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MSc THESIS ON

Runoff Estimation and Water Management for Holetta River, Awash subbasin, Ethiopia

By:

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June, 2013

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An MSc Thesis on:

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Water Resources Engineering and Management (Specialization: Surface Water Hydrology)

By Mahtsente Tibebe Tadese

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Declaration

I hereby certify that I have prepared this MSc thesis independently, and that only those sources, aides, and advisors that noted herein have been used and/or consulted. I declare that this thesis is my work and that all sources of materials used for this thesis have been duly acknowledged.

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ACRONYMS AND ABBREVIATIONS

AAU	Addis Ababa University
AGRC	Agricultural Land -Close-Grown
AGRR	Agricultural Land- Row Crops
ARS	Agricultural Research Service
CWR	Crop Water Requirements
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization of the United Nation
ETo	Reference Evapotranspiration
FRSD	Forest -Deciduous
FRST	Forest-Mixed
GIS	Geographical Information System
HARC	Holetta Agricultural Research Center
HRUs	Hydrological Response Units
IR	Irrigation Requirement
IVF	Index of Volumetric Fit
Kc	Crop coefficient
LH-OAT	Latin Hypercube One-factor-At-a-Time
NSE	Nash-Sutcliffe Efficiency Coefficient
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
USDA	United State Department of Agriculture
WETL	Wetlands-Mixed
WMO	World Meteorological Organization

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ABSTRACT

The hydrology of Holetta River and its seasonal variability is not fully studied. In addition to this, due to scarcity of the available surface water and increase in water demand for irrigation, the major users of the river are facing a challenge to allocate the available water. Therefore, the aim of this research was to investigate the water availability of Holetta River and to study the water management in the catchment using Geographical Information Systems (GIS) tool, statistical methods, and hydrological model. The rainfall runoff process of the catchment was modeled by Soil and Water Assessment Tool (SWAT). According to SWAT classification, the watershed was divided in to 6 subbasins and 33 hydrological response units (HRUs). The only gauged subbasin in the catchment was subbasin one that is found in the upper part of the area. Therefore, sensitivity analysis, calibration, and validation of the model was performed at subbasin one and then the calibrated model was used to estimate runoff at the ungauged part of the catchment. The performance of SWAT model was evaluated by using statistical (coefficient of determination [R^2], Nash-Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF]) and graphical methods. The result showed that R^2, NSE, and IVF were 0.85, 0.84 and 102.8 respectively for monthly calibration and 0.73, 0.67 and 108.9 respectively for monthly validation. These indicated that SWAT model performed well for simulation of the hydrology of the watershed. After modeling the rainfall runoff relation and studying the availability of water at the Holetta River, the water demand of the area was assessed. The survey form was used to identify information, which includes the number of Holetta River consumers, major crops grown by irrigation and the total area coverage. CropWat model was used to calculate the irrigation water requirement for major crops. Based on the result of CropWat model and survey analysis, the irrigation water demand for the three major users of Holetta River was calculated. The total water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM from January to May respectively. The available river flow from January to May was taken from the result of SWAT simulation at subbasins 2,3,4 and 5. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM from January to May respectively. From the five months, the demand and the supply showed a gap during February, March and April. This indicated that there is shortage of supply during these months with 0.59 MCM. Therefore, in order to solve this problem *alternative source of water supply should be studied and integrated water management system should be implemented.*

Keywords: runoff estimation, Holetta River, Awash basin, Ethiopia, hydrological modeling

1. INTRODUCTION

1.1. Background and Justification

Ethiopia is endowed with a huge surface and ground water resources. Many perennial and annual rivers exist in the country. A number of lakes, dams, and reservoirs are also exists in various parts of Ethiopia. Ethiopia has 12 river basins and the estimated total mean annual flow from all the 12 river basins is 122 billion cubic meters (BMC)(see table 1).

Table 1. Ethiopian River basin's runoff and ground water potential (Awulachew et al., 2007)

River Basin	Area (Km^2)	Runoff (BMC)	Estimated ground water potential (BMC)
Tekeze	82,350	8.2	0.2
Abbay	199,812	54.8	1.8
Baro-Akobo	75,912	23.6	0.28
Omo-Ghibe	79,000	16.6	0.42
Rift Valley	52,739	5.6	0.1
Mereb	5,900	0.65	0.05
Afar /Denakil	74,002	0.86	-
Awash	112,696	4.9	0.14
Aysha	2,223	-	-
Ogaden	77,121	-	-
Wabi-Shebelle	202,697	3.16	0.07
Genale-Dawa	171,042	5.88	0.14
Total	**1,135,494**	**124.25**	**2.86**

Holetta River is one of the rivers found in the upper part of Awash basin and facing challenges of runoff variability and scarcity of water availability during the dry season. The catchment has fertile soils (loam) and a high potential for water resource development. However, development in the catchment is limited to a few hundred hectares of irrigation and a small milling plant due to a very high seasonal variation of water availability. Farmers in this area depend exclusively on rainfed agriculture and most crops grown in the main rainy season (Kramer, 2000). The Holetta River is the main source of surface water in the study area and it is a perennial river having three major users. These are Holetta Agricultural Research Center (HARC), Tesdey Farm, and Village Farmers. Holetta Agricultural Research Center is founded in 1963 and it is one of the potential consumers of Holetta River. In early time, the HARC uses the Holetta River only for fruits and horticulture, but starting from 2011, HARC is improving the facility of irrigation in the center to expand the irrigation coverage. Tsedey Farm is a private company, which use Holetta River for irrigation purpose. They mostly produce potato and vegetables like cabbage. The other major users of Holetta River are the village farmers. These farmers use the river for traditional irrigation purposes. The total area of irrigated farm by each farmer is about 0.25 hectares. The major products of the farmers are vegetables and crops like potato, cabbage, and tomato. In addition to increasing water demand in the area, there is no facility to store the water in the rainy season for future use in the dry season. Therefore, the competition for water is increasing due to scarcity of water and increasing pressure by expanding populations and increasing irrigation. In order to alleviate this challenge, integrated water resources management, and effective water allocation system is essential. Therefore, the aim of this research was to investigate the water availability of Holetta River and to study the water management in the catchment using GIS tool, statistical methods and hydrological model.

1.2. Problem Statement

With the risk of water shortages around the world becoming more and more of an issue, water has become the fuel of certain conflicts in many regions around the world. Conflict due to water sources are becoming usual in the world's future as the misuse of water resources continues among countries that share the same water source. The rapid population increase has greatly affected the amount of water readily available to many people. Many parts of Ethiopia share one water resource for the use of their populations. A large percentage of these populations are very dependent on the weather to provide proper irrigation to the agricultural industry, since water resources are so scarce. Conflicts may rise from unequal distribution of water supplies amongst neighboring users. With the growing demand for water resources, conflicts seem almost inevitable, especially with poor management of resources and inadequate conflict resolution mechanisms.

Holetta River is one of the rivers that face conflict between users. The competition for water between the major users of Holetta River is increasing due to socio-economic development and population growth in the catchment. Furthermore, the hydrology of Holetta River is not fully assessed and studies investigating the variability and availability of water at Holetta River are scarce. In addition to this, due to scarcity of the available surface water and increase in water demand for irrigation, the major users of the river are facing a challenge to allocate the available water. Furthermore, there is no rules and regulation to use the river properly and to manage the watershed. Even if there is an irrigation committee of users, it is not well established. Due to all the above reasons, the competing users start to face conflicts when allocating the available water. With growing demands on limited water resources, effective allocation and management of stream flow and reservoir storage have become increasingly important. Therefore, this research mainly focuses on studying the hydrology of the Holetta River and assessing the water management in the catchment.

1.3. Research Questions

- What is the relationship between rainfall and runoff in the catchment?
- How much water is available in the Holetta River?
- How much is the water demand in the catchment?
- Is there a gap between the available river water supply and demand in the catchment?

1.4. Objectives

General Objective

- To study the hydrology of the Holetta River and to assess the water management in the catchment

The specific objectives are to

- model rainfall runoff relationship process of the catchment,
- investigate the seasonal variability of runoff and water availability in the catchment,
- study the water demand in the catchment, and to quantify the gap between the available river water supply and demand in the catchment.

