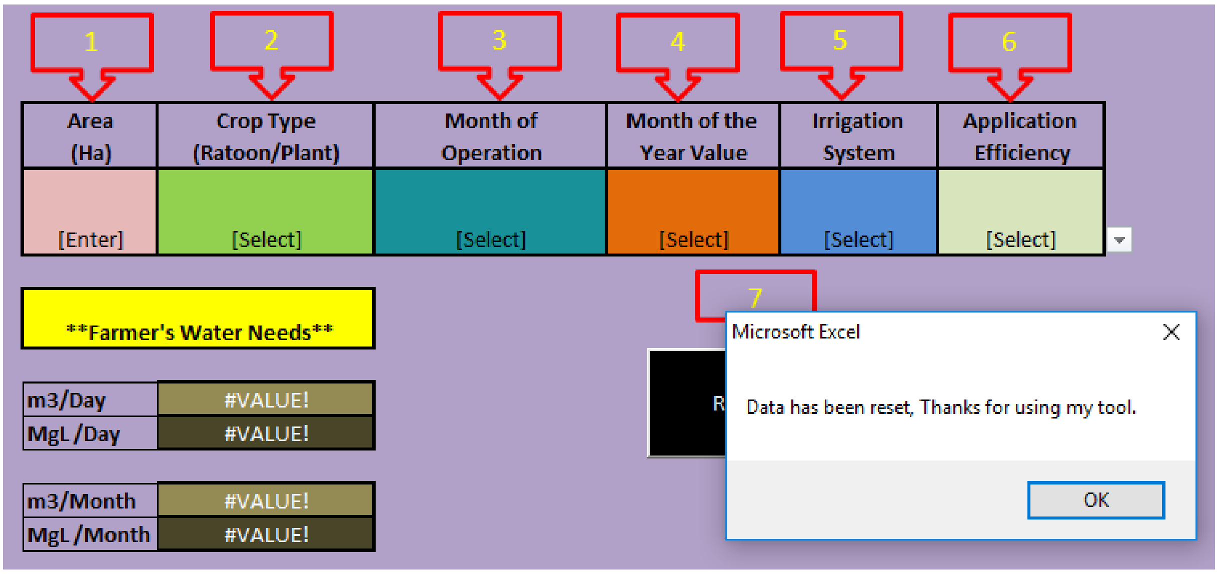
Source: (Author, 2018)

Figure 5-9: Calibration Tool Interface Showing Generated Results

The results are computed in m^3/sec, Litres/ sec, m^3/day, Mega litres (Mgl)/ day, m^3/month and Mgl/ month. For water budgeting purposes at Catchment level, only the monthly water needs are submitted. A farmer needs to write down the water needs on a separate sheet of paper as tool calculates for each required month.

5.3.7. Final Step in the Use of the Tool 'The Reset Button'

Step 7: Still on the same field, after a farmer gets his / her monthly water needs he / she might need to compute water needs for the other months. To allow for new entry, the previous calculation has to be reset by clicking on the Reset Button. After clicking the Reset Button, the Interface is reset to its default and a Message Box pops up with inscribed text written "Data has been reset, thanks for using my tool", see Figure 5-10 below.



Source: (Author, 2018)

Figure 5-10: Reset Button Function

To allow for new entry, the Farmer / User has to click Ok to proceed.

5.4. Overview of the results

The development of this tool resulted in 100 % time saving, 60 % improved water management strategies and 30 % efficient and effective utilization of water resources.

5.5. Conclusion

In order for one to be able to use the calibration tool, one has to follow the steps from step 1 to step 7. Failure to follow the steps and going through the Tools manual ‘Principle of Operation’ might result in getting erroneous results. The use of the tool results in efficient time saving, improved water management strategies and efficient and effective utilization of water resources.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.0. Introduction

All the chapters are summarized below and conclusions are made. A set of recommendations are drawn from the findings that the Researcher came across during the course of doing the project.

6.1. Conclusion

Sugarcane is a high water demanding crop, therefore, it is essential to make sure that all its water needs are met to prevent yield loss. In the case of the Zimbabwean South Eastern Lowveld, water needs for the sugarcane crop are largely dependent on the Catchment Water Management Agency (CWMA) who releases water from the reservoirs located hundreds of kilometers away to the farmers based on the farmer's demand. There is lack of cooperation between the CWMA and farmers resulting in poor water management strategies. This is as a result of the unavailability of the budgeting tools that synchronize their operations.

There was potential to save time and to efficiently and effectively utilize water resources through the development of the water budgeting tool. It was in this context that a sugarcane crop water use based water budgeting calibration tool was developed. After the development of the tool, time was indeed saved, water management strategies were improved and water resources are now efficiently and effectively utilized hence the sustainability of farming is improved. The developed tool resulted in 100 % time saving, 60 % improved water management strategies and 30 % efficient and effective utilization of water resources.

Time is saved through the incorporation of a database in the tool which enable the User to get the water requirements for any month of choice from just a click. The User is only required to provide the field parameters such as the landscape area, whether the crop is a Plant/ Ratoon crop, month in which the crop was planted/ cut and the irrigation system used for the tool to compute the water needs.

The water resource are now being utilized efficiently and effectively since less water is now lost to the oceans due to effective communication and cooperation between the CWMA and the Farmers. When the Farmers submit their water needs to the CWMA, the CWMA is empowered to be an active and very important stakeholder in farming industry as he/ she will be able to advice farmers on whether they can be able to increase or reduce production based on what will be on the reserves. Conflict amongst farmers is also reduced as each individual farmers are now withdrawing water as per their request.

It is evident that the developed sugarcane crop water use based water budgeting calibration tool for catchment water management will go a long way in improving the life style of the sugarcane farmers in the Zimbabwean South-Eastern Lowveld through improved yields from good water management strategies. After each two years, the database for the water budgeting calibration tool will be updated and some features will be added to allow for continuous improvement of the water management strategies.

6.2. Recommendations

1. Before using the calibration tool, one has to go through the tool's manual first to prevent any misuse of the tool.
2. The tool is site specific hence only the sugarcane farmers in the Lowveld area of Zimbabwe can use the tool.
3. The tool is only for quantifying the total water needs for a required period, however, the application of that water to the crops entirely depends on management who will have to take into account the terrain, TAM, etc.
4. The user needs to have a writing pad and a pen to write down all the monthly water requirements as the tool computes for each month.
5. It is advised that upon making an error in the inputting/ selection of parameters, one has to click the reset button and start the process again.
6. Last but not least, there is need to develop a tool that can automatically compute the yearly water needs from a single entry of in farm parameters e.g. upon providing the landscape area, whether the crop is ratoon/ plant, the month when the crop was planted/ cut and the irrigation system being used,

the tool has to be able to compute the water needs for such a crop up to maturity. “Watch out for Version 2.”

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Appendix

7.0. Appendix 1

Questionnaire for the Farmers and CWMA

Put an X on the answer which best suite you.

1. How far do you think the tool can effectively save time?

10 %	20 %	30 %	40 %	50 %
60 %	70 %	80 %	90 %	100 %

Support your answer: ....

....

2. How far is the tool in improving water management strategies?

10 %	20 %	30 %	40 %	50 %
60 %	70 %	80 %	90 %	100 %

Support your answer:..

....

3. How effectively and efficiently is the tool helping in utilizing the water resources?

10 %	20 %	30 %	40 %	50 %
60 %	70 %	80 %	90 %	100 %

Support your answer:..

....

4. How far is the tool helping in combating conflict among water users?

10 %	20 %	30 %	40 %	50 %
60 %	70 %	80 %	90 %	100 %

Support your answer:..

....