

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULICS ENGINEERING STREAM



**IMPACT ASSESSMENT OF IRRIGATION WATER USE
ON LAKE ZIWAY WATER LEVEL**

A thesis submitted to the School of Graduate Studies of Addis Ababa
University in partial fulfillment of the requirements for the degree of
Master of Science in Hydraulics Engineering

By Habtamu Girma

September 2015

DEDICATION

The success of this thesis is dedicated to my fiancée Betelihem Zena and my family for their love and support they have given to my life.

**Impact Assessment of Irrigation Water Use
on Lake Ziway Water Level**

Thesis

Submitted in partial fulfillment of the requirements of the degree of Master of
Science in Civil Engineering (Hydraulics Engineering)

By

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This is to certify that the thesis prepared by Habtamu Girma Jabir, entitled “**Impact Assessment of Irrigation Water Use on Lake Ziway Water Level**” and Submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil and Environmental Engineering (Hydraulic Engineering major) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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List of Acronyms

cm	Centimeters
CRL	Central Rift Valley Lakes
CWR	Crop Water Requirements
°C	Degree Centigrade
E	East
ET	Evapotranspiration
ETc	Crop Evapotranspiration under standard conditions
ETcadj	Crop Evapotranspiration under non-standard conditions
ETo	Reference Evapotranspiration
FAO	Food and Agricultural organization of the United Nations
FC	Field Capacity
GDP	Gross domestic Product
GIRD	Generation Integrated Rural Development
GIS	Global Information System
ha	Hectare
IR	Irrigation Requirement
IRn	Net Irrigation Requirement
IRg	Gross Irrigation Requirement
JICA	Japan International Cooperation Agency
Kc	Crop Coefficient
Ks	Water stress coefficient
km ²	Kilo Meter Square
m ³	Cubic Meter
m	Meter
m ²	Meter Square
m.a.s.l	meters above sea level
Mm ³	Million Meter Cube
mm	Millimeter
MoWR	Ministry of Water Resources
N	North
OIDA	Oromiya Irrigation Development Authority
RF	Rainfall
RVLB	Rift Valley Lake Basin
USA	United States of America
USDA	United States Department of Agriculture
UNESCO	United Nations Educational, Scientific and Cultural Organization
WP	Welting Point
WWDSE	Water Work Design and Supervision Enterprise

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Abstract

The study area is located in the central rift valley lake basin of Ethiopia. This area has a fresh water lake called lake Ziway but this precious resource is endangered due to abstraction directly from the lake and from feeder rivers (Meki and Katar). This research was intended to show the impact of irrigation water use on lake Ziway water level. The methodology used was CROPWAT 8.0 model to estimate the irrigation water requirements of five major crops irrigated in the study area. Bathymetric data was used to analyze the impact of irrigation water use on the level of the lake. River inflow and outflow data were collected, precipitation and evaporation data were estimated from mean monthly rainfall and annual evaporation data respectively to compare percentage reduction of initial volume of the lake without considering irrigation water abstraction with irrigation water abstraction condition. The results showed that for the whole existing and potential irrigation development area crop water requirements were 197,844,647.3m³. This much irrigation water abstraction holds 9.31% of initial volume of lake Ziway and it reduces 0.4m water level of the lake annually. This much rate of lake level reduction (0.4m/year) may lead to the loss of the lake after 27.5 years and it may also become the cause to cease the downstream flow after 6.25 years. And again, the results showed that regardless of irrigation water abstraction only 7.74% of the initial volume of the lake was reduced, but when irrigation water abstraction was considered 17.05% of the initial volume of the lake was reduced and this showed that irrigation water abstraction merely reduced 9.31% of initial volume of the lake which indicated greater reduction due to irrigation water abstraction relative to reduction with no irrigation water use condition (7.74%). These all results revealed that irrigation water use for the whole existing and potential irrigable area brings drastic impact on the lake Ziway and the downstream area that benefit from the lake. Therefore, the study area needs integrated water resources management to sustain the life of the area.

Key Words: Impact, Lake Ziway, Gross irrigation water requirements, Irrigation water abstraction, Lake level reduction, Downstream area

1. Introduction

1.1. Background

Water is the greatest resource of humanity. It not only helps in survival but also in making life comfortable and luxurious. Besides various uses of water, the largest uses of water in the world is made for irrigating lands. Irrigation, in fact, is nothing but "a continuous and a reliable water supply to the different crops in accordance with their different needs". when sufficient and timely water does not become available to the crops, the crop fade away, resulting in lesser yield, consequently creating famines and disasters. Irrigation can, thus, save us from such disasters.(Santosh Kumar Garg, 2005).

Of all the substances that are necessary to life on the earth, water is by far the most important to sustain life. Water is abundant, yet frequently scarce and characterized by uneven spatial and temporal distribution.

Water is finite resource and must be managed in sustainable way to meet human as well as environmental needs. The sustainable use of water is becoming increasingly important in legislative agenda of the country. The overall goal of the National Water Resource Policy is to enhance and promote all national efforts toward the efficient, equitable and optimum utilization of the available water resources of the country for significant socio-economic development on sustainable basis.

Rift valley and its environment are important area in the country in connection with their water resources. It is where lakes useful for agricultural production, industrial and recreation are present. Recently, the cumulative effect of increase in population and climate change that enhance over abstraction of water to meet fast growing demand are threatening the area. In order to manage equitable distribution of water in the area, determination of total available resources is critically important. Information about the temporal and spatial distribution, as well as dynamics of the resource, is important to plan for areas of more feasible development; and the alternative uses of the available resources. Identification of factors accountable for depletion of water resources is useful for policy makers to manage the problem with respect to the rising demand. (Alemu Dribssa, 2006).

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The future Water resource availability in RVLB is dependent on changes in the climate and hydrology in the basin, changes in environmental and human demands for water and changes in water resource management practices. Climatic and hydrological changes may occur due to climatic change and land use change. Human demands may change due to irrigation development, increases in domestic water supply requirements, and increase in industrial demands. (HALCROW Group Limited and GIRD Consultants, 2008). Assessing these precisely as possible is important to show the problem and find the solution how to use the available resource sustainably.

The most important large-scale withdrawals of water in the Ethiopian Rift are used for irrigation and soda (NaCO_3) production. These activities have reduced the levels of some of the lakes, and modified the limnological settings and the chemistries of the lakes as a result of changes in groundwater and surface water fluxes (Makin et al 1976; Gebremariam and Dadebo 1989; Ayenew 2002).

The trend of lake levels in the Ethiopian rift is not uniform, some are expanding and some are shrinking. The most drastic changes have been observed in lakes Abiyata and Beseka, the former is shrinking and the later expanding; slight decline is evident in lake Ziway and rise in lakes Langano and Awassa. Any abstraction of water in the Ziway catchment results in a greater reduction in the level of Lake Abiyata than in that of Lake Ziway. Many of the levels of the rift lake fluctuate according to the precipitation trends in the adjacent highlands. However, the drastic changes have come in the last few decades after large-scale water use for irrigation and soda abstraction. (Tenalem Ayenew , 2007).

The scenarios developed for the years 2001-2099 showed that both, temperature and precipitation are likely to increase from the 1981-2000 level. These changes are likely to have significant impacts on the inflow volume into the lake. Despite the increasing trend of both climatic variables, the increase in precipitation seems to be obscured by increases in temperature. Hence, the total average annual inflow volume into Lake Ziway might decline significantly. (Lijalem Zeray Abraham et al., 2007). In this study, irrigation water requirement of the study area and the corresponding impact on lake Ziway water level is assessed. Moreover, length of time that takes to abstract total initial volume of the lake and to cease the downstream flow with obtained annual abstraction rate are determined. Therefore, the research is an important input for

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water resources management of the study area to provide irrigation water use impact on lake Ziway water level.

1.2. Statement of the problem

Water resources development is widely recognized as crucial for sustainable economic growth and poverty reduction in developing countries. However, such development incurs positive impact as well as negative impact to the existing condition. Before any planning activity for water resources development works in a certain river basin it is essential first to identify and evaluate water resources development and its sustainability.

Lake Ziway is a fresh water lake that uses as a source of water for irrigation and water supply. It is also a place of fish farm, the site for five islands, the location of recreation and tourism, and it is generally the life of the population living around and at downstream of the lake, but this precious resource is facing the following main problems.

- The lake water level is reducing due to over abstraction of irrigation water.
- The lake water quality is being polluted due to irrigation practice.

This thesis tries to address the impact of irrigation water use on the lake water level.

1.3. Research questions

- ✚ What is the irrigation water requirements for the existing and the potential irrigation development area?
- ✚ What percentage of lake Ziway volume is abstracted?
- ✚ How much the level of the lake is reduced due to abstraction annually?
- ✚ How long it takes to abstract total initial volume of the lake with obtained annual abstraction rate?
- ✚ How long it takes to cease downstream flow to Bulbula river with obtained annual abstraction rate?

1.4. Research Objectives

1.4.1. Main Objective

The general objective of the research is to assess the impact of irrigation water use on lake Ziway water level for the betterment of water resources development and management on the study area.

1.4.2. Specific Objective

The specific objectives are the following:

1. To determine irrigation water requirements of the study area.
2. To assess the impact of irrigation water use on lake Ziway water level.
3. To determine length of time that takes to abstract total initial volume of the lake and to cease the downstream flow with obtained annual abstraction rate.

2. Literature Review

2.1. Theoretical Concepts

2.1.1 Evaporation, Transpiration and Evapotranspiration

In a cropped field water can be lost through two processes (Figure 2-1):

1. Water can be lost from the soil surface and wet vegetation through a process called *evaporation* (E), whereby liquid water is converted into water vapour and removed from the evaporating surface. Energy is required to change the state of the molecules of water from liquid to vapour. The process is affected by climatological factors such as solar radiation, air temperature, air humidity and wind speed. Where the evaporating surface is the soil surface, the degree of shading of the crop canopy and the amount of water available at the evaporating surface are the other factors that affect the evaporation process.

2. The second process of water loss is called *transpiration* (T), whereby liquid water contained in plant tissues vaporizes into the atmosphere through small openings in the plant leaf, called stomata. Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind. Hence solar radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water logging and soil salinity. Crop characteristics, environmental aspects and cultivation practices also have an influence on the transpiration.

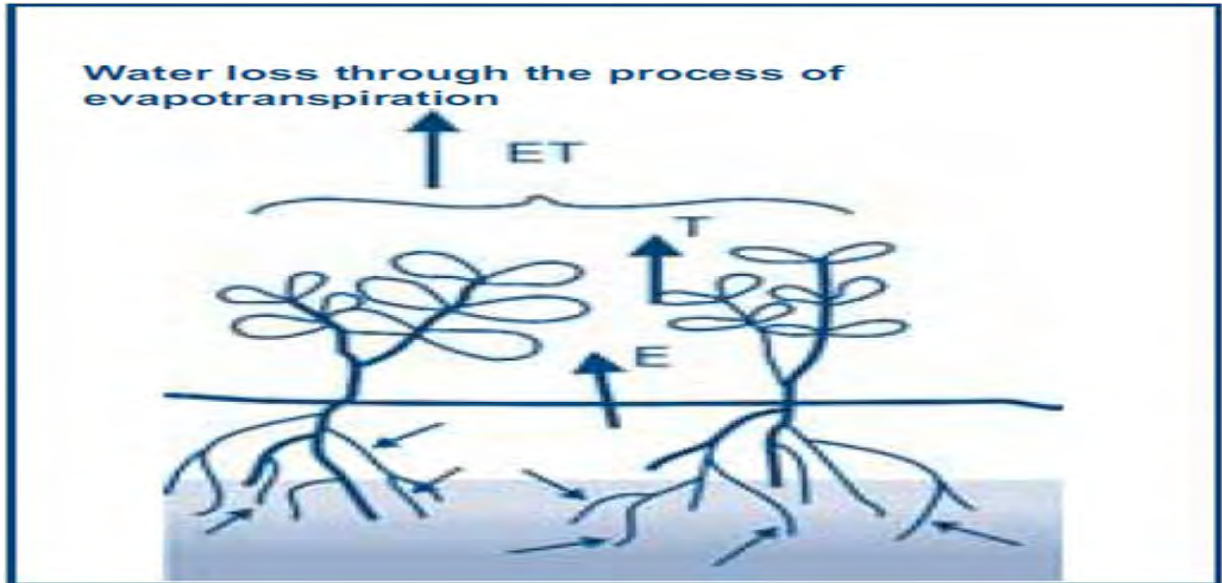


Figure 2-1 Evapotranspiration

The combination of these two separate processes, whereby water is lost on one hand by evaporation from the soil surface and on the other hand by transpiration from a plant, is called *evapotranspiration* (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

When the crop is small evaporation is the main process, but once the crop is fully grown and completely covers the ground transpiration becomes the dominant process. It has been estimated that at crop sowing 100% of the total ET comes from evaporation, while at full crop cover evaporation accounts for about 10% of ET and transpiration for the remaining 90%.