1.5. Significance of the Study

As it is indicated earlier, studies investigating the variability and availability of water at Holetta River are scarce. Furthermore, there is always a conflict between users during the dry season. In order to have a proper river water management, identification of available water and water demand is essential. Therefore, the result of this study can be an input for planning and design of river management system in the area. In addition to this, it will give preliminary information to develop water allocation system in the catchment.

1.6. Structure of the Thesis

This research paper is organized into five chapters. The first chapter deals with background, statement of the problem, objectives and significance of the study. The second chapter reviews related literature. The third chapter presents description of the study area and research methodology. The fourth chapter explains the results and discussions of this research. The last chapter presents the conclusions and recommendations of the study.

2. LITERATURE REVIEW

2.1. Global Water Management and Allocation Issues

Integrated Water Resource Management is a way of analyzing the change in demand and operation of water institutions that evaluates a variety of supply side and demand side management measures to determine the optimal way of providing water services. Demand side management includes any measure or initiative that will result in the reduction in the expected water usage or water demand. Supply side management includes any measure or initiative that will increase the capacity of a water resource or water supply system to supply water (Buyelwa, 2004).

The growing pressure on the world‘s fresh water resources is enforced by population growth that leads to conflicts between demands for different purposes. The main concern on water use is the conflict between the environment and other purposes like hydropower, irrigation for agriculture and domestic, and industry water supply, where total flows diverted without releasing water for ecological conservation. Consequently, some of the common problems related to water faced by many countries are shortage, quality deterioration and flood impacts. Hence, utilization of integrated water resources management in a single system, which built up by river basin, is an optimum way to handle the question of water (Tessema, 2011).

There are several problems concerning water allocation and management, some of these are

- ➢ Variability in rainfall, fluctuations in temperature and other meteorological conditions greatly affect the variation in the magnitude and timing of hydrologic events such as the distribution of stream flow.
- ➢ Water demand driven by the rapid increase of population and increasing demand for agricultural irrigation. This quick rate of growth brings severe consequences that result from high stresses on water resources and their unprecedented impacts on socio-economic development.
- ➢ Water scarcity is also one of the problems in the river basins. The major reasons are high water demand from population growth, degraded water quality and pollution

of surface and groundwater sources, and the loss of potential sources of fresh water supply due to old and unsustainable water management practices.

- Conflicts often arise when different water users of the river compete for limited water supply (Lizhong, 2005).

2.2. Hydrological Models

A hydrological model is a simplified representation of a real-world system, and consists of a set of simultaneous equations or a logical set of operations contained within a computer program. Models have parameters, which are numerical measures of a property or characteristics that are constant under specified conditions. Computer modeling offers a methodology to investigate hydrological processes and make predictions on what the flow might be in a river given a certain amount of rainfall. There are different types of models, with different amounts of complexity, but all are a simplification of reality and aim to either make a prediction or improve our understanding of biophysical processes (Davie, 2008). Figure 1 showed different types of models.

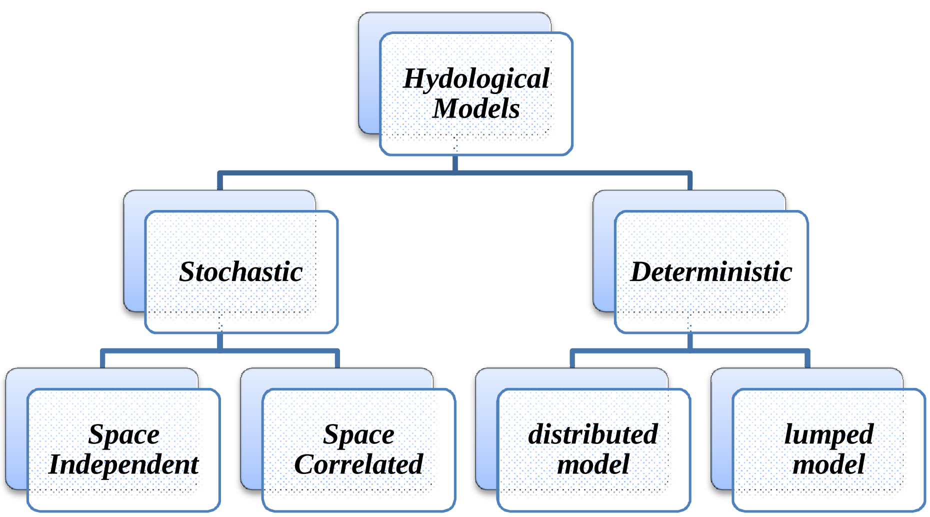


Figure 1. Hydrological model classifications (Chow et al., 1988)

For this study, SWAT model was selected because of the following character and these characters help to represent the catchment accurately,

- It is physically based distributed model
- Was capable of operating on a watershed scale with several subbasins
- Allowed topographical, land use and soil differences
- Was capable of simulating several management practices
- Could simulate long periods of time

2.3. Description of SWAT Model

Soil and Water Assessment Tool (SWAT) is a river basin, or watershed, scale model developed by Dr.Jeff Arnold for the US department of Agriculture (USDA) - Agricultural Research Service (ARS) (Neitsch et al., 2005). Soil and Water Assessment Tool use to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods. Soil and Water Assessment Tool is physically based distributed model requiring specific information about soil, topography, weather, and land management practices within the watershed. The physical processed associated with water movement, sediment movement, crop growth and nutrient cycling directly modeled by SWAT using this input data (Arnold et al., 1998). For modeling purposes, the watershed divided into a number of sub watersheds or subbasins. Input information for each subbasin is organized into the following categories: climate, hydrological response units (HRUs); ponds/wetlands; groundwater; and the main channel or reach.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each subbasin. The second division is the water or routing phase of the hydrologic cycle, which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet (Neitsch et al., 2005).

2.3.1. Land Phase of the Hydrologic Cycle

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad \text{................ equation 1}$$

Where, SW_t is the final soil water content (mm H_2O),

SW_0 is the initial soil water content on day i (mm H_2O),

t is the time (days),

R_{day} is the amount of precipitation on day i (mm H_2O),

Q_{surf} is the amount of surface runoff on day i (mm H_2O),

E_a is the amount of evapotranspiration on day i (mm H_2O),

W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O),

Q_{gw} is the amount of return flow on day i (mm H_2O).

The subdivision of watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and it routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

2.3.1.1. Climate

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different component of the hydrologic cycle. The climatic variables required by SWAT consist of daily precipitation, maximum or minimum air temperature, solar radiation, wind speed, and relative humidity. The model allows values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed, and relative humidity to be an input from records of observed data or generated during the simulation (Neitsch et al., 2005).

2.3.1.2. Hydrology

As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapotranspired or it may slowly make its way to the surface water system via underground paths.

Potential Evapotranspiration

Potential Evapotranspiration is the rate at which evapotranspiration would occur from a large area uniformly covered with growing vegetation which has access to an unlimited supply of soil water content. The model offers three methods for estimating potential evapotranspiration. These are Hargreaves (Hargreaves et al., 1985), Priestley-Taylor (Priestley and Taylor, 1972), and Penman-Monteith (Monteith, 1965). The three PET methods included in SWAT vary based on the amount of required inputs. The Penman-Monteith method requires solar radiation, air temperature, relative humidity, and wind speed. Priestley-Taylor method requires solar radiation, air temperature, and relative humidity. The Hargreaves method requires air temperature only. In this study, Penman-Monteith method was used. The Penman-Monteith equation combines components that account energy needed to sustain evaporation, the strength of the mechanism required to remove the water vapor, aerodynamic and surface resistance terms. The Penman-Monteith equation is:

$$\lambda E = \frac{\Delta * \left(H_{net} - G\right) + \rho_{air} * C_p * \left[e_z^o - e_z\right] / r_a}{\Delta + \gamma * \left(1 + \frac{r_c}{r_a}\right)}$$ .... equation 2

Where: λ is latent heat flux density (MJ/m^2day)

E is depth rate evaporation (mm/day)

Δ is slope of saturation vapor pressure – temperature curve, de/dT (kPa/°C)

H_{net} is net radiation (MJ/ m^2day)

G is heat flux density to the ground (MJ/ m^2day)

ρ_{air} is air density (kg / m^3)

C_p is specific heat at constant pressure (MJ/kg.^{o}C)

e_z is water vapor pressure of air height z (kpa)

γ is psychometric constant (kpa /^{o}C)

r_c is pant canopy resistant (s/m)

r_a is diffusion resistance of the air layer (aerodynamic resistance) (s/m)

Surface Runoff

Surface runoff, or overland flow, is flow that occurs along a sloping surface. Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. Soil and Water Assessment Tool computes surface runoff by using the modified soil conservation service (SCS) curve number method (USDA - SCS, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911). In the curve number method, the curve number varies non-linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The Green & Ampt method requires sub daily precipitation data and calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity. Water that does not infiltrate becomes surface runoff. The SWAT model includes a provision for estimating runoff from frozen soil where a soil is defined as frozen if the temperature in the first soil layer is less than 0°C. In this study, modified SCS curve number method was used.

The SCS curve number equation is (USDA - SCS, 1972):

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{R_{day} - I_a + S} \quad \text{.............................. equation 3}$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O),

R_{day} is the rainfall depth for the day (mm H_2O),

I_a = is the initial abstractions prior to runoff (mm H_2O),

S is the retention parameter (mm H_2O).

The retention parameter varied especially due to changes in soils, land use, management, and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad \text{.................... equation 4}$$

Where, CN is the curve number for the day.

The Initial abstractions, I_a is commonly approximated as 0.2S and then the equation 3 becomes

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{R_{day} + 0.8S} \quad \text{................... equation 5}$$

Runoff will only occur when $R_{day} > I_a$.

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and used to predict sediment loss. Soil and Water Assessment Tool calculates the peak runoff rate with a modified rational method. The rational method is based on the assumption that if a rainfall of intensity i begins at time t = zero and continuous indefinitely, the rate of runoff will be increase until the time of concentration, $t = t_{conc}$, when the entire subbasin area is contributing to flow at the outlet.

The rational formula is:

$$q_{peak} = \frac{C * i * Area}{3.6} \quad \text{.....................} \quad \text{equation 6}$$

Where, q_{peak} is the peak runoff rate (m^3/s),

C is the runoff coefficient,

i is the rainfall intensity (mm/hr),

Area is the subbasin area (km^2),

3.6 is a unit conversion factor (Neitsch et al., 2005).

2.3.2. Routing Phase of the Hydrologic Cycle

Once SWAT determines the loadings of water, sediment, nutrients, and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure. In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and streambed (Neitsch et al., 2005).

2.4. Description of CROPWAT Model

CropWat is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation. CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. For this study, CropWat 8.0 was used. CropWat 8.0 is a computer programme 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. In CropWat 8.0, the calculation of crop water requirements is carried out per decade.

2.4.1. Crop Water Requirement

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and water to compensate for non-uniformity of water application. For the calculations of the Crop Water Requirements (CWR), the crop coefficient approach is used (Allen et al., 1998).

2.4.2. Crop Coefficient Approach

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the FAO Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., reference evapotranspiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate crop evapotranspiration under standard conditions (ETc) to ETo. This is known as the crop coefficient approach.

$$ETc = Kc * ETo \quad \text{......................} \quad \text{equation 7}$$

Radiation, air Temperature, Humidity and Wind speed are all incorporated into the ETo estimate. Therefore, ETo represents an index of climatic demand, while Kc varies predominately with the specific crop characteristics and only to a limited extent with climate and soil evaporation. This enables the transfer of standard values for Kc between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the Kc factors developed in past studies. The reference ETo is defined and calculated using the FAO Penman-Monteith equation. The crop coefficient, Kc represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, Albedo of the crop soil surface, canopy resistance, and evaporation from soil, especially exposed soil (Allen et al., 1998).

2.4.3. Effective Rainfall

For agricultural production, effective rainfall refers to the portion of rainfall that can effectively be used by plants. This shows not all rain is available to the crops as some is lost through runoff and deep percolation. How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity, and the initial soils water content. 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 (Allen et al., 1998).

2.5. Previous Study in the Area

2.5.1. Design of a community based Dam in Holetta, Ethiopia

The purpose of this work was to design a small dam in the Holetta area, which can be constructed economically using local labor skills. The study proposed two dam sites in which both found in the Mintile River and have a catchment area of 38.06km² and 63.72km². The overall annual water demand for the irrigation area was about 9 to 11 million cubic meters (MCM) for the years 1985-1993. In this estimation, the water demand for drinking water was included. The drinking water demand was found to be 1,700m³/day, which means a yearly demand of 620,500m³/year. The annual water demand was 5.6 MCM/year. According to Ethiopian consultants, a rough estimation value for water irrigation per hectare of land per year was 10,000m³/ha/year, with an irrigation area of 680ha this was an annual water demand of 6.8MCM/year (Kramer, 2000).

2.5.2. Simulation and Optimization for Irrigation and Crop planning

In this work, simulation and optimization models were assembled for the optimization of irrigation systems and their operation. The simulation model CropWat was used for estimation of the crop water requirement, time, and depth. The study area encompasses three command areas that are Holetta Research Center, farmers and Tsedey State Farm, and five different types of crops, i.e. potato, tomato, apple, peach, and winter wheat. The simulation results of the CropWat model illustrated that crop water requirement for apple was highest (993 mm), followed by peach (908 mm), tomato (470 mm), potato (443 mm) and wheat (294 mm). The study reveals that fruit crops have more crop water requirements than cereals (Darshana et al., 2011).

3. MATERIALS AND METHODS

3.1. Description of Study Area

The study was conducted at Holetta catchment, which is located in the upper part of Awash River basin, Ethiopia. The study area lies at an altitude of 2069 - 3378 meters above sea level and located at a latitude range of $8^0$56'N to $9^0$13'N and longitude range of $38^0$24'E to $38^0$36' E. It is a catchment with drainage area of 403.47 km^2. According to the national census conducted in 1994, the population of the town for that year was 16,785, consisting mainly of *Oromo* people. However, according to census carried out by the municipality of the town in 1998, the estimated population is 29,421(Kramer, 2000). The loamy soil of the study area is the main cause of erosion in the rainy season. The annual rainfall of the study area ranges between 818-1226 mm. The climate of the study area is described with the air temperature ranging from 6^0C to 23^0C with the mean of 14 ^{0}C.

The town of Holetta is the major settlement in the catchment of the Holetta River, which is the capital of the *Wolmera Genet* area and 45 km in the west direction from Addis Ababa. The total length of streams in the watershed is about 45.51 km. About 5km north of Holetta town is the conjunction of the Holetta and the Mintile River, which originates in the mountains. At the end, the Holetta River will join with Awash River at *Ilu Woreda*. In addition to HARC and Tsedey Farm, four *kebele*'s in the downstream use the river for irrigation which was considered as the major users of the river. These are *Medi Gudina, Dewana Lafto, Tulu Wato Dalecha* and *Hamus Gebeya*. Farmers in these kebeles produce cereals under rainfed agriculture from June to November for subsistence. Potatoes and tomatoes are the dominant irrigated horticultural crops, although several other crops are also cultivated.