➤ Factors affecting crop evapotranspiration

The main factors affecting evapotranspiration are climatic parameters, crop characteristics, management practices and environmental aspects. The main climatic factors affecting evapotranspiration are solar radiation, air temperature, air humidity and wind speed.

The crop type, variety and development stages affect evapotranspiration. Differences in crop resistance to transpiration, crop height, crop roughness, reflection, canopy cover and crop rooting characteristics result in different evapotranspiration levels in different types of crops under identical environmental conditions.

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Factors such as soil salinity, poor land fertility, limited use of fertilizers and chemicals, lack of pest and disease control, poor soil management and limited water availability at the root zone may limit the crop development and reduce evapotranspiration. Other factors that affect evapotranspiration are groundcover and plant density. Cultivation practices and the type of irrigation system used can alter the microclimate, affect the crop characteristics or affect the wetting of the soil and crop surface. All these affect evapotranspiration.

➤ Reference crop evapotranspiration

The evapotranspiration from a reference surface not short of water is called the reference crop evapotranspiration and is denoted by E_{To} . The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of E_{To} was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development stage and management practices. As water is abundant at the evapotranspiring surface, soil factors do not affect evapotranspiration. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. It removes the need to define a separate evapotranspiration level for each crop and stage of growth. The only factors affecting E_{To} are climatic parameters. As a result, E_{To} is a climatic parameter and can be computed from weather data. E_{To} expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors.

➤ Crop evapotranspiration under standard conditions

The crop evapotranspiration under standard conditions, denoted as E_{Tc} , is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of E_{Tc} and CWR (Crop Water Requirements) are identical, whereby E_{Tc} refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. E_{Tc} can be calculated from climatic data by directly integrating the effect of crop characteristics into E_{To} . Using recognized methods, an estimation of E_{To} is done.

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Experimentally determined ratios of ET_c/ET_o , called crop coefficients (K_c), are used to relate ET_c to ET_o as given in the following equation:

$$ET_c = ET_o \times K_c \dots\dots\dots \text{Equation 1}$$

Where:

ET_c = Crop evapotranspiration (mm/day)

ET_o = Reference crop evapotranspiration (mm/day)

K_c = Crop coefficient

Differences in leaf anatomy, stomata characteristics, aerodynamic properties and even albedo (solar radiation reflected by the surface) cause ET_c to differ from ET_o under the same climatic conditions. Due to variations in crop characteristics throughout its growing season, K_c for a given crop changes from sowing till harvest.

➤ Crop evapotranspiration under non-standard conditions

The crop evapotranspiration under non-standard conditions, $ET_c \text{ adj}$, is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. When cultivating crops in the field, the real crop evapotranspiration may be different from ET_c due to non-optimal conditions such as occurrence of pests and diseases, soil salinity, poor soil fertility and waterlogging. $ET_c \text{ adj}$ is calculated by using a water stress coefficient (K_s) and/or by adjusting K_c for all kinds of other stresses and environmental constraints on crop evapotranspiration. The concepts of ET_o , ET_c and $ET_c \text{ adj}$ are illustrated in Figure 2-2.

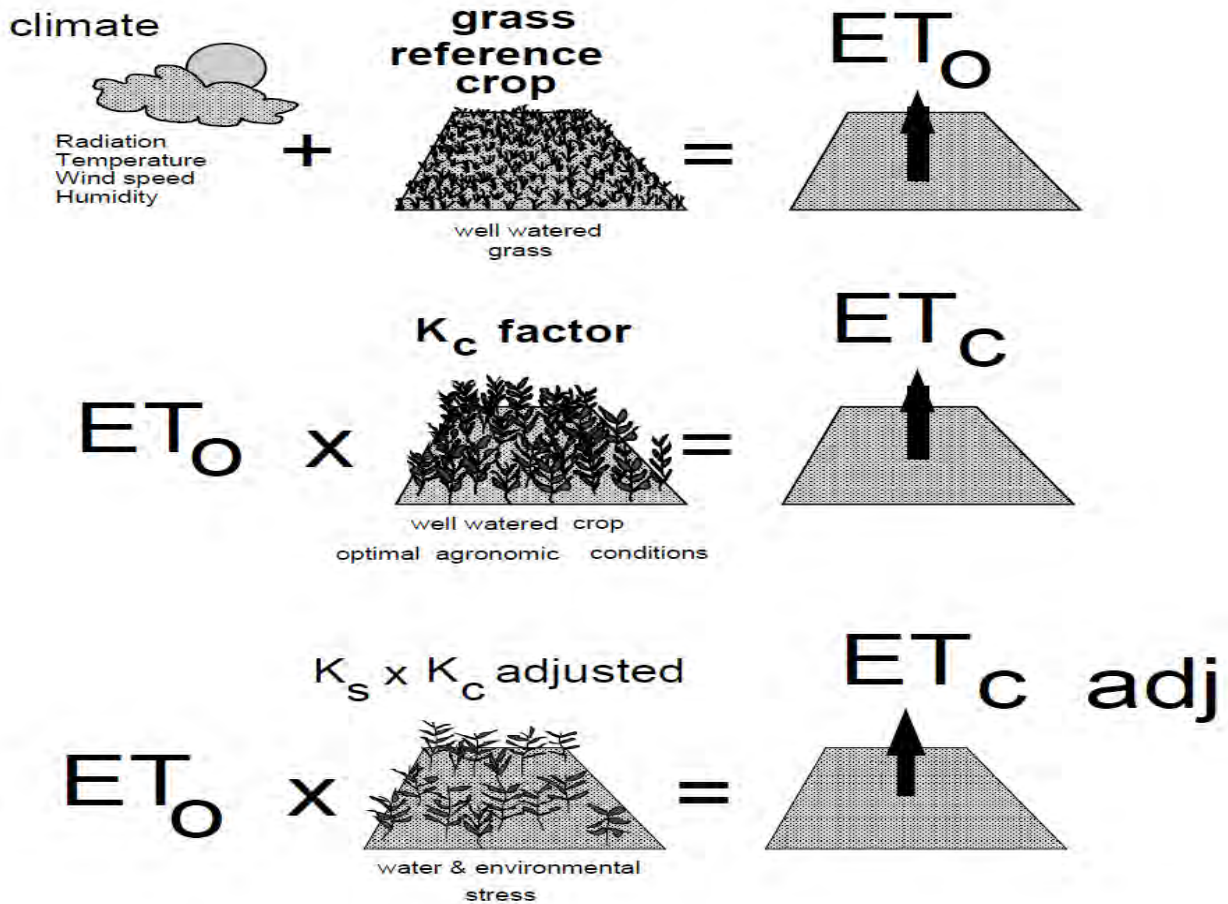


Figure 2-2 ET₀, ET_c and ET_cadj

2.1.2. Crop Water and Irrigation Requirements

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. FAO (1984) defined crop water requirements as „the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment“.

Irrigation requirements (IR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement.

2.1.3. Irrigation scheduling

Once the crop water and irrigation requirements have been calculated, the next step is the preparation of field irrigation schedules. Three parameters have to be considered in preparing an irrigation schedule:

- The daily crop water requirements
- The soil, particularly its total available moisture or water-holding capacity.
- The effective root zone depth

Plant response to irrigation is influenced by the physical condition, fertility and biological status of the soil. Soil condition, texture, structure, depth, organic matter, bulk density, salinity, sodicity, acidity, drainage, topography, fertility and chemical characteristics all affect the extent to which a plant root system penetrates into and uses available moisture and nutrients in the soil. Many of these factors influence the water movement in the soil, the water holding capacity of the soil, and the ability of the plants to use the water. The irrigation system used should match all or most of these conditions.

Soils to be irrigated must also have adequate surface and subsurface drainage, especially in the case of surface irrigation. Internal drainage within the crop root zone can either be natural or from an installed subsurface drainage system.

2.1.4. Estimating irrigation requirements

- Crop water requirements versus irrigation requirements

It is important to make a distinction between crop water requirement (CWR) and irrigation requirement (IR). Whereas crop water requirement refers to the water used by crops for cell construction and transpiration, the irrigation requirement is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. If irrigation is the sole source of water supply for the plant, then the irrigation requirement will be at least equal to the crop water requirement, and is generally greater to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the soil, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement. The Net Irrigation Requirement (IR_n) does not include losses that are occurring in the process of applying the water. IR_n plus losses constitute the Gross Irrigation Requirement (IR_g).

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The estimation of crop water requirements is the first stage in the estimation of irrigation requirements of a given cropping programme. Hence the calculation of crop water requirements and irrigation requirements are related procedures.

➤ Importance of estimating irrigation requirements

Estimating the crop water and irrigation requirements for a proposed cropping pattern is an essential part of the planning and design of an irrigation system. The irrigation requirement (IR) is one of the principal parameters for the planning, design and operation of irrigation and water resources systems. Detailed knowledge of the IR quantity and its temporal and spatial variability is essential for assessing the adequacy of water resources, for evaluating the need of storage reservoirs and for the determining the capacity of irrigation systems. It is a parameter of prime importance in formulating the policy for optimal allocation of water resources as well as in decision-making in the day-to-day operation and management of irrigation systems. Incorrect estimation of the IR may lead to serious failures in the system performance and to the waste of valuable water resources. It may result in inadequate control of the soil moisture regime in the root zone, it may cause water logging, salinity or leaching of nutrients from the soil. It may lead to the inappropriate capacities of the irrigation network or of storage reservoirs, to a low water use efficiency and to a reduction in the irrigated area. Overestimating IR at peak demand may also result in increased development costs.

➤ Calculating gross irrigation requirements

The gross irrigation requirements account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements, as shown below:

$$IR_g = IR_n / E \dots \dots \dots \text{Equation 2}$$

Where:

IR_g = Gross irrigation requirements (mm)

IR_n = Net irrigation requirements (mm)

E = Overall project efficiency

2.1.5. CROPWAT 8.0 Model

CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. All calculation procedures used in CROPWAT 8.0 are based on the FAO guidelines as laid down in the publication No. 56 of the Irrigation and Drainage Series of FAO "Crop Evapotranspiration - Guidelines for computing crop water requirements". Input and output data of the model are listed on the Table 2-1.

Table 2-1 Input and Output data of CROPWAT 8.0 Model

Input Data	Output Data
1. Climate/ET _o	1. CWR
2. Rainfall	2. Schedule
3. Crop	3. Scheme
4. Soil	
5. Cropping Pattern	

2.1.5.1. *Climate/ET_o input data of the Model*

The Reference Evapotranspiration (ET_o) represents the potential evaporation of a well-watered grass crop. The water needs of other crops are directly linked to this climatic parameter. Although several methods exist to determine ET_o, the Penman-Monteith Method has been recommended as the appropriate combination method to determine ET_o from climatic data from temperature, humidity, sunshine and wind speed. The module is primary for data input, requiring information on the meteorological station (country name, altitude, latitude and longitude) together with climatic data. CROPWAT 8.0 can calculate reference ET_o using only temperature, but humidity, wind speed and sunshine should be entered if available. For the benefit of CROPWAT 8.0 users a climatic database called CLIMWAT has been developed to provide the basic climatic information needed by the program. CLIMWAT Version 2.0 contains monthly climatic data that can be exported in the appropriate format required by CROPWAT 8.0. After inserting all input parameters into Climate/ET_o module of the model, it gives average reference evapotranspiration and radiation of the study area using the FAO Penman-Monteith approach.

2.1.5.2. Rain input data of the Model

The rainfall contributes to a greater or lesser extent in satisfying CWR, depending on the location. During the rainy season in tropical and some semi-tropical regions, a great part of the crop's water needs are covered by rainfall, while during the dry season, the major supply of water should come from irrigation. How much water is coming from rainfall and how much water should be covered by irrigation is, unfortunately, difficult to predict as rainfall varies greatly from season to season.

In order to estimate the rainfall deficit for irrigation water requirements, a statistical analysis needs to be made from long-term rainfall records. In addition to the variability of rainfall from year to year, not all rain which falls is used by the crop. The intensity of rain may be such that part of the rainfall is lost due to surface runoff or due to deep percolation below the root zone. In order to determine that part of the rainfall which effectively contributes to cover CWR, a number of definitions are first given, while subsequently it is explained how the different rainfall values can be calculated and how they are incorporated in the CWR calculations.

➤ Rainfall Definitions

- *Average monthly rainfall:*

Mathematically determined average for a series of rainfall records, most commonly available. To be used for CWR calculation to represent average climatic conditions.