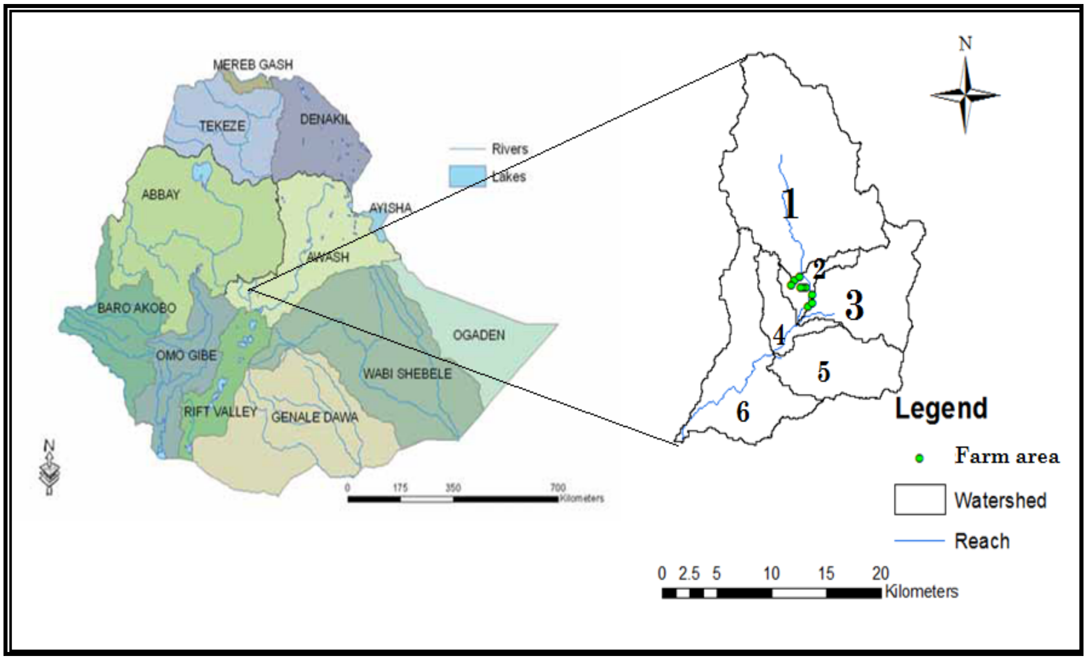


Figure 2. Location of Holetta catchment

3.1.1 .Topography

The altitude of the study area ranges from 2069 to 3378 meters (m) above sea level (a.s.l) with a mean of 2496m a.s.l. According to Food and Agricultural Organization (FAO/UNESCO, 1974) slope classification, most slope in watershed (54.01%) are flat to gently undulating with a dominant slopes ranging between 0-8%, 41.9% of the area is rolling to hilly with a dominant slopes ranging between 8-30% and only 4.09% are steeply dissected to mountainous with dominant slopes over 30%. Figure 3 showed the graphical distribution of these slopes.

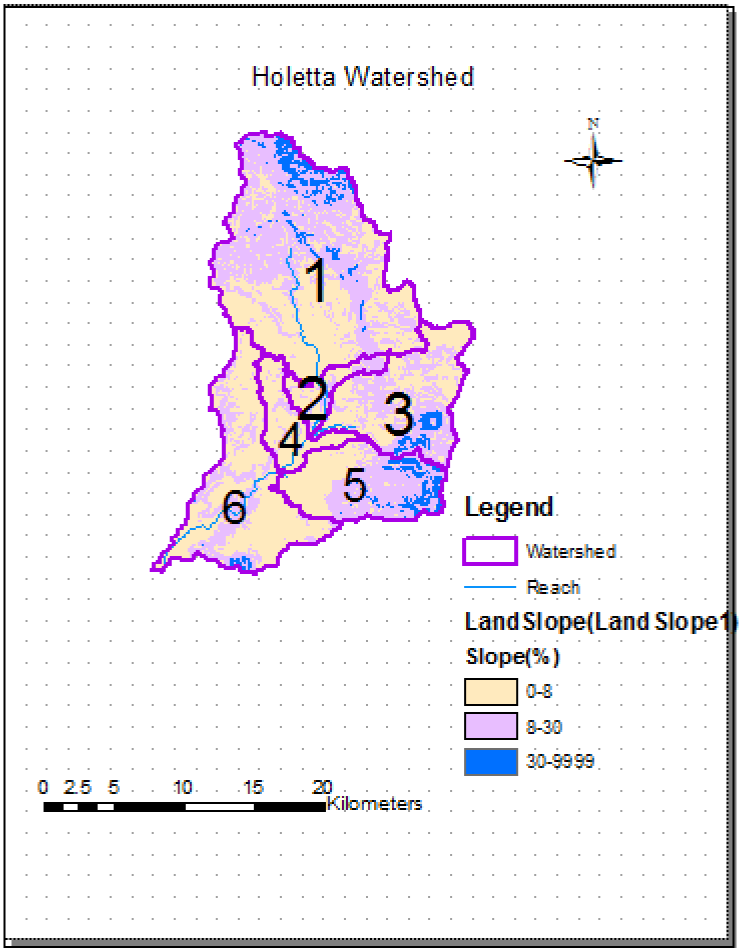


Figure 3. Slop classification map of study area

3.1.2. Climate

The central and most of the eastern part of the country have two rainy periods and one dry period. These seasons are known locally as the main *Kiremt* rains from June to September, small *Belg* rains, from February to May, and dry *Bega* season from October to January. The annual rainfall of the study area ranges between 818-1226 mm, with a bimodal pattern of main rainy season during June to September and short rain

y season during January to May. There is relatively intensive rainfall during June to August with the highest mean monthly rainfall recorded in July - 243 mm. The months with the lowest rainfall are November and December.

3.1.3. Land use/ Land cover

The major land use and land cover types of the watershed are agriculture land, forest, pastureland, settlement, and water bodies. Forests and woodlands occur on the better-drained soils of mountains and sides of the valleys, and grasslands occupy areas of heavy clay soil of the valley bottom.

The forest coverage of the *Welmera Wereda* is 8,917 ha (8.5%) of the total area of the *Wereda*. This forest coverage is high due to the existence of *Suba* state forest, *Managasha* Church and Monastery and *Finfinnee* area Forest Enterprise plantation Forest. There are some remnants of indigenous tree species such as Podocarpus gracilior, Juniperus procera, Olea Africana, Croton macrostachyus and Acacia spp in the watershed. The dominant cultivated Eucalyptus species are Eucalyptus globules and Eucalyptus camaldulensis. The cultivated Eucalyptus mostly used for construction and as an energy source in the *wereda*. Nowadays it has become one of the cash crops in the *wereda* and a means of income source. This pushes the farmers to unplanned harvesting of the plantation forest thereby reducing land cover and having an effect on soil erosion on the area (Ayele, 2011).

3.1.4. Soil Classification

The soil type in the study area is classified as vertisols, cambisols and nitisols. However, the dominant are vertisols and nitisols. Vertisols occur on smooth plains and on rolling topography of the plateau. They are characterized by their high clay content and have in general a good natural fertility. Due to clay mineralogy they are very hard and crack when dry; sticky and plastic when wet. Nitisoil generally occur on steeper hill slopes of the plateau and in the upper parts of the Holetta catchment. These soils contain more than 35% clay. The high clay content of Nitisoils result in somewhat better chemical and physical properties than other tropical soils related to the soil depth, stable structure and high water holding capacity permeability (Kramer, 2000).

3.2. Data Collection

All meteorological data (rainfall, temperature, relative humidity, wind speed, and sunshine hour) were collected from National Meteorology Agency and Holetta Research Center. Flow data and GIS data (topographic, land use/cover data and map, soil map) were collected from Ministry of Water and Energy. Primary data of crop type and area coverage were collected from major water users of Holetta River (Holetta Agricultural Research Center, Tsedey Farm, and Farmers). The method of data collection was documents, field survey, and questionnaire.

The survey form was used to collect crop type, area coverage and water use data from the three users of Holetta River and Agricultural office. Then, the sample size of households was determined by the following formula (Cochran, 1977).

$$n = \frac{(Z^2 pq)/d^2}{1 + \frac{1}{N}\left[((Z^2 pq)/d^2) - 1\right]} \qquad \text{...................... equation 8}$$

Where, n= is the desired sample size

N = the number of sample size when the population is less than 1000

Z = 95% confidence limit i.e. 1.96

P = 0.1(proportion of the population to be included in the sample i.e. 10%)

q =1-P =1- 0.1, =0.9

N = total number of population

d = margin of error or degree of accuracy desired (0.05)

Based on the above formula 100 respondents were selected using random sampling techniques.