- *Dependable rainfall:*

The amount of rainfall which can be depended upon in 1 out of 4 or 5 years corresponding to a 75 or 80% probability of exceedance and representing a dry year. The dependable rainfall (80%) is used for the design of the irrigation system capacity.

- *Rainfall in wet, normal and dry years:*

Defined as the rainfall with a respectively 20, 50 and 80% probability of exceedance, representing a wet, normal and dry year. The three values are useful for the programming of irrigation supply and simulation of irrigation management conditions. The rainfall in normal years (50% probability) is, in general, well approached by the average rainfall.

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- *Historical or actual rainfall data:*

The actual recorded rainfall used for evaluation purposes.

- *Effective rainfall:*

Defined as that part of the rainfall which is effectively used by the crop after rainfall losses due to surface run off and deep percolation have been accounted for. The effective rainfall is the rainfall ultimately used to determine the crop irrigation requirements.

The CROPWAT 8.0 model uses Effective Rainfall method to calculate effective rain from monthly mean rainfall. The Rain module in the model require input data station and to choose one effective rainfall methods from the four. Effective rainfall methods to account for the losses due to runoff or percolation, a choice can be made of one of the four methods given in CROPWAT 8.0 (Fixed percentage, Dependable rain, Empirical formula, USDA Soil Conservation Service). In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. (FAO, 1998).

2.1.5.3. Soil input data of the Model

For different types of soils the following input data are collected and inserted in the soil module of model to calculate the initial available soil moisture in mm/meter.

- Total available soil moisture (FC- WP) in mm/meter
- Maximum rain infiltration rate in mm/day
- Maximum rooting depth in centimeters
- Initial soil moisture depletion (as % TAM) in %

Total Available Soil Moisture Content (TAM), defined as the difference in soil moisture content between field capacity and wilting point. It represents the ultimate amount of water available to the crop and depends on texture, structure and organic matter content of the soil, expressed in mm/meter. Indicative values for different texture class are presented on Table 3-3.

Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased. In

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the absence of water supply, the water content in the root zone decreases as a result of water uptake by the crop. As water uptake progresses, the remaining water is held to the soil particles with greater force, lowering its potential energy and making it more difficult for the plant to extract it. Eventually, a point is reached where the crop can no longer extract the remaining water. The water uptake becomes zero when wilting point is reached. Wilting point is the water content at which plants will permanently wilt. As the water content above field capacity cannot be held against the forces of gravity and will drain and as the water content below wilting point cannot be extracted by plant roots, the total available water in the root zone is the difference between the water content at field capacity and wilting point.

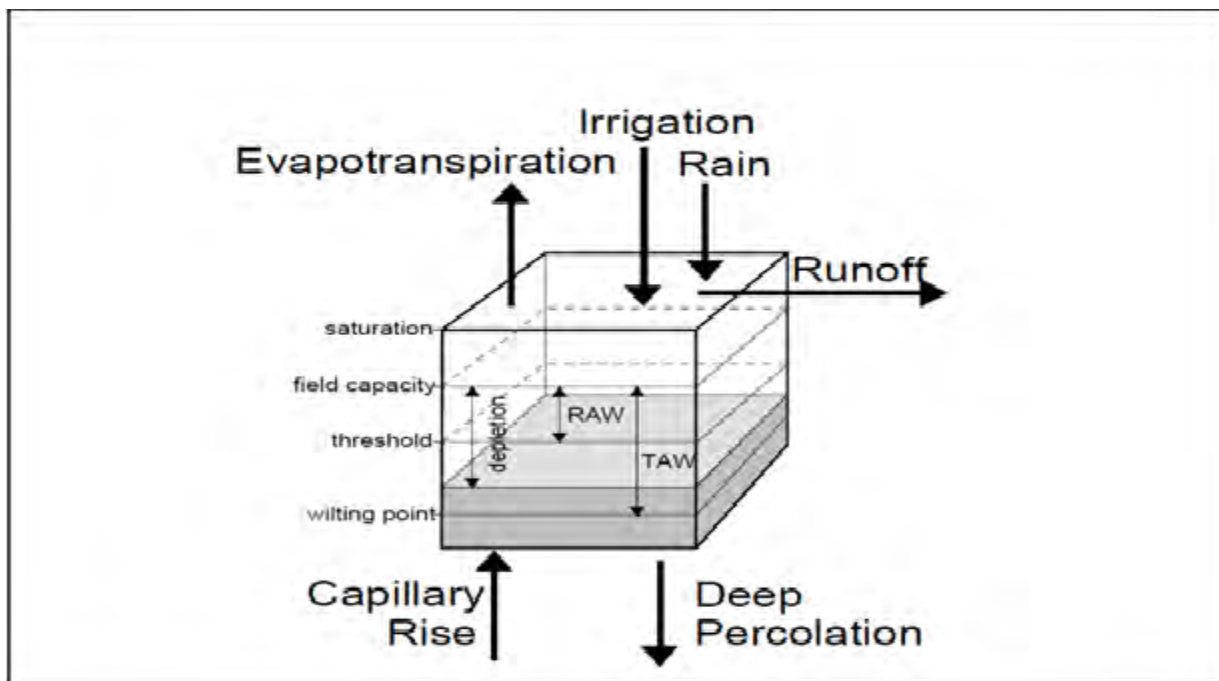


Figure 2-3 Water balance of root zone

Maximum Rain Infiltration rate, to allow an estimation of surface runoff for the effective rain calculation, the maximum rain infiltration rate expressed in mm/day, can be set, limiting the maximum amount of rain which can infiltrate the soil on any one day, as a function of rain intensity, soil type and slope class. Default value is set at 30mm/day.

- The maximum infiltration rate has the same value as the soil hydraulic conductivity under saturation (CROPWAT 8.0 Manual). The saturated hydraulic conductivity expresses property of the soil to conduct water through a saturated soil. (Dirk RAES, 2002)

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Maximum Rooting depth, although in most cases the genetic characteristics of the crop will determine the rooting depth, in some cases the soil and certain disturbing soil layers may restrict the maximum soil depth. Default value is set arbitrarily on 900cm, indicating no soil depth limitation.

Initial Soil Moisture Depletion (% TAM), indicating the dryness of the soil at the start of the growing season. The initial soil moisture is expressed as a depletion percentage from field capacity. Default value 0% represents a fully wetted soil profile, 100% is a soil at wilting point. In most cases only an estimation can be made of the initial soil moisture condition, depending on previous crop and periods of a preceding fallows or dry seasons period.

2.1.5.4. Crop input data of the Model

Crop input data are crop name, planting date, crop coefficient (Kc), stages length, rooting depth, critical depletion fraction (p), yield response factor (Ky) and maximum crop height.

The crop module requires crop data over the different development stages, defined as follow:

- Initial stage: it starts from planting date to approximately 10% ground cover.
- Development stage: it runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering.
- Mid-season stage: it runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the ETo.
- Late season stage: it runs from the start of maturity to harvest or full senescence.

The cropping pattern module is primary data input, requiring information on the crops (Up to 20) being part of the scheme. With reference to each crop, the following input data are provided:

- Crop file
- Planting date
- Area: extension of the area dedicated to each crop, as a percentage of the total cropped area. At any given moment the sum of the individual crops does not exceed 100 % of total scheme area.

2.1.5.5. *Output data of Model*

❖ Crop Water Requirements

After inserting all required CROPWAT 8.0 input data (climate/ET_o, Rain and Crop) and by calling up successively the appropriate climate and rainfall data sets, together with the crop files and the corresponding planting dates CWR module has calculated the irrigation water requirement of the crop on a decadal basis and over the total growing season, as the difference between the crop evapotranspiration under standard conditions (ET_c) and the effective rainfall.

❖ Scheme and Canal Water Requirements Output Data

The irrigation supply to any irrigation scheme or canal command area can be calculated by adding up the requirements of each cropped area. Any changes in cropping pattern can be conveniently calculated by modifying area size of the different crops. Similarly, the irrigation supply for each canal unit can be determined through CROPWAT 8.0.

The scheme module includes calculations, producing:

- Irrigation requirement for each crop of the scheme
- Net scheme irrigation requirement
- Irrigated area as a percentage of the total area
- Irrigation requirement for the actual area

❖ Irrigation Scheduling Output Data

An important element of CROPWAT 8.0 is the irrigation scheduling module, which has several application possibilities:

- To develop indicative irrigation schedules:
 - For the agricultural extension service to promote better irrigation practices
 - For the irrigation service to establish improved rotational delivery schedules;
- To evaluate existing irrigation practices on water use efficiency and water stress conditions;
- To evaluate crop production under rainfed conditions, to assess feasibility of supplementary irrigation and to develop appropriate irrigation schedules;
- To develop alternative water delivery schedules under restricted water supply conditions.

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The calculations of the scheduling module are based on a soil water budget, where, on a daily basis, the soil moisture status is determined, accounting for incoming and outgoing water in the root zone.

2.2. Previous Studies in the Area

Number of studies have been carried out in Central Ethiopian Rift Valley that includes the study area. These studies have been focusing on geology, volcano-tectonics, hydrogeology, hydrology and water resource potential assessment which directly or indirectly related to the current study. Some of the works are briefly described as follows:

According to Malefia (2009), study carried out with the objective of assessing the impact of floriculture industries on the water quality of lake Ziway five sites were chosen on the lake near the outlet of flower farms. The first site which was used as a control was located in the upstream area before the effluent joins the lake water and the other four sites were at the downstream. A total of 60 samples were tested for physicochemical, oxygen demanding, nutrient and micronutrient parameters. The results were analyzed using SAS (Stastical Analysis System) software to see if there were significant differences between the control and impaired sites. The result revealed that the water quality of lake Ziway is threatened and becoming less suitable for the variety of purposes being used. Therefore, environmental audit and waste water management actions should be taken to minimize the direct discharge of fertilizer rich effluents in to the lake.

Tigist, 2009 studied that with the intention of assessing the effects of current and future water use practices on the hydrology mainly lake level change of the Lake Abiyata and its surroundings used a WEAP (Water Evaluation And Planning system) model and creating different scenarios. The results revealed that unless the minimum historical flow requirements are maintained, all scenarios indicated the future effects on Lake Abiyata. Therefore, any new projects on the study area demand Integrated Water Resources Management and Environmental Impact Assessment before the realization of the projects.

According to Amare (2008), study carried out with the objective of assessing the water balance components of the Lake Ziway continuity equation was used. The monthly water budget of lake Ziway is determined from rainfall, evaporation, estimated inflow from ungauged and gauged

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inflow and out flow from the lake. Average rainfall for the area was estimated using Thiessen polygon. Evaporation was estimated using Cropwat, Penman combination and Pitche reading. Inflow from the ungauged is developed using area ratio method. The result of the water balance simulation for the lake has shown that 77.5% lost due to evaporation.

Tenalem, 2004 studied that with the intention of assessing lake level changes and their environmental repercussions, based on evidence from hydrometeorological records, hydrogeological field mapping supported by aerial photography and satellite imagery interpretations, water balance estimation, and hydrological modeling. The results revealed that the major changes in the rift valley are mainly related to anthropogenic factors.

Alemu, 2006 studied that with the objective of assessing groundwater–surface water interaction and analysis of recent changes in hydrologic environment of lake Ziway Catchment used empirical formula, soil moisture budgeting and groundwater balance methods to estimate direct groundwater recharge of the catchment. Groundwater and surface water interaction in the area have been analyzed using groundwater table contour, field base river discharge measurements, channel water balance and hydrographic analysis. Assessment of recent changes in hydrologic environment has been analyzed by trends in short and long term precipitation, evaporation, abstraction, rivers discharge, lake level and direct groundwater recharge. All these parameters revealed that changes of hydrologic environment; attributed both to climate change and human interference.

Tenalem, 2007 studied that with the objective of assessing some improper water resources utilization practices and environmental problems in the last few decades in the Main Ethiopian Rift (MER). The methods employed include field hydrogeological mapping supported by aerial photograph and satellite imagery interpretations, hydrometeorological data analysis, catchment hydrological modeling and hydrochemical analysis. The result revealed that the major changes in the rift valley are related mainly to recent improper utilization of water and land resources in the lakes catchment and direct lake water abstraction.

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Most studies conducted so far consider the impact of irrigation water use on the study area but the methods used are different from the method used in this thesis work. Therefore, the current study considers the impact of existing and potential irrigation water use on lake Ziway and it provides useful information for Policy makers and general public to manage the resources on sustainable basis.

3. Materials and Methods

3.1. Study Area Description

3.1.1. Location and Topography

Lake Ziway is found in the Great East African Rift Valley lakes of Ethiopia. It has an open water area of 434 km², average depth of 4 m, and an elevation of 1636 m.a.s.l. The Ziway Watershed falls in between 7°15'N to 8°30'N latitude and 38°E to 39°30'E longitude covering a total area of about 7300 km² (Figure 3-1). It is composed of two main rivers flowing into the lake, Meki and Katar, and one river flowing out of the lake, Bulbula. The climate is characterized by semi-arid to sub-humid with mean annual precipitation and temperature of 650mm and 25°C, respectively.(Lijalem Zeray et al., 2006).