3.3. SWAT Model Input

Soil and Water Assessment Tool required the following data to be defined for the physical watershed representation, topography data (Digital Elevation Model), climate (daily measured and monthly statistical weather data), flow data, soil and land use data (maps and physical parameters).

3.3.1. Digital Elevation Model Data

The Digital Elevation Model (DEM) of Awash basin was taken from Ministry of Water and Energy GIS department. Then, a 90m resolution DEM was used in SWAT model to delineate the Holetta catchment and to analyze the drainage patterns of the land surface terrain.

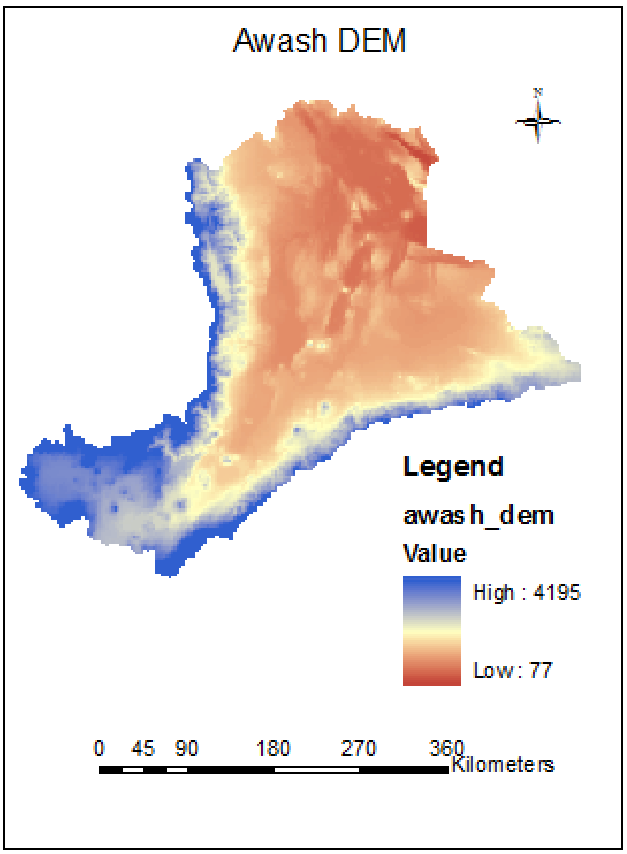


Figure 4. Digital elevation model (90m) of Awash basin

3.3.2. Land Use Map

The land use map of Awash basin clipped and dissolved into Holetta River catchment. Then, the clipped land use map was used for SWAT land use reclassification. According to SWAT land use classification, the catchment has five categories (figure 5). These are, Agricultural Land- Row Crops (AGRR) with an area of 13.54%, Agricultural Land -Close-Grown (AGRC) - 0.17%, Wetlands-Mixed (WETL) - 0.14%, Forest -Deciduous (FRSD) - 57.26% and Forest-Mixed (FRST) - 28.9%.

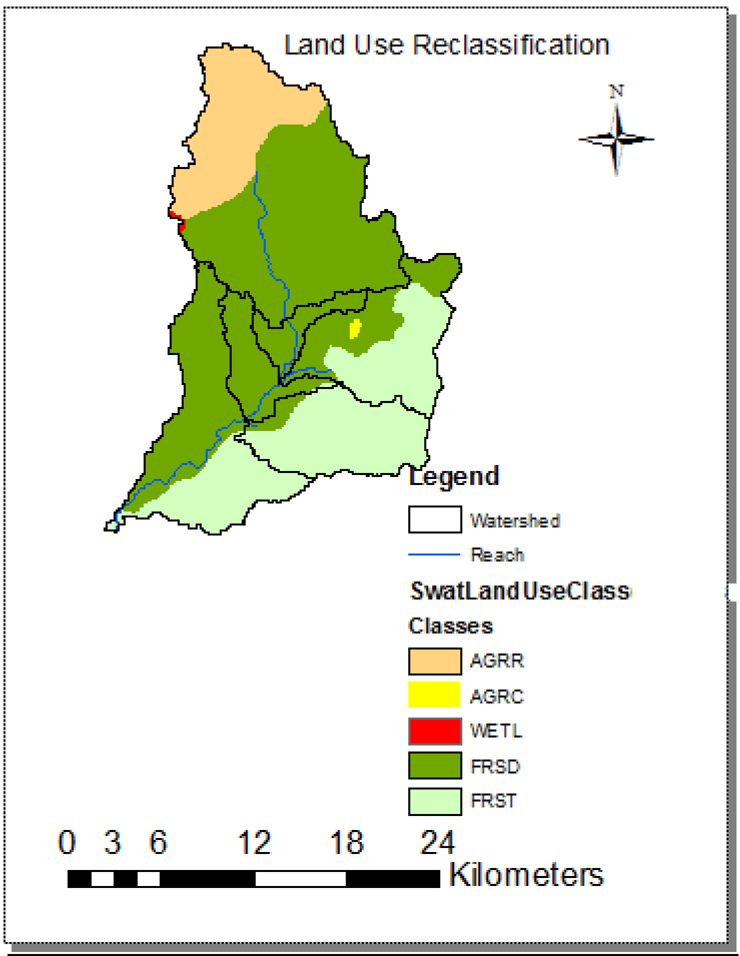


Figure 5. Land use classification of SWAT model for Holetta watershed

3.3.3. Soil Map

The soil map of Awash basin clipped and dissolved in to Holetta River catchment. Then, the clipped soil map was used for SWAT soil reclassification. Based on SWAT reclassification, the catchment has four soil categories (figure 6). These are Chromic Luvisols (Chluvisols) with an area of 33.26%, Humic Nitisols (Huntisols) - 56.57%, Vertic Cambisols (Vtcambisol) -1.71% and Eutric Vertisols (Euvertisols) - 8.27%. Based on their texture, Vtcambisol and Euvertisol classified as clay whereas Chluvisols and Huntisols classified as loam (Belete et al., 2012).

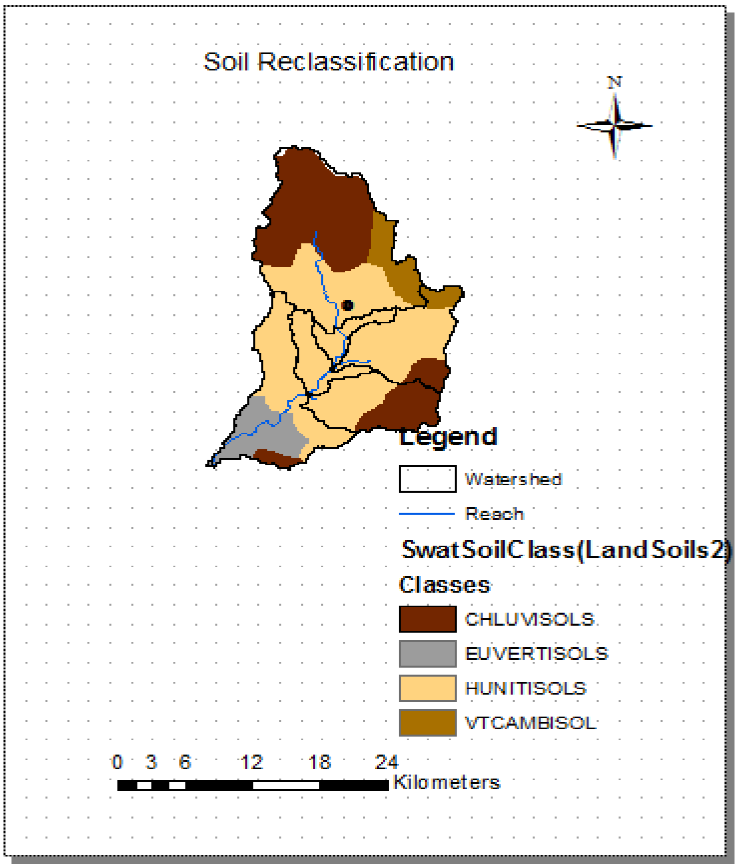


Figure 6. Soil classification of SWAT model for Holetta watershed

3.3.4. Meteorological Data

One of the meteorological stations (Holetta) found inside the catchment. The other meteorological stations, which were found outside the catchment, are Addis Alem, Kimoye and Welenkomi. The meteorological data measured from Holetta station are Rainfall, Maximum and Minimum temperature, Relative humidity, Wind speed, and Sunshine hour. All the other meteorological stations were used only for rainfall data. The consistency, homogeneity, and outlier test for the data was performed by using Excel software and XLSTAT software. The percentage of miss data for rainfall is 14% at Addis Alem station, 13% at Kimoye station, 1% at Holetta station, and 18% at Welenkomi station. Therefore, missing data are filled from observations at the three nearby stations by using the normal ratio method. The normal ratio method is a better method than the arithmetic mean method and is usually applied when the normal annual precipitation at the site with the missing record differs by more than 10% of the normal annual precipitation at the other sites where the concurrent data are available. The location of the four meteorological stations was shown in figure 7.