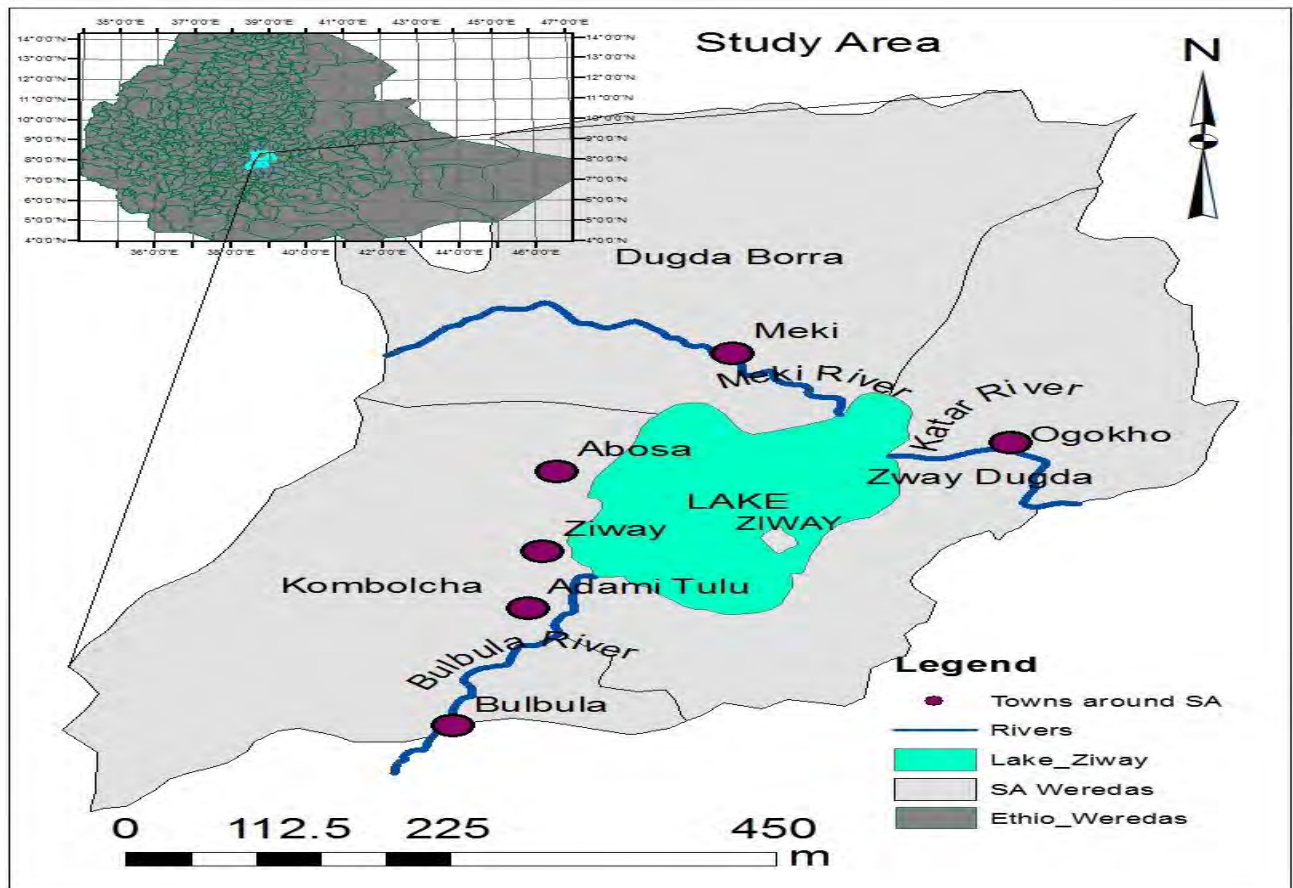


Figure 3-1 Location map of the study area

3.1.2. Geology

Most of the CRL region is covered by volcanic rocks that mainly consist of ignimbrites, basalts and rhyolites (Tesfaye Chernet, 1982). On the rift floor, lacustrine sediments derived from the rift escarpments are found around the lakes. The rift formation is associated with extensive volcanism where various volcanic products such as fissured basaltic lava flows alternating with volcano-clastic deposits are found in many places. With the exception of some patchy Precambrian outcrops to the south and north edge, the geological and morphological features of the CRL are the results of Cenozoic volcano-tectonic and sedimentation process (Tenalem Ayenew, 2002a).

3.1.3. Soil

Soil in the study area is closely related to parent material and degree of weathering (Makin et al 1976). The main parent materials are basalt, ignimbrite, volcanic ash, pumice, riverine and lacustrine alluvium. Weathering varies from deeply weathered basalt in humid highland areas to unweathered recent alluvial deposits in the drier central part of the rift valley.

Generally, there are four soil types in the area (Makin et al, 1976, Halcrow, 1992):

Type I: covers predominantly the rift floor and western escarpment on flat to undulating plains with some hills formed on pyroclastic deposits (Figure 3.2). Generally, the soils are dark grayish free draining friable silty loam to sandy loam with moderate structure and good moisture storing properties.

Type II: is found on steep faulted undulating and rolling low plateau escarpments of the rift zone. The soil is well drained, moderately deep to deep dark gray or brown, friable silty loam to sandy loam with moderate structure and good moisture storing properties.

Type III: is well drained deep reddish brown to red friable clays to clay loams with strong structure. This soil type is found on flat to undulating plateau of western margin and dominantly in eastern plain.

Type IV: is very thin and shallow soil covering the eastern margin of the study area. The soil is well drained and limited moisture storing property, stony and has no diagnostic horizon (Rigosols/Lithosols according to FAO /UNESCO soil classification).

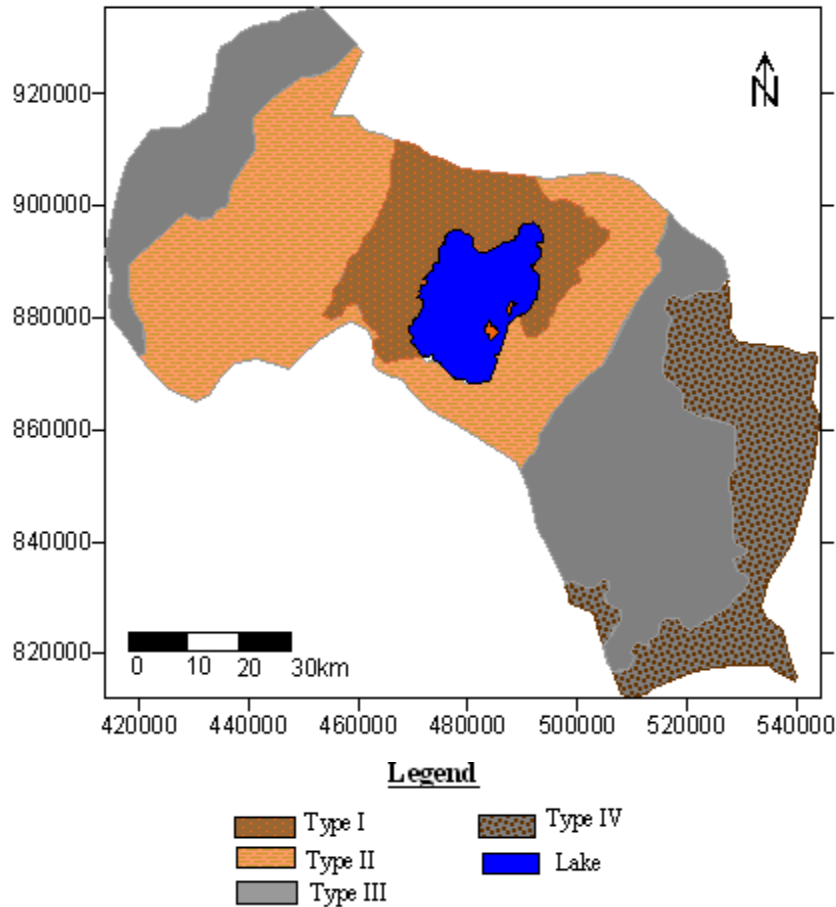


Figure 3-2 Generalized soil map of Lake Ziway catchment (from Makin et al, 1976)

3.1.4. Climate

Lake Ziway and Lake Abiyata are both located in mid-altitude regions of the sub-tropical (monsoon) agro-climatic zone. The rainfall pattern is largely influenced by the annual oscillation of the inter-tropical convergence zone, which results in warm, wet summers (with most of the rainfall occurring from June to September) and dry, cold and windy winters. Mean annual rainfall varies in the valley from approximately 500 mm (weather station at Lake Langano) and 650 mm (weather station Lake Ziway) to 1150 mm on the plateau. According to Tamiru Alemayehu *et al.*, (2006), there is no clear trend (increase or decrease) in rainfall characteristics in the region during the last 40 years (Tamiru Alemayehu *et al.*, 2006). The mean annual temperature in the highlands is approximately 15⁰C and 25⁰C close to the lakes. Actual evapotranspiration depends on the land use and availability of water and varies between 700 and 900 mm per year (Tenalem Ayenew, 2003).

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3.1.5. Population

The Human population in the CRL is estimated to be 1.5 Million with an average family size of 5.3 persons and growth rate of + 3% (Hengsdijk *et al*, 2007). Although there is uncertainty in the size of livestock density due to the seasonality of availability of fodder while the livestock population approaches 85 thousand Tropical Livestock Units (Scholten, 2007).

3.1.6. Agriculture

The Rift Valley Lakes Basin (RVLB) is primarily an agricultural basin and agriculture will continue to be an important part of the economy. Related sectors of livestock and industry based on processing of agricultural and livestock products will also be of importance. Most of the agriculture in the RVLB is subsistence and rain fed farming. There is some potential to increase the area under irrigation, but all new irrigations must be developed with caution as all water abstractions will impact the sensitive lakes of the RVLB and may not be sustainable. (MoWR, 1999).

3.1.7. Tourism

In Ethiopia, according to a World Bank study, tourism is the third next to coffee and oilseeds in terms of foreign earnings. RVLB encompasses natural, cultural, historical and religious tourist attractions that are currently in use. Lake Ziway provides various tourist attractions such as bird watching, fishing, boating, and churches on the island and horticulture.



Figure 3-3 Boating activity for tourists at Ziway Lake

3.1.8. Hydrology

The Ziway-Abiyata catchment basin covering some 5610 km² (Dagnachew Legesse *et al.*, 2004), is a closed basin that includes Lake Ziway which contains fresh water and Lake Abiyata saline and a terminal lake of the catchment. The major incoming rivers in this basin are the Ketar River and Meki River. The former discharges the water from the eastern and south-eastern plateaus while the later discharges the runoff from the plateau west of Lake Ziway. Both lakes are hydrologically connected, the major part of the water inflow of Lake Abiyata originated from Lake Ziway through the Bulbula River. However, considerably less water is discharged from Lake Langano to Lake Abiyata through the HoraKelo River (Dagnachew Legesse, 2002; Tamiru Alemayehu *et al.*, 2006). This has made Lake Abiyata relatively shallow in depth which consequently made it susceptible to changes in climate and input from precipitation and discharge (Tenalem Ayenew, 2003). However, Lake Shalla and its catchment do not have a surface water connection with the other lakes in the CRL. As a closed lake, as Tenalem Ayenew, (1998) explained, the only significant water loss from Lake Abiyata is through evaporation (Tenalem Ayenew, 1998). Thus, a fluctuation in lake level and volume depicts the changes in inputs from rainfall and rivers discharges. The level of Lake Abiyata is influenced strongly by the input into Lake Ziway, which transfers water through Bulbula River. This explains why the level of Lake Abiyata falls consistently over a number of dry years and recovers during wet years. Hence, changes in Lake Abiyata should be perceived jointly with the abstraction of water for irrigation around Lake Ziway (Tenalem Ayenew, 2002a).

3.1.8.1. Rivers

Meki River

Meki River originates in the highlands of Guraghe and travels a distance of about 100 km from the highlands at altitude of 3600 m to 1636 m before draining into the Lake Ziway. The total catchment area of the river near Meki town is 2433 km². It feeds 180,177,098 m³ average water to lake Ziway every year (Halcrow, 2008). The high discharge occurs during the months of August and September, while low discharge generally occurs during the dry season from December to February.