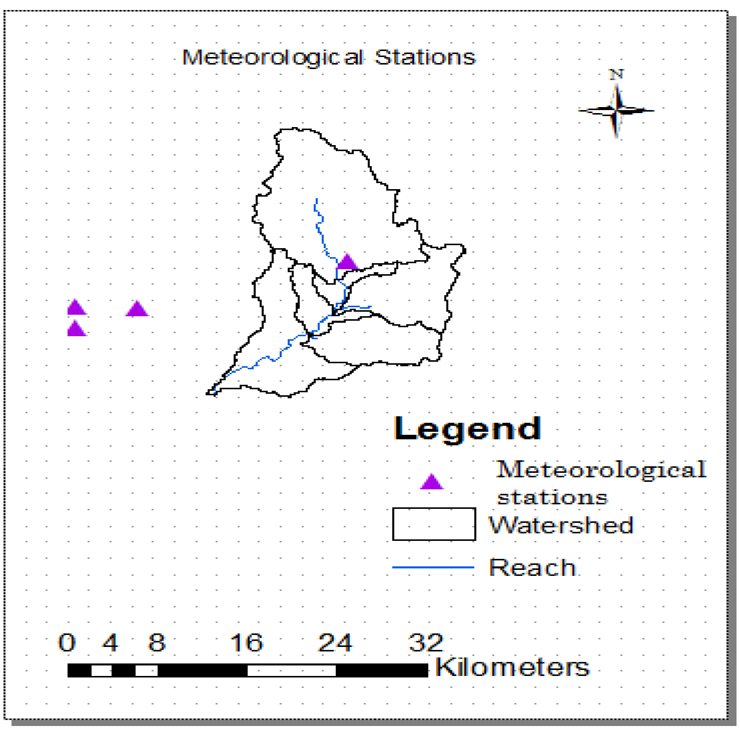


Figure 7. Location of rainfall stations for the study area

Table 2. Information of climate and hydrology stations

No	Station	Record Period	Coordinate		Elevation	Data collected
			XPR	YPR		
1	Addis Alem	1994 -2004	475810.95	981592.52	2100	Rainfall
2	Holetta	1994 -2004	447252.34	1003731.64	2395	Climate and Flow data
3	Kimoye	1994 -2004	423058.00	998462.26	2260	Rainfall
4	Welenkomi	1994 -2004	423058.00	996021.93	2160	Rainfall

The climate data obtained from Holetta station showed that the air temperature in the area ranges from 6^0C to 23^0C. The mean maximum temperature was 25^0C. Based on meteorological data from 1994-2004, the mean monthly relative humidity value varied from 45 to 85% (figure 8).

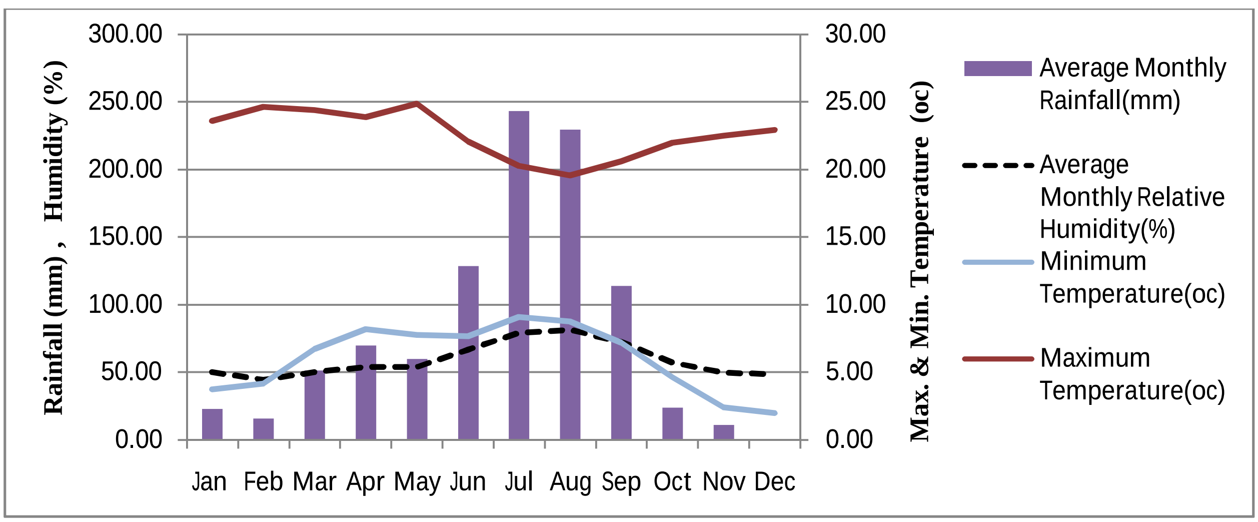


Figure 8. Average Rainfall, Temperature and Relative humidity of Holetta watershed (1994 - 2004)

3.3.5. Flow Data

The Holetta River is a tributary of the larger Awash River, which joins it after travelling about 25km downstream of the gauging station. The Holetta River is the main source of surface water in the study area. The River is gauged since 1975 and for this study, the 1994 - 2004 time series of the river discharge data was used. The daily flow data from gauging station was used for sensitivity analysis, model calibration (1994 – 1999) and validation (2000-2004).

The average annual river flow at Holetta River was 44 MCM (figure 9). The flow was low from January to May and it started to increase at June. The peak flow was 17 MCM, which occurred in August, and the minimum flow was 0.524 MCM in February.

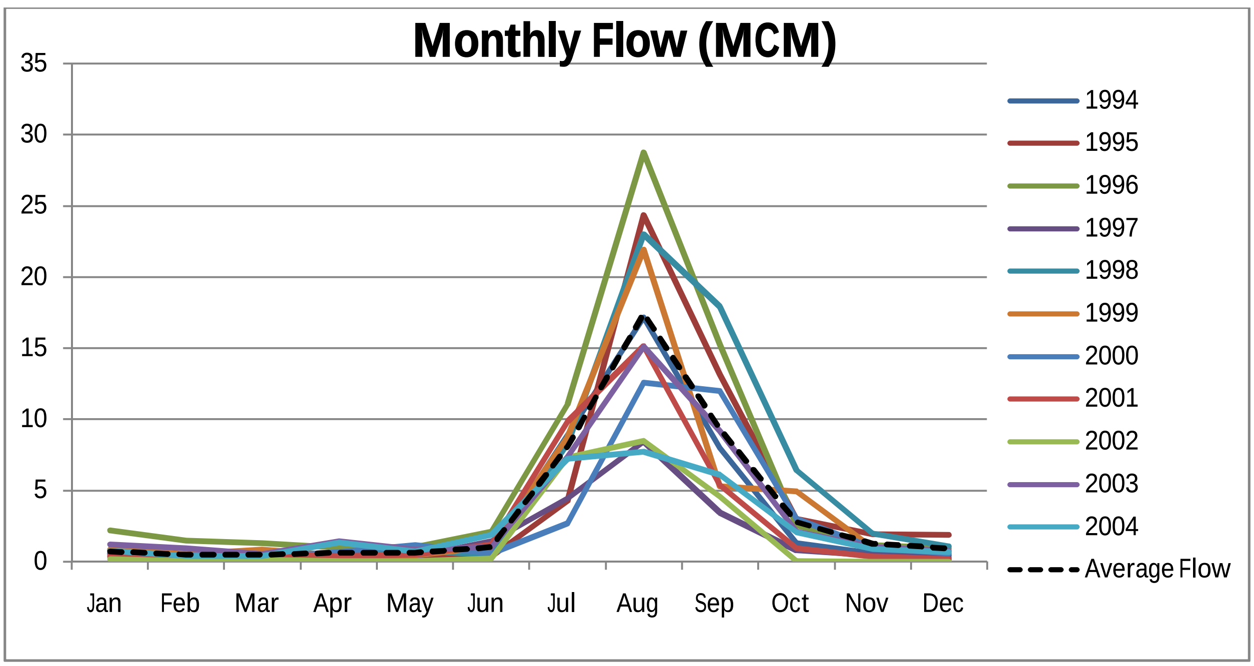


Figure 9. Average monthly flows at Holetta River (1994 -2004)