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Katar River

The catchment of the Katar River ascends to over 4000 m on the summits of Mounts Badda and Cacca. Because of the steep configuration of the Katar valley, areas suitable for irrigation are few in number and very limited in extent (Makin *et al.*, 1976). The prime importance of the Katar River is the contribution it makes to the Lake Ziway. The total catchment area of the river near Abura is 3350 km². It feeds lake Ziway 302,357,895 m³ (Halcrow, 2008) average volume of water annually.

Bulbulla River

Bulbulla River descends some 58 m over a distance of 30 km between Lake Ziway and Abiyata. The level of this river for the first 6 km of its length is virtually the same as that of Lake Ziway due to a lava rock sill which effectively controls the level of the lake which is 1635.5 m a.s.l. Except periodically during the wet season the flow in Bulbulla River usually derives entirely from Lake Ziway. Whenever the level of Lake Ziway falls below that of the controlling sill, the Bulbulla River dries up (WWDSE, 2008). Average annual outflow volume from lake Ziway to Bulbulla river is 116,383,645 m³ (Halcrow, 2008).

3.1.8.2. Lake Ziway

The main water source for the lake is the flows of Katar and Meki Rivers. The total catchment area of Ziway lake is about 7380 km². Apart from the Meki and the Katar, Lake Ziway has its own catchment covering about 1700 km². Although the lake catchment has no perennial rivers as such, there are several mineralised springs around the lakeshore and there may be a significant groundwater flow towards the lake. The lake level record shows marked variations. These variations have had a striking impact on flows in Bulbulla River; consequently, there is a close correlation between level of the lake and that of the Bulbulla River.

3.2. Methodology

3.2.1. General Approach

During the study of impact assessment of irrigation water use on lake Ziway water level the following general approach were carried out.

- ✚ Desk review of available information, previous reports and studies on the study area.
- ✚ Consultation with relevant government departments and farmers living in the study area.

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- ✚ Field visit to collect first hand data.
 - Irrigated crops in the study area,
 - Date of planting and harvesting,
 - Dominantly irrigated crops in the study area, and other related crop data that helps to draw valid assumption in cropping pattern percentage area determination were collected. This in turn directly related with the result obtained.
- ✚ CROPWAT 8.0 model was used to estimate irrigation water requirements of the study area.

3.2.2. Conceptual Framework

The overall procedure adopted for estimation of irrigation requirements of crops irrigated in the study area using CROPWAT 8.0 Model and water balance of lake Ziway are described on Figure 3-4 using flow chart.

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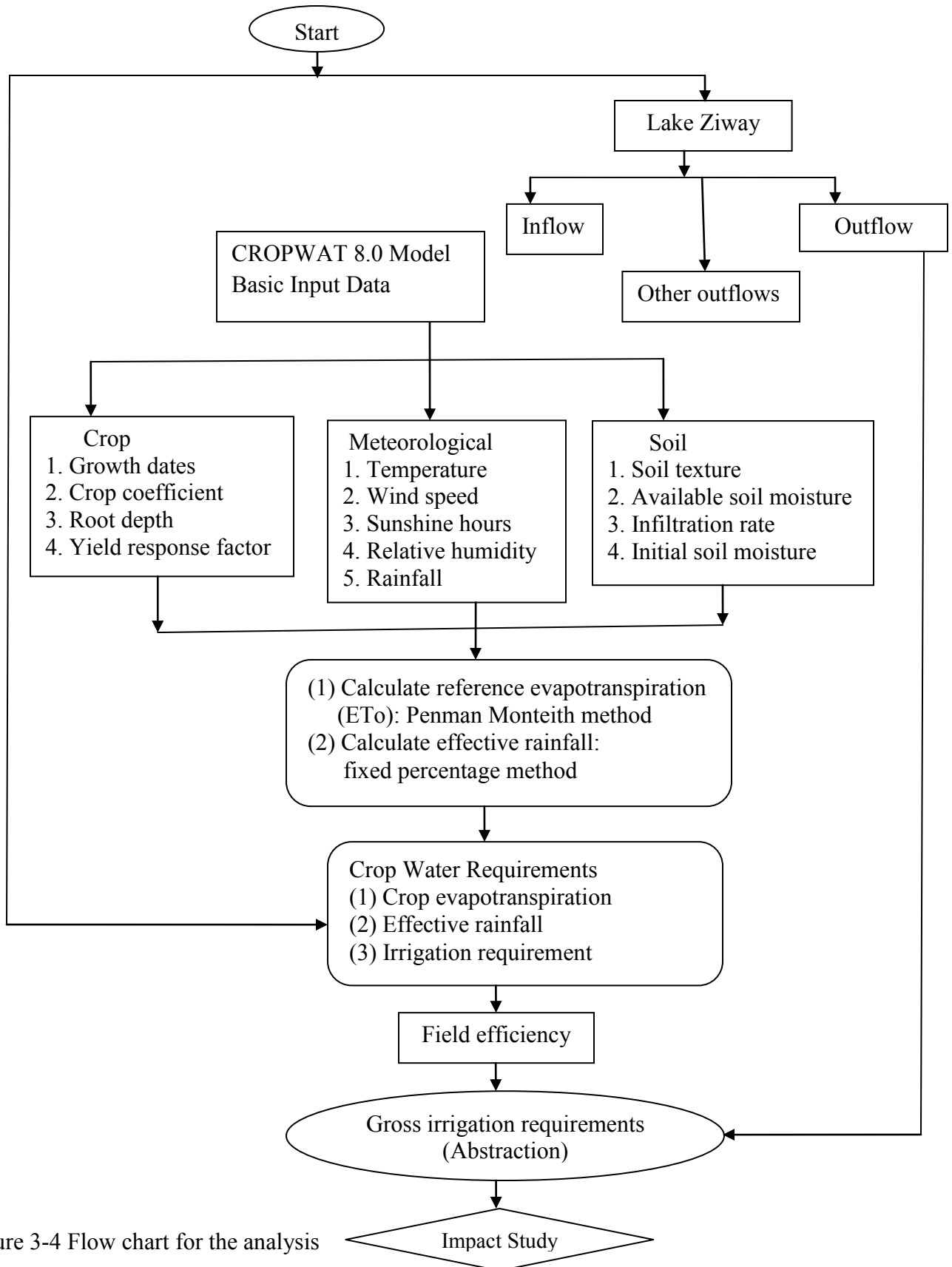


Figure 3-4 Flow chart for the analysis

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3.2.3. Data Collection

3.2.3.1. Climate Data Collection

For the model climatic input data were collected from RVLB Integrated Resources Development Mater Plan, Halcrow Group Limited and GIRD Consultants, and mentioned on Table 3-1.

Table 3-1 Climate/ETo input parameters - Ziway

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tmax (°C)	26.7	27.8	28.9	28.7	29.0	27.7	25.2	25.2	26.3	27.0	26.9	26.4	27.2
Tmin (°C)	12.6	13.8	15.1	15.5	15.6	15.2	14.9	14.9	14.2	12.9	12.0	11.7	14.0
R.H. (%)	66.7	65.9	66.7	68.7	67.7	68.8	76.1	76.8	74.6	67.0	63.9	66.7	69.1
Windspeed (m/s)	1.4	1.4	1.3	1.3	1.5	2.0	1.9	1.6	1.1	1.3	1.5	1.5	1.5
Sunshine (hrs/day)	9.5	9.4	8.4	8.4	9.1	8.4	6.4	6.7	7.1	9.1	10.2	10.1	8.6
Monthly mean RF(mm)	15.9	28.8	58.5	74.8	72.1	79.7	149.1	125.2	76.1	40.3	4.4	4.1	729

Source: Halcrow Group Limited and GIRD Consultants, 2008

In this research fixed percentage of 80% effective rainfall was used for rainfall values. A printout of climatic/ETo and rain data inserted and of calculated ETo, Radiation and effective rain is shown on Appendix A respectively.

3.2.3.2. Soil Data

The study area soil type is sandy loam (Makin et al, 1976, Halcrow, 1992) and for this type of soil the following input data were collected and inserted in the soil module of model to calculate the initial available soil moisture in units mm/meter for the study area. For sandy loam the total available soil moisture (FC- WP) 120 mm/m was determined for the study area referring TAM (mm/m) of Martin Smith for different soil texture on Table 3-2.

Table 3-2 TAM (mm/m)

Soil texture	Coarse	Sandy	Loamy	Clayey
TAM(mm/m)	60	100	140	180

Source: CROPWAT by Martin Smith, 1992

The maximum infiltration rate has the same value as the soil hydraulic conductivity under saturation (Cropwat 8.0 Manual). Maximum rain infiltration rate for sandy loam soil was determined to be 300 mm/day from Dirk RAES reference manual version 5.0 - June 2002.

Maximum rooting depth (cm) and initial soil moisture depletion (%) for each crop are listed on Table 3-3.

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Table 3-3 Maximum rooting depth (cm) and initial soil moisture depletion (%)

Crops	Max. rooting depth (cm)	Initial soil moisture depletion (%)
Onion	40	30
Tomato	80	40
Maize	120	55
Beans	60	55
Cabbage	60	45

Source: FAO Irrigation and Drainage Paper No. 56

From these all soil data the model has calculated initial available soil moisture in mm/m for each crop and the full detail is available on Appendix (B - F).

3.2.3.3. Crop and Cropping Pattern Data

In order to get crop and cropping pattern data local survey was carried out in the irrigation scheme to assess the type of crops grown in rainfed as well as under irrigation through field observations, interviews with extension agents and farmers first hand data were collected and assessed to made the present cropping pattern. Cropping Pattern input data inserted to the model are listed on Table 3-4.

Table 3-4 Cropping Pattern input data

No.	Crop file	Crop name	Planting date	Harvest date	Area(%)
1	Ziway-M-Crop.cro	Maize	20/12	23/04	30
2	Ziway-O-Crop.cro	Onion	15/11	13/04	30
3	Ziway-T-Crop.cro	Tomato	01/12	29/05	20
4	Ziway-B-Crop.cro	Beans	10/12	22/02	15
5	Ziway-C-Crop.cro	Cabbage	20/11	02/02	5

Crop input data are crop name, planting date, crop coefficient (Kc), stages length, rooting depth, critical depletion fraction (p), yield response factor (Ky) and maximum crop height. These crops input data were taken from "FAO Irrigation and Drainage Paper No. 56" publications and other source.

The major crops grown around the study area are Onion, Tomato, Cabbage, Pepper, Beans, Papaya, Maize, Sorghum , Grape and Flowers. From these crops, five major crops are selected due to lack of crop input data for each crops irrigated in the study area. These crops are Maize, Onion, Tomato, Beans and Cabbage. All crops input data are listed on Table 3-5, Table 3-6, Table 3-7 and Table 3-8.

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Table 3-5 Lengths of crop development stages for various planting periods and climatic regions (days)

Crops	L _{ini.} (days)	L _{dev.} (days)	L _{mid.} (days)	L _{late.} (days)	Total(days)	Planting date	Region
Onion (dry)	15	25	70	40	150	April	Mediterranean
Maize (grain)	20	35	40	30	125	Oct.	India
Beans (green)	20	30	30	10	90	Feb./Mar.	Mediter.
Cabbage	15	30	20	10	75	Oct.	E.Africa

Source: FAO Irrigation and Drainage Paper No. 56

NB: Planting and harvesting date input data are collected from the study area and matched these data with the FAO's recommendation values to get lengths of crop development stages from FAO Irrigation and Drainage Paper No. 56

Table 3-6 Single (time averaged) crop coefficients, K_c, and mean maximum plant heights (m)

Crops	K _{cini.}	K _{cmid}	K _{cend}	Maximum Crop Height(m)
Onion(dry)	0.7	1.05	0.75	0.4
Tomato	0.6	1.15	0.7-0.9	0.6
Maize(grain)	0.3	1.20	0.6,0.35	2
Beans(green)	0.5	1.05	0.90	0.4
Cabbage	0.7	1.05	0.95	0.4

Source: FAO Irrigation and Drainage Paper No. 56

Table 3-7 Ranges of maximum effective rooting depth (Z_r) and soil water depletion fraction (P)

Crops	Maximum Root Depth(m)	Depletion Fraction, P for (ET _c ≈ 5mm/day)
Onion(dry)	0.3-0.6	0.30
Tomato	0.7-1.5	0.4
Maize(grain)	1.0-1.7	0.55
Beans	0.5-0.7	0.45
Cabbage	0.5-0.8	0.45

Source: FAO Irrigation and Drainage Paper No. 56

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Table 3-8 Yield Response Factor (Ky)

Crop	Vegetative period			Flowering period	Yield formation	Ripening	Total growing period
	Early	Late	Total				
Beans			0.20	1.10	0.75	0.20	1.15
Cabbage	0.20				0.45	0.60	0.95
Maize			0.40	1.50	0.50	0.20	1.25
Onion			0.45		0.80	0.30	1.10
Tomato			0.40	1.10	0.80	0.40	1.05

Source: Dirk Raes, Reference Manual, Version 5.0 - June 2002

Appendix (B - F) shows a printout of the Crop module for Maize, Onion, Tomato, Beans and Cabbage respectively.