The rainfall runoff relation showed that there was a positive relation between rainfall and surface runoff in the catchment (figure 10).

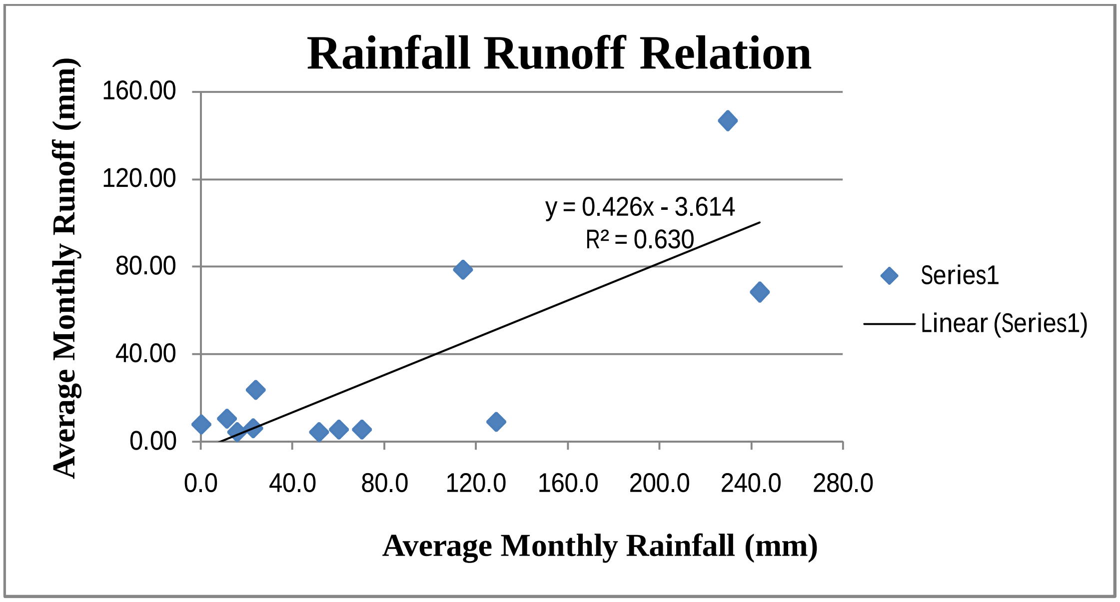


Figure 10. Monthly rainfall runoff relations for Holetta subbasin (1994-2004)

3.4. SWAT Data Preparation and Model Setting

First new SWAT project was set up and saved, and then watershed delineation was performed. In order to delineate the watershed, automatic watershed delineation was selected. Then, the DEM was added and stream network was defined. Finally, the watershed outlet was selected to delineate the basin. The next step in setting up a watershed simulation was to divide the watershed into subbasins. The subbasins possess a geographical position in watershed and they are spatially related to one another. In this study, the DEM of Awash basin was used to delineate the watershed. Once the subbasin delineation completed, the user has the option of modeling a single soil, land use and management scheme for each subbasin or partitioning the subbasins into multiple hydrologic response units (HRUs). Hydrological response units are portion of a subbasin that possesses unique land use, management and soil attributes. A subbasin will contain at least one HRU, a tributary channel and a main channel or reach. Hydrological response units are used in most SWAT runs because they simplify a run by lumping all similar soil and land use areas into a single response unit and it will increase the accuracy (Neitsch et al., 2004).

After that land use/soil / slop definition and HRU definition was performed by using the land use and soil map in combination with look up tables. By using these data, SWAT classified the watershed. Then, writing input tables was continued by defining weather data. The first step to proceed was defining the weather generator data. To define the weather generator data, the user weather station was created through edit SWAT database section. Then, the weather station parameters were fitted in the new station.

In order to prepare the station parameters, different software was used. These are WGNmaker4.Xlsm, dew.exe and pcpSTAR.exe. WGNmaker 4.Xlsm was used to calculate the weather station statistics needed to create user weather station files. The program dew.exe was used to calculate the average daily dewpoint temperature per month using daily temperature and humidity data. The program pcpSTAT.exe was used to calculate statistical parameters of daily precipitation data used by weather generator of SWAT model (Stefan, 2003). Then, the arranged data was used by SWAT weather generator to fill in missing information and to simulate weather data. To finalize the weather writing part, write all section was selected and then all the watershed data was written and the model was made to be ready to run.

Once we run the model with default parameter setting, the sensitivity analysis and calibration was performed. The sensitivity analysis was performed by selecting the SWAT simulation, subbasin, sensitivity parameters and observed data. The calibration can be performed in two methods, auto calibration and manual calibration methods. In this study, manual calibration was used. That was by changing the sensitive parameters manually until the simulation was better fit with the observed data.

3.5. Sensitivity Analysis

Sensitivity analysis explores how changes in parameter values affect the overall change in the output of the model. This can be done by using simple sensitivity analysis, where only one parameter is changed or more complex arrangements that explore the relationships between multiple parameters. Sensitivity analysis is important for a model to reduce the number of model parameters for calibration and to examine the more sensitive parameters. Thus, a sensitivity analysis for SWAT model was performed for the entire data (1994 -2004). Then, the most sensitive parameters was identified and used for calibration of the model.

The Latin Hypercube - One-factor-At-a-Time (LH-OAT) sensitivity analysis method combines the robustness of the Latin Hypercube sampling with the precision of One-factor-At-a-Time (OAT) designs. The LH ensures the full range of all parameters has been sampled and OAT assured that the changes in the output in each model run could be unambiguously attributed to the input changed in such a simulation leading to a robust and efficient sensitivity analysis method. The method is also efficient, as for m intervals in the LH method, a total of m*(p+1) runs are required. Latin-Hypercube is a sophisticated way to perform random sampling such as Monte-Carlo sampling to allow a robust analysis requiring not too many runs. One-factor-At-a-Time design is an example of an integration of a local to a global sensitivity method. As in local methods, each run has only one parameter changed, so the changes in the output in each model run can be unambiguously attributed to the input parameter changed (VanGriensven, 2005).

3.6. Model Calibration and Validation

Model calibration is often important in hydrologic modeling studies, since uncertainty in model predictions can be increased if models are not properly calibrated. Calibration is changing of model parameters based on sensitivity results against observations to ensure the same response over time. This involves comparing the model results, entered with the recorded stream flows. In this process, model sensitive parameters varied until recorded flow patterns are accurately simulated. Model validation involves re-running the model using input data independent of data used in calibration keeping the calibrated parameters constant. For this study, the calibration was carried out for six years (1994 - 1999) with one-year warm up period and it was done based on the result of sensitivity analysis. Then, validation of SWAT model was performed for the next five years (2000 -2004).

3.7. Model Evaluation

The SWAT model performance was evaluated by using statistical measures and graphical methods of comparing simulated with observed data. Three methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these numerical model performance measures are coefficient of determination [R^2], the Nash-Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF].