3.2.3.4. Existing and Potential Irrigation development area

The existing irrigation area are irrigation lands that were under irrigation during the master plan preparation period. Whereas, potential irrigation development area are irrigation lands that can be develop in the future and that were identified during the master plan preparation due to land suitability for irrigation and it does not take water availability into account (RVLB master plan by Halcrow Group Limited and GIRD Consultants, 2006-2009).

The existing irrigation area and potential irrigation development area were collected from the RVLB master plan. These data were used to estimate irrigation water requirements of the study area in units of volume (Table 3-9).

Table 3-9 Existing and Potential Irrigation development areas

Lake/River	Existing Irrigation area (ha)	Potential area (ha)
Ziway	2,543	17,300
Katar	2,340	4,090
Meki	1,290	5,000
Total	6,173	26,390

Source: HALCROW Group Limited and GIRD Consultants, 2008

3.2.3.5. Annual River Inflow and Outflow Volume of lake Ziway

Annual river inflow and outflow data were collected from RVLB master plan. These data were used to compare percentage reduction of initial volume of the lake without considering irrigation water abstraction and with irrigation water abstraction conditions (Table 3-10).

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Table 3-10 Annual River Inflow and Outflow Volume of lake Ziway

Lake Ziway Initial Area = 500,000,000m ² Lake Ziway Initial Volume = 2,124,000,000m ³ Lake Ziway Initial Elevation = 1638m Sill level of Bulbula River = 1635.5m
Inflow from upstream: Meki River = 180,177,098m ³ Katar River = 302,357,895m ³ Other tributaries = 23,743,811m ³ Total inflow = 506,278,804m ³
Outflow to downstream: Bulbula River = 116,383,645m ³

Source: Halcrow Group Limited and GIRD Consultants, 2008

3.2.3.6. Lake Ziway elevation-storage relationship

The bathymetric survey data of lake Ziway were obtained from MoWR and used to analyze the impact of irrigation water use on the level of the lake (Table 3-11).

Table 3-11 Lake Ziway elevation-storage relationship

Volume (Mm ³)	Elevation (m)
0	1,627
0.1	1,628
2.08	1,629
7.85	1,630
19.36	1,631
42	1,632
139	1,633
394	1,634
755	1,635
1,159	1,636
1,624	1,637
2,124	1,638

Source: MoWR bathymetric survey of Lake Ziway, 2005.

3.2.3.7. Irrigation Efficiency

Since both types of irrigation (Surface and Pressurized) practiced in the study area, field application efficiency of 70% was assumed as input for the schedule module of the model to estimate gross irrigation requirements of the study area.

3.2.4. Data Analysis

Input data for the CROPWAT 8.0 Model were collected from FAO manual (FAO Irrigation and Drainage Paper No. 56), RVLB master plan (HALCROW Group Limited and GIRD Consultants, (2006-2009) MoWR, Field visit, and other sources.

From all these input data CROPWAT 8.0 Model has calculated irrigation requirements for five dominantly irrigated crops in the study area. This is due to lack of crop input data (like Kc value) for each crop grown in the study area for the model. These crops with their respective cropping pattern percentage area are onion (30%), tomato (20%), maize (30%), beans (15%) and cabbage (5%).

Throughout this study the selected dominantly irrigated crops are assumed to hold the whole existing and potential irrigable lands in the study area. Consequently, the total irrigation water requirements that obtained through this assumption also assumed to represent irrigation water requirements of the study area.

4. Results and Discussion

4.1. Irrigation Water Requirements

The gross irrigation water requirements of each crop irrigated in the study area are 468.5mm, 788.7mm, 795.3mm, 344.9mm and 392.4mm for maize, onion, tomato, beans and cabbage respectively. Full details are available on Appendix (B - F). Irrigation water requirements in units of volume for each crop as the given cropping pattern area per growing periods are shown in Table 4-1.

As shown on Table 4-1, the total irrigation water requirements for existing irrigation area are 37,505,604.75 m³ and for potential irrigation development area are 160,339,042.5 m³ and overall irrigation water requirements of the study area become 197,844,647.3 m³. This much abstraction of irrigation water directly from the lake Ziway and the feeder rivers (Meki and Katar) annually have negative impacts on the lake Ziway water level and the downstream river (Bulbula) and these have been discussed in the following parts.

Table 4-1 Gross Irrigation Requirements (m³)

Crop	Gross Irr.Requ.(mm)	Area (%)	Existing Irrigated area(ha)*	Potential Irrigable area(ha)**	Gross Irrigation Requirement(m ³)	
					Existing	Potential
Maize	468.5	30	1,851.9	7,917	8,676,151.5	37,091,145
Onion	788.7	30	1,851.9	7,917	14,605,935.3	62,441,379
Tomato	795.3	20	1,234.6	5,278	9,818,773	41,975,934
Beans	344.9	15	925.95	3,958.5	3,193,601.55	13,652,866.5
Cabbage	392.4	5	308.65	1,319.5	1,211,142.6	5,177,718
Sub total					37,505,604.75	160,339,042.5
Total					197,844,647.3	

*Indicates Percentage area of each crop multiplied by total existing irrigation area (6,173ha).

**Indicates Percentage area of each crop multiplied by total potential irrigable area (26,390ha).

4.2. Irrigation Water Use Impact

4.2.1 Lake water level reduction

The main negative impact of irrigation water used is lake Ziway water level reduction. As shown on Table 4.1, total irrigation water requirements for the whole existing and potential irrigation development area are $197,844,647.3\text{m}^3$. This much irrigation water abstraction holds 9.31% of initial volume of the lake and 0.4m water level of the lake reduces annually. This may lead to the disappearance of the lake after 27.5 years and the downstream flow will cease after 6.25 years.

These results were obtained by subtracting total irrigation water requirements of the study area ($197,844,647.3\text{ m}^3$) from initial volume of the lake ($2,124,000,000\text{ m}^3$), it gives $1,926,155,352.7\text{ m}^3$ and interpolating this value in the bathymetric data, it puts lake Ziway elevation at 1637.6 m which implies 0.4 m reduction from initial lake Ziway level (1638 m) annually. If lake Ziway level reduces with this much rate (0.4m/year) and the total depth of the lake is 11m (from bathymetric data) and dividing total depth of the lake (11m) by 0.4m/year, it gives 27.5 years.

Similarly, sill level of Bulbula river is 1635.5 m and this indicates 2.5 m below the initial lake Ziway level (1638m) and dividing 2.5m by 0.4m/year, it gives 6.25years.

Therefore, irrigation water abstraction of $197,844,647.3\text{ m}^3$ per year may lead to lose the lake water resource within 27.5 years and after 6.25 years there may not be downstream flow to Bulbula river. This reveals that Irrigation water use practice has a drastic impact on lake Ziway water level and the downstream area that benefits from the lake.

As related studies in the area described that large-scale irrigation was started in the 1970s in the Lake Ziway catchment, taking water directly from the lake and its two main feeder rivers (Maki and Katar). A three-phase irrigation development project was proposed covering a total area of 5500ha. Since 1970, major irrigation activities were introduced around Lake Ziway and its catchments. The present annual abstraction for irrigation is estimated at only 28 Mm^3 . If all the proposed irrigated areas are developed, the estimated annual water requirement will be 150 Mm^3 (Makin *et al.*, 1976). This would result in a 3 m reduction in the level of Lake Ziway and ultimately lead to a drastic reduction in the level of Lake Abiyata and drying up of the feeder Bulbula River. (Tenalem Ayenew, 2007).

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

The range of lake level fluctuations in Ziway is lower than for Langanu and Abiyata, since wide and shallow lakes with an outlet do not usually show a large range of seasonal lake level changes. The lowest level of Ziway was recorded in June 1975 (0.13 m) and the maximum in September and October 1983 (2.17 m). However, for the last three years of the late 1970s and early 1980s the level was slightly lower due to the dry years of the 1970s. The lake shows a slight reduction after the late 1980s due to the abstraction of water for irrigation. (Aysenew, 2001).

Any abstraction of water in the lake Ziway catchment results in a greater reduction in the level of Abiyata than in that of Ziway. The magnitude of the lake level fluctuations in Ziway is lower than for Langanu and Abiyata, since lakes with an outlet usually show a smaller range of lake level changes. The lowest level of Ziway was recorded in June 1975 (0.13 m) and the maximum in September and October 1983 (2.17 m). However, for the last three years of the late 1970s and in the early 1980s the level was slightly lower due to the dry years of the 1970s. Ziway shows a slight reduction after the late 1980s due to the abstraction of water for irrigation. In fact there are no large lake level changes as for Abiyata. The cumulative effect of the abstraction of water from Ziway is passed to the terminal lake Abiyata via the Bulbula river. As revealed by the author, the extremely dry years of 2002 and 2003, and extensive irrigation activities around the lake resulted in the River Bulbula completely drying-up and the level of Ziway visibly dropped (1.5 m below the long-term average). (Tenalem Ayenew, 2004).

The scenarios developed for the years 2001-2099 showed that both, temperature and precipitation are likely to increase from the 1981-2000 level. These changes are likely to have significant impacts on the inflow volume into the lake. Despite the increasing trend of both climatic variables, the increase in precipitation seems to be obscured by increases in temperature. Hence, the total average annual inflow volume into Lake Ziway might decline significantly. This is likely to drop the lake level up to two third of a meter and shrink the water surface area up to 25 km², which is about 6% of the base period water surface area. This combined with the unbalanced supply-demand equation in the watershed is expected to have significant impact on the lake water balance. Therefore, in Lake Ziway Watershed, runoff is likely to decrease in the future and be insufficient to meet future demands for water of the ever increasing population.

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Both scenarios show a significant decline of the Lake water level and shrinkage of the lake water surface area. The reduction might be especially eminent during the 2051-2075 period, where the lake level decline might reach up to 62cm. Consequently, the water surface area might also shrink up to 25 km². (Lijalem Zeray Abraham et al., 2007).

4.2.2 Percentage volume reduction

Annual inflow and outflow data were used to compare percentage reduction of initial volume of the lake regardless of irrigation water abstraction with that of irrigation water abstraction condition (Table 4-2).

As shown on Table 4.2, regardless of irrigation water abstraction only 7.74% of the initial volume of the lake is reduced, but when irrigation water abstraction is considered 17.05% of the initial volume of the lake is reduced and this shows that irrigation water abstraction merely reduces 9.31% of initial volume of the lake which indicates that there is greater reduction of the lake due to irrigation water abstraction relative to reduction of the lake without considering irrigation water abstraction condition which is 7.74%. This revealed that Irrigation water use has a severe impact on lake Ziway.

All results revealed that irrigation water use for the whole existing and potential irrigable area brings drastic impact on the lake and the downstream area. This severe negative impact on the lake Ziway implies the negative impact on the population that benefit from the lake. Therefore, the study area needs integrated water resources management to sustain the life of the area.

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Table 4-2 Annual Inflow and Outflow Volume of lake Ziway

Lake Ziway Initial Area = 500,000,000m ² Lake Ziway Initial Volume = 2,124,000,000m ³ Lake Ziway Initial Elevation = 1638m Sill level of Bulbula River = 1635.5m
Inflow from upstream: Meki River = 180,177,098m ³ Katar River = 302,357,895m ³ Other tributaries = 23,743,811m ³ Total inflow = 506,278,804m ³
Outflow to downstream: Bulbula River = 116,383,645m ³
Irrigation requirements = 197,844,647.3 m ³ * Evaporation from lake Ziway = 918,790,000 m ³ ** Precipitation on lake Ziway = 364,500,000 m ³ ***
Overall total inflow into the lake = 870,778,804 m ³ Overall total outflow from the lake without irrigation water abstraction = 1,035,173,645 m ³ Overall total outflow from the lake with irrigation water abstraction = 1,233,018,292.3 m ³
Change in storage without irrigation water abstraction = -164,394,841 m ³ Change in storage with irrigation water abstraction = -362,239,488.3 m ³ <i>Note: Negative sign indicates outflow from the lake.</i>

Source: Halcrow Group Limited and GIRD Consultants, 2008, and Bathymetric data MoWR, 2005

*Note: *Output of the model converted into volume units for existing irrigation area and potential irrigation development area.*

*** Evaporation loss estimated from 1875 mm lake Ziway annual evaporation. Coulomb et al. 2001.*

**** Precipitation on the lake surface area was estimated from annual mean monthly rainfall (729mm from RVLB master plan).*

N.B. The overall total inflow was estimated without considering groundwater recharge and overall total outflow was calculated regardless outflows from lake Ziway for water supply and groundwater discharge due to lack of data.

5. Conclusion and Recommendations

5.1. Conclusion

CROPWAT 8.0 model, bathymetric data and lake water balance data were used to assess the impact of irrigation water use on lake Ziway water level. The model was used to estimate irrigation water requirements of five dominantly irrigated crops in units of mm and to convert the depth of water into volume units existing and potential irrigation development area were used. These crops which were identified during field visit with their respective cropping pattern percentage area are maize (30%), onion (30%), tomato (20%), beans (15%) and cabbage (5%).

Since these selected dominantly irrigated crops were assumed to hold the whole existing and potential irrigable lands in the study area, the total irrigation requirements were also assumed to represent irrigation water requirements of the study area.

The results showed that for the whole existing and potential irrigation development area crop water requirements are $197,844,647.3\text{m}^3$. This much irrigation water abstraction holds 9.31% of initial volume of lake Ziway and it reduces 0.4m water level of the lake annually. This much rate of lake level reduction (0.4m/year) may lead to the disappearance of the lake after 27.5 years and it may also become the cause to cease the downstream flow after 6.25 years.

Moreover, the results showed that regardless of irrigation water abstraction only 7.74% of the initial volume of the lake was reduced, but when irrigation water abstraction was considered it was 17.05% of the initial volume of the lake was reduced and this showed that irrigation water abstraction merely reduced 9.31% of initial volume of the lake which indicated greater reduction due to irrigation water abstraction relative to reduction with no irrigation water use condition (7.74%).

These all results revealed that irrigation water use for the whole existing and potential irrigable area brings drastic impact on the lake and the downstream area. This severe negative impact on the lake Ziway implies the negative impact on the population that benefit from the lake. Therefore, the study area needs integrated water resources management to sustain the life of the area.

5.2. Recommendations

- Awareness creation about the problem and make the users to be part of the solution.
 - As lake Ziway is the source of water supply, a place of fish farm, the site for five islands, the location of recreation and tourism, and it is generally the life of the population living around and at downstream of the lake Ziway, so that awareness should be created how this valuable resource in severe condition and show them the way how to use the lake and the feeder river in integrated and sustainable manner.
- Plan the available resources in a sustainable ways.
 - By transforming small lands into large scale irrigation projects, the efficiency and method of irrigation can be improved from surface (flooding and furrow) to pressurized (sprinkler and drip), in other words modernizing the irrigation practice in the area is needed. This should be done by giving appropriate compensation to the land owners that enable them to creates other business opportunities.
 - In addition, emphasis should be given to improve the benefit and efficiency of existing irrigation, and to improve economic return of rain-fed agriculture which dominates the agriculture sector.
- Adaptation of fast growing and minimum water consuming crops
 - Since the impact of abstraction for existing and potential irrigation area is very severe on the lake Ziway and the downstream environment, it should be given a great attention and the problem could be minimized by adaptation of crop species which grows fast and require minimum water consumption.

Finally, if all crop data (like Kc value) for all crops irrigated in the study area are available and if the percentage area of each crop is exactly known, and again if unknown outflow parameters such as outflow from the lake for water supply, groundwater discharge and groundwater recharge data are available, more representative result will be obtained.

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Appendix 2. Maize Output data

DRY CROP DATA

(File: C:\ProgramData\CROPWAT\data\crops\Ziway-M-Crop.CRO)

Crop Name: Maize	Planting date: 20/12	Harvest: 23/04			
Stage	initial	develop	mid	late	total
Length (days)	20	35	40	30	125
Kc Values	0.30	-->	1.20	0.35	
Rooting depth (m)	1.20	-->	1.20	1.20	
Critical depletion	0.55	-->	0.55	0.55	
Yield response f.	0.40	1.50	0.50	0.20	1.25
Cropheight (m)			2.00		

SOIL DATA

(File: C:\ProgramData\CROPWAT\data\soils\Ziway-M-Soil.SOI)

Soil name: Sandy loam

General soil data:

Total available soil moisture (FC - WP)	120.0	mm/meter
Maximum rain infiltration rate	300	mm/day
Maximum rooting depth	120	centimeters
Initial soil moisture depletion (as % TA)	55	%
Initial available soil moisture	54.0	mm/meter

CROP WATER REQUIREMENTS

ETo station: Ziway
Rain station: Ziway

Crop: Maize
Planting date: 20/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2	Init	0.30	1.24	1.2	0.1	1.2
Dec	3	Init	0.30	1.24	13.6	1.9	11.7
Jan	1	Deve	0.31	1.27	12.7	3.2	9.5
Jan	2	Deve	0.49	2.01	20.1	4.2	15.9
Jan	3	Deve	0.75	3.20	35.2	5.4	29.8
Feb	1	Deve	1.02	4.45	44.5	6.1	38.4
Feb	2	Mid	1.18	5.30	53.0	7.1	46.0
Feb	3	Mid	1.18	5.36	42.9	9.9	33.0
Mar	1	Mid	1.18	5.41	54.1	13.3	40.8
Mar	2	Mid	1.18	5.45	54.5	16.1	38.5
Mar	3	Late	1.11	5.14	56.5	17.3	39.1
Apr	1	Late	0.84	3.87	38.7	19.0	19.7
Apr	2	Late	0.56	2.59	25.9	20.6	5.2
Apr	3	Late	0.38	1.77	5.3	6.1	0.0
					458.1	130.2	328.7

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

CROP IRRIGATION SCHEDULE

ETo station: Ziway Crop: Maize Planting date: 20/12
 Rain station: Ziway Soil: Sandy loam Harvest date: 23/04

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrigate at 100 % depletion
 Application: Refill to 100 % of field capacity
 Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	IrrDeficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
20 Dec	1	Init	0.0	1.00	100	56	80.4	0.0	0.0	114.9	13.30
5 Feb	48	Dev	0.0	1.00	100	57	81.7	0.0	0.0	116.7	0.29
25 Feb	68	Mid	0.0	1.00	100	58	83.2	0.0	0.0	118.9	0.69
20 Mar	91	Mid	0.0	1.00	100	57	82.6	0.0	0.0	118.0	0.59
23 Apr	End	End	0.0	1.00	100	29					

Totals:

Total gross irrigation	468.5 mm	Total rainfall	167.7 mm
Total net irrigation	327.9 mm	Effective rainfall	166.3 mm
Total irrigation losses	0.0 mm	Total rain loss	1.4 mm
Actual water use by crop	456.4 mm	Moist deficit at harvest	41.3 mm
Potential water use by crop	456.4 mm	Actual irrigation requirement	290.1 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	99.2 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season
Reductions in ETC	0.0	0.0	0.0	0.0	0.0 %
Yield response factor	0.40	1.50	0.50	0.20	1.25
Yield reduction	0.0	0.0	0.0	0.0	0.0 %
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0 %

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Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Appendix 3. Onion Output data

DRY CROP DATA

(File: C:\ProgramData\CROPWAT\data\crops\Ziway-O-Crop.CRO)

Crop Name:	Onion	Planting date:	15/11	Harvest:	13/04
Stage	initial	develop	mid	late	total
Length (days)	15	25	70	40	150
Kc Values	0.70	-->	1.05	0.75	
Rooting depth (m)	0.40	-->	0.40	0.40	
Critical depletion	0.30	-->	0.30	0.30	
Yield response f.	0.45	0.45	0.80	0.30	1.10
Cropheight (m)			0.40		

SOIL DATA

(File: C:\ProgramData\CROPWAT\data\soils\Ziway-O-Soil.SOI)

Soil name: Sandy loam

General soil data:

Total available soil moisture (FC - WP)	120.0	mm/meter
Maximum rain infiltration rate	300	mm/day
Maximum rooting depth	40	centimeters
Initial soil moisture depletion (as % TA)	30	%
Initial available soil moisture	84.0	mm/meter

CROP WATER REQUIREMENTS

ETo station: Ziway
Rain station: Ziway

Crop: Onion
Planting date: 15/11

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.70	3.08	18.5	0.0	18.5
Nov	3	Deve	0.70	3.02	30.2	0.3	29.9
Dec	1	Deve	0.79	3.33	33.3	0.9	32.4
Dec	2	Deve	0.93	3.82	38.2	0.7	37.5
Dec	3	Mid	1.04	4.27	47.0	1.9	45.1
Jan	1	Mid	1.04	4.30	43.0	3.2	39.8
Jan	2	Mid	1.04	4.29	42.9	4.2	38.7
Jan	3	Mid	1.04	4.42	48.7	5.4	43.3
Feb	1	Mid	1.04	4.55	45.5	6.1	39.4
Feb	2	Mid	1.04	4.69	46.9	7.1	39.8
Feb	3	Mid	1.04	4.72	37.8	9.9	27.9
Mar	1	Late	1.03	4.69	46.9	13.3	33.7
Mar	2	Late	0.96	4.40	44.0	16.1	27.9
Mar	3	Late	0.88	4.04	44.4	17.3	27.1
Apr	1	Late	0.80	3.67	36.7	19.0	17.8
Apr	2	Late	0.75	3.45	10.3	6.2	0.0
					614.3	111.5	498.7

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

CROP IRRIGATION SCHEDULE

ETo station: Ziway Crop: Onion Planting date: 15/11
 Rain station: Ziway Soil: Sandy loam Harvest date: 13/04

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrigate at 100 % depletion
 Application: Refill to 100 % of field capacity
 Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	IrrDeficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
15 Nov	1	Init	0.0	1.00	100	36	17.5	0.0	0.0	25.0	2.89
20 Nov	6	Init	0.0	1.00	100	32	15.4	0.0	0.0	22.0	0.51
25 Nov	11	Init	0.0	1.00	100	31	14.9	0.0	0.0	21.3	0.49
30 Nov	16	Dev	0.0	1.00	100	31	14.9	0.0	0.0	21.3	0.49
5 Dec	21	Dev	0.0	1.00	100	34	16.1	0.0	0.0	23.0	0.53
10 Dec	26	Dev	0.0	1.00	100	34	16.1	0.0	0.0	23.0	0.53
14 Dec	30	Dev	0.0	1.00	100	31	14.9	0.0	0.0	21.3	0.62
18 Dec	34	Dev	0.0	1.00	100	31	14.9	0.0	0.0	21.3	0.62
22 Dec	38	Dev	0.0	1.00	100	34	16.2	0.0	0.0	23.1	0.67
26 Dec	42	Mid	0.0	1.00	100	36	17.1	0.0	0.0	24.4	0.71
30 Dec	46	Mid	0.0	1.00	100	36	17.1	0.0	0.0	24.4	0.71
3 Jan	50	Mid	2.0	1.00	100	32	15.2	0.0	0.0	21.7	0.63
7 Jan	54	Mid	2.0	1.00	100	32	15.2	0.0	0.0	21.7	0.63
11 Jan	58	Mid	0.0	1.00	100	36	17.2	0.0	0.0	24.5	0.71
15 Jan	62	Mid	0.0	1.00	100	30	14.5	0.0	0.0	20.7	0.60
19 Jan	66	Mid	0.0	1.00	100	30	14.5	0.0	0.0	20.7	0.60
24 Jan	71	Mid	0.0	1.00	100	39	18.6	0.0	0.0	26.6	0.62
29 Jan	76	Mid	0.0	1.00	100	39	18.8	0.0	0.0	26.8	0.62
2 Feb	80	Mid	0.0	1.00	100	37	18.0	0.0	0.0	25.7	0.74
6 Feb	84	Mid	0.0	1.00	100	38	18.2	0.0	0.0	26.0	0.75
10 Feb	88	Mid	0.0	1.00	100	38	18.2	0.0	0.0	26.0	0.75
15 Feb	93	Mid	0.0	1.00	100	40	19.0	0.0	0.0	27.1	0.63
20 Feb	98	Mid	0.0	1.00	100	40	19.0	0.0	0.0	27.1	0.63
25 Feb	103	Mid	0.0	1.00	100	36	17.4	0.0	0.0	24.9	0.58
2 Mar	108	Mid	0.0	1.00	100	39	18.8	0.0	0.0	26.9	0.62
6 Mar	112	End	0.0	1.00	100	39	18.8	0.0	0.0	26.8	0.78
10 Mar	116	End	0.0	1.00	100	39	18.8	0.0	0.0	26.8	0.78
16 Mar	122	End	0.0	1.00	100	37	17.6	0.0	0.0	25.1	0.48
20 Mar	126	End	0.0	1.00	100	37	17.6	0.0	0.0	25.1	0.73
26 Mar	132	End	0.0	1.00	100	34	16.1	0.0	0.0	23.1	0.44
30 Mar	136	End	0.0	1.00	100	34	16.1	0.0	0.0	23.1	0.67
6 Apr	143	End	0.0	1.00	100	31	14.7	0.0	0.0	21.0	0.35
10 Apr	147	End	0.0	1.00	100	31	14.7	0.0	0.0	21.0	0.61
13 Apr	End	End	0.0	1.00	0	0					

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Totals:

Total gross irrigation	788.7 mm	Total rainfall	144.5 mm
Total net irrigation	552.1 mm	Effective rainfall	73.2 mm
Total irrigation losses	0.0 mm	Total rain loss	71.3 mm
Actual water use by crop	610.9 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	610.9 mm	Actual irrigation requirement	537.7 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	50.7 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.45	0.45	0.80	0.30	1.10	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

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Impact Assessment of Irrigation Water Use on lake Ziway Water Level

CROP IRRIGATION SCHEDULE

ETo station: Ziway Crop: Tomato Planting date: 01/12
 Rain station: Ziway Soil: Sandy loam Harvest date: 29/05

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrigate at 100 % depletion
 Application: Refill to 100 % of field capacity
 Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	IrrDeficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
1 Dec	1	Init	0.0	1.00	100	44	31.3	0.0	0.0	44.8	5.18
14 Dec	14	Init	0.0	1.00	100	43	31.2	0.0	0.0	44.6	0.40
27 Dec	27	Init	1.2	1.00	100	41	29.4	0.0	0.0	42.0	0.37
9 Jan	40	Dev	0.0	1.00	100	40	29.0	0.0	0.0	41.5	0.37
21 Jan	52	Dev	0.0	1.00	100	43	31.2	0.0	0.0	44.6	0.43
31 Jan	62	Dev	0.0	1.00	100	41	29.8	0.0	0.0	42.5	0.49
9 Feb	71	Dev	0.0	1.00	100	43	31.1	0.0	0.0	44.4	0.57
16 Feb	78	Dev	0.0	1.00	100	41	29.5	0.0	0.0	42.2	0.70
22 Feb	84	Mid	0.0	1.00	100	42	30.1	0.0	0.0	42.9	0.83
1 Mar	91	Mid	0.0	1.00	100	41	29.8	0.0	0.0	42.6	0.70
10 Mar	100	Mid	0.0	1.00	100	46	33.1	0.0	0.0	47.4	0.61
20 Mar	110	Mid	0.0	1.00	100	45	32.1	0.0	0.0	45.9	0.53
30 Mar	120	Mid	0.0	1.00	100	43	31.0	0.0	0.0	44.3	0.51
10 Apr	131	Mid	0.0	1.00	100	47	34.0	0.0	0.0	48.5	0.51
20 Apr	141	Mid	0.0	1.00	100	40	29.1	0.0	0.0	41.6	0.48
30 Apr	151	End	0.0	1.00	100	41	29.9	0.0	0.0	42.7	0.49
11 May	162	End	0.0	1.00	100	45	32.7	0.0	0.0	46.7	0.49
22 May	173	End	0.0	1.00	100	45	32.3	0.0	0.0	46.1	0.49
29 May	End	End	0.0	1.00	0	16					

Totals:

Total gross irrigation	795.3 mm	Total rainfall	254.4 mm
Total net irrigation	556.7 mm	Effective rainfall	214.3 mm
Total irrigation losses	0.0 mm	Total rain loss	40.0 mm
Actual water use by crop	753.6 mm	Moist deficit at harvest	11.4 mm
Potential water use by crop	753.6 mm	Actual irrigation requirement	539.3 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	84.3 %
Deficiency irrigation schedule	0.0 %		

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.40	1.10	0.80	0.40	1.05	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

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Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Appendix 5. Beans Output data

DRY CROP DATA

(File: C:\ProgramData\CROPWAT\data\crops\Ziway-B-Crop.CRO)

Crop Name: Beans	Planting date: 10/12	Harvest: 22/02			
Stage	initial	develop	mid	late	total
Length (days)	15	25	25	10	75
Kc Values	0.50	-->	1.05	0.90	
Rooting depth (m)	0.60	-->	0.60	0.60	
Critical depletion	0.45	-->	0.45	0.45	
Yield response f.	0.20	1.10	0.75	0.20	1.15
Cropheight (m)			0.40		

SOIL DATA

(File: C:\ProgramData\CROPWAT\data\soils\Ziway-B-Soil.SOI)

Soil name: Sandy loam

General soil data:

Total available soil moisture (FC - WP)	120.0	mm/meter
Maximum rain infiltration rate	300	mm/day
Maximum rooting depth	60	centimeters
Initial soil moisture depletion (as % TA	45	%
Initial available soil moisture	66.0	mm/meter

CROP WATER REQUIREMENTS

ETo station: Ziway
Rain station: Ziway

Crop: Beans
Planting date: 10/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.50	2.11	2.1	0.1	2.1
Dec	2	Init	0.50	2.06	20.6	0.7	19.9
Dec	3	Deve	0.56	2.29	25.2	1.9	23.3
Jan	1	Deve	0.77	3.18	31.8	3.2	28.6
Jan	2	Mid	0.98	4.04	40.4	4.2	36.2
Jan	3	Mid	1.04	4.42	48.6	5.4	43.3
Feb	1	Mid	1.04	4.55	45.5	6.1	39.4
Feb	2	Late	0.99	4.44	44.4	7.1	37.3
Feb	3	Late	0.90	4.08	8.2	2.5	8.2
					266.8	31.2	238.2

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

CROP IRRIGATION SCHEDULE

ETo station: Ziway Crop: Beans Planting date: 10/12
 Rain station: Ziway Soil: Sandy loam Harvest date: 22/02

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrigate at 100 % depletion
 Application: Refill to 100 % of field capacity
 Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	IrrDeficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
10 Dec	1	Init	0.0	1.00	100	48	34.5	0.0	0.0	49.3	5.71
27 Dec	18	Dev	1.2	1.00	100	47	33.5	0.0	0.0	47.9	0.33
9 Jan	31	Dev	0.0	1.00	100	47	33.7	0.0	0.0	48.2	0.43
19 Jan	41	Mid	0.0	1.00	100	48	34.2	0.0	0.0	48.9	0.57
28 Jan	50	Mid	0.0	1.00	100	45	32.7	0.0	0.0	46.7	0.60
6 Feb	59	Mid	0.0	1.00	100	51	36.7	0.0	0.0	52.5	0.68
15 Feb	68	End	0.0	1.00	100	50	36.0	0.0	0.0	51.4	0.66
22 Feb	End	End	4.4	1.00	100	30					

Totals:

Total gross irrigation	344.9 mm	Total rainfall	35.7 mm
Total net irrigation	241.4 mm	Effective rainfall	31.8 mm
Total irrigation losses	0.0 mm	Total rain loss	3.8 mm
Actual water use by crop	262.7 mm	Moist deficit at harvest	21.9 mm
Potential water use by crop	262.7 mm	Actual irrigation requirement	230.9 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	89.3 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season
Reductions in ETC	0.0	0.0	0.0	0.0	0.0 %
Yield response factor	0.20	1.10	0.75	0.20	1.15
Yield reduction	0.0	0.0	0.0	0.0	0.0 %
Cumulative yield reduction	0.0	0.0	0.0	0.0	%

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Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Appendix 6. Cabbage Output data

DRY CROP DATA

(File: C:\ProgramData\CROPWAT\data\crops\Ziway-C-Crop.CRO)

Crop Name: Cabbage	Planting date: 20/11	Harvest: 02/02			
Stage	initial	develop	mid	late	total
Length (days)	15	30	20	10	75
Kc Values	0.70	-->	1.05	0.95	
Rooting depth (m)	0.60	-->	0.60	0.60	
Critical depletion	0.45	-->	0.45	0.45	
Yield response f.	0.20	0.20	0.45	0.60	0.95
Cropheight (m)			0.40		

SOIL DATA

(File: C:\ProgramData\CROPWAT\data\soils\Ziway-C-Soil.SOI)

Soil name: Sandy loam

General soil data:

Total available soil moisture (FC - WP)	120.0	mm/meter
Maximum rain infiltration rate	300	mm/day
Maximum rooting depth	60	centimeters
Initial soil moisture depletion (as % TA	45	%
Initial available soil moisture	66.0	mm/meter

CROP WATER REQUIREMENTS

ETo station: Ziway
Rain station: Ziway

Crop: Cabbage
Planting date: 20/11

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.70	3.08	3.1	0.0	3.1
Nov	3	Init	0.70	3.02	30.2	0.3	29.8
Dec	1	Deve	0.72	3.05	30.5	0.9	29.7
Dec	2	Deve	0.83	3.43	34.3	0.7	33.6
Dec	3	Deve	0.95	3.92	43.2	1.9	41.3
Jan	1	Mid	1.04	4.28	42.8	3.2	39.6
Jan	2	Mid	1.04	4.29	42.9	4.2	38.7
Jan	3	Late	1.01	4.29	47.1	5.4	41.8
Feb	1	Late	0.95	4.14	8.3	1.2	8.3
					282.4	17.8	265.8

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

CROP IRRIGATION SCHEDULE

ETo station: Ziway Crop: Cabbage Planting date: 20/11
 Rain station: Ziway Soil: Sandy loam Harvest date: 02/02

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrigate at 100 % depletion
 Application: Refill to 100 % of field capacity
 Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	IrrDeficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
20 Nov	1	Init	0.0	1.00	100	49	35.5	0.0	0.0	50.7	5.87
1 Dec	12	Init	0.0	1.00	100	46	32.8	0.0	0.0	46.9	0.49
12 Dec	23	Dev	0.0	1.00	100	46	33.3	0.0	0.0	47.6	0.50
22 Dec	33	Dev	0.0	1.00	100	48	34.9	0.0	0.0	49.8	0.58
31 Dec	42	Dev	0.0	1.00	100	47	34.2	0.0	0.0	48.8	0.63
9 Jan	51	Mid	0.0	1.00	100	48	34.6	0.0	0.0	49.4	0.63
18 Jan	60	Mid	0.0	1.00	100	46	33.3	0.0	0.0	47.6	0.61
28 Jan	70	End	0.0	1.00	100	50	36.1	0.0	0.0	51.6	0.60
2 Feb	End	End	4.4	1.00	100	24					

Totals:

Total gross irrigation	392.4 mm	Total rainfall	20.6 mm
Total net irrigation	274.7 mm	Effective rainfall	19.0 mm
Total irrigation losses	0.0 mm	Total rain loss	1.6 mm
Actual water use by crop	278.3 mm	Moist deficit at harvest	17.0 mm
Potential water use by crop	278.3 mm	Actual irrigation requirement	259.3 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	92.4 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season
Reductions in ETc	0.0	0.0	0.0	0.0	0.0 %
Yield response factor	0.20	0.20	0.45	0.60	0.95
Yield reduction	0.0	0.0	0.0	0.0	0.0 %
Cumulative yield reduction	0.0	0.0	0.0	0.0	%

Impact Assessment of Irrigation Water Use on lake Ziway Water Level

Appendix 7. Cropping Pattern and Scheme Supply Output data

CROPPING PATTERN DATA

(File: C:\ProgramData\CROPWAT\data\sessions\Ziway-All-Pattern.PAT)

Cropping pattern name: Diversified

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1	Ziway-M-Crop.cro	Maize	20/12	23/04	30
2	Ziway-O-Crop.cro	Onion	15/11	13/04	30
3	Ziway-T-Crop.cro	Tomato	01/12	29/05	20
4	Ziway-B-Crop.cro	Beans	10/12	22/02	15
5	Ziway-C-Crop.cro	Cabbage	20/11	02/02	5

SCHEME SUPPLY

ETo station: Ziway
Rain station: Ziway

Cropping pattern: Diversified

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Maize	55.2	117.3	118.4	24.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
2. Onion	121.3	106.6	88.3	17.8	0.0	0.0	0.0	0.0	0.0	0.0	48.4	114.7
3. Tomato	83.4	110.4	114.9	98.3	73.4	0.0	0.0	0.0	0.0	0.0	0.0	73.8
4. Beans	107.9	84.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.3
5. Cabbage	119.9	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.9	104.5
Net scheme irr.req.												
in mm/day	3.0	3.7	2.7	1.1	0.5	0.0	0.0	0.0	0.0	0.0	0.5	2.1
in mm/month	91.8	102.4	85.0	32.4	14.7	0.0	0.0	0.0	0.0	0.0	16.2	65.1
in l/s/h	0.34	0.42	0.32	0.13	0.05	0.00	0.00	0.00	0.00	0.00	0.06	0.24
Irrigated area												
(% of total area)	100.0	100.0	80.0	80.0	20.0	0.0	0.0	0.0	0.0	0.0	35.0	100.0
Irr.req. for actual area												
(l/s/h)	0.34	0.42	0.40	0.16	0.27	0.00	0.00	0.00	0.00	0.00	0.18	0.24

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