The coefficient of determination (R^2) is defined as the squared value of the coefficient of correlation according to Bravais- Pearson. It is calculated as:

$$R^2 = \left(\frac{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\left(\sqrt{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2}\right)\left(\sqrt{\sum_{i=1}^{n} \left(P_i - \bar{P}\right)^2}\right)} \right)^2 \quad \text{............. equation 9}$$

Where, O is observed and P is predicted values.

The coefficient of determination (R^2) expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values. Therefore, it estimates the combined dispersion against the single dispersion of the observed and predicted series. The range of R^2 lies between zero and one, which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all whereas a value of one means that the dispersion of the prediction is equal to that of the observation (Krause et al., 2005).

The Nash-Sutcliffe Efficiency Coefficient (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). Nash-Sutcliffe Efficiency indicates the degree of fitness of the observed and simulated plots.

The Nash–Sutcliffe Efficiency Coefficient is used to assess the predictive power of hydrological models. It is defined as:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2} \quad \text{............. equation 10}$$

Where, O is observed and P is predicted values (Krause et al., 2005).

The Nash Sutcliffe Efficiency Coefficient (NSE) ranges between $-\infty$ and 1.0 (1 inclusive), with NSE = one being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. Essentially, when the model efficiency is closer to one, the model is more accurate. General performance rating for NSE for monthly time step is very good for 0.75 < NSE < 1.00, good for 0.65 < NSE < 0.75, satisfactory for 0.60 < NSE < 0.70 and unsatisfactory for NSE< 0.5 (Moriasi et al., 2007).

The Index of Volumetric Fit, IVF is the ratio of total volume of Q_p to the total volume of Q_0, and is given by,

$$IVF = \frac{\sum_{i=1}^{n} Q_p}{\sum_{i=1}^{n} Q_o} * 100 \quad \text{................ equation 11}$$

Where, Q_0 is observed flow and Q_p is predicted flow

For the Index of Volumetric Fit IVF, the value of unity indicates a perfect volumetric match of the observed flows with the estimated flows over a certain period, indicating water balance (Birhanu, 2009).

3.8. Runoff Estimation

Runoff for ungauged catchments can be estimated by three regionalization method. The first method is by establishing a regional model between catchment characteristics and model parameters. The second method is Spatial Proximity; it simply transfers model parameters from nearby catchments to ungauged catchments to allow for runoff simulation. The third method is Area Ratio method; in this case, parameter sets of gauged catchments are transferred to ungauged catchments by a simple area comparison.

3.9. CropWat Model Input

Calculations of the crop water requirements and irrigation requirements were carried out with inputs of climatic, crop and soil data. The model required the following data for estimating crop water requirements (CWR).

3.9.1. Climatic Data

In order to calculate the reference evapotranspiration, CropWat model use 11 years (1994 -2004) of monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data that was collected from Holetta station.

3.9.2. Rainfall Data

Effective rainfall was calculated based on 11 years (1994 -2004) monthly rainfall data collected from Holetta station. The annual rainfall in the catchment ranges 818 -1226 mm. The average maximum monthly rainfall is 243 mm, which occurred in July, and the minimum is zero occurred in December.

3.9.3. Cropping Pattern Data

A Cropping pattern data includes planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area).

A survey was carried out in the study area to assess the crops grown under irrigation. The present cropping pattern data was assessed through field observations, interviews with farmers, HARC, and Tsedey farm workers. Additional information was taken from Agricultural office, *kebele* Administration and FAO-33 (Doorenbos and Kassam, 1986). Essential information collected from the above sources includes:

- Crop and crop variety
- Planting date
- Crop coefficient (Kc)
- Field irrigation methods
- Rooting depth
- Allowable depletion levels
- Critical depletion fraction (p)
- Length of individual growth stages

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.

3.9.4. Soil Type Data

Soil type data includes total available soil moisture, maximum rooting depth, initial soil moisture depletion (percentage of total available moisture), and maximum infiltration rate. The above data of soil collected from the soil survey carried out at HARC and FAO-33 document (Doorenbos and Kassam, 1986).

4. RESULTS AND DISCUSSIONS

4.1. Hydrological Analysis

Watershed delineation and determination of HRUs were the first step in SWAT model analysis. Then, weather station and all the necessary data were fitted. After setting and running SWAT model, sensitivity analysis, calibration and validation was performed. In this study, the calibration and validation was performed at subbasin one (see figure 12 and figure 15). A long term data was required for the analysis and the results are highly dependent on the accuracy of the data.

4.1.1. Watershed Delineation and Determination of HRUs

Holetta River catchment delineated by SWAT model has six subbasins. Then, the subbasins were divided into HRUs. The HRUs can be determined either by assigning only one HRU for each subbasin considering the dominant soil/land use combinations, or by assigning multiple HRUs for each subbasin considering the sensitivity of the hydrologic processes based on a certain threshold values of soil/land use combinations. In this study, a multiple HRU definition with a threshold value of 15% for land use, 20% for soil class, 5% for slope were given and as a result, 33 HRUs were identified.

4.1.2. Sensitivity Analysis

Sensitivity analysis was performed for the entire period (1994-2004). About 270 iteration have been done by SWAT sensitivity analysis for flow calibration with the output of 26 parameters were reported as sensitive in different degree of sensitivity for flow. Among these 26 parameters, eight of them have more effect on the simulated result when changed. Based on the result of sensitivity analysis, table 3 showed the most sensitive parameters for the watershed. Then, these parameters were used for calibration.

Table 3. Result of sensitivity analysis of flow at Holetta subbasin

Rank	parameter	Description	Mean
1	Canmx	Maximum canopy storage [mm]	0.18
2	Alpha_Bf	Base flow alpha factor [days]	0.15
3	Revapmn	Threshold water depth in the shallow aquifer for "revap" [mm]	0.15
4	Gwqmn	Threshold water depth in the shallow aquifer for flow [mm]	0.06
5	Gw_Revap	Groundwater "revap" coefficient	0.06
6	Esco	Soil evaporation compensation factor	0.04
7	Cn2	Initial SCS CN II value	0.01
8	Sol_K	Saturated hydraulic conductivity [mm/hr]	0.00

4.1.3. Model Calibration

After sensitivity analysis has been carried out, the calibration of SWAT model was done manually. The calibration was carried out using the output of the sensitivity analysis of the model and by changing the more sensitive parameter at a time while keeping of the rest of the parameters constant. The analysis of simulated result and observed flow data comparison was considered daily and monthly. The calibration was performed until the best-fit curve of simulated versus measured flow was obtained.

The sensitive parameters were adjusted based on the allowable range until the best fitting value was found. Table 4 showed the initial/default and finally adjusted parameter values.

Table 4. Initial and final adjusted value of calibrated flow parameters at Holetta subbasin

No	parameter	Default	Range (Upper & Lower Limit)	Final Calibrated Value
1	Canmx	0	0-10	10
2	Alpha_Bf	0.048	0-1	0.4
3	Revapmn	1	0 -1	0.01
4	Gwqmn	0	0-5000	70
5	Gw_Revap	0.02	0.02 -0.2	0.2
6	Esco	0	0-1	0.01
7	Cn2	72	±50%	+12%
8	Soil_K	18	0-2000	120

The SWAT model performance was evaluated by using statistical and graphical methods of comparing simulated with observed data. The goodness-of-fit statistics was used in describing the model's performance relative to the observed data. These statistical measures were the coefficient of determination (R^2), Nash-Sutcliffe Efficiency Coefficient (NSE), and Index of Volumetric Fit (IVF) between the observations and the final best simulations. Figure 11 and 12 showed the daily and monthly graphical performance evaluation of SWAT model during calibration period respectively. Both the daily and monthly graphs implied that the model simulation is best fitted with the observed flow measurement. During some years on daily bases, it showed that the model does not exactly capture the peak values; this may be due to inadequate gauging stations in the area. The catchment has only one gauging station and according to World Meteorological Organization (WMO, 2008) standard, it failed to represent the rainfall for the whole area. The WMO guide manual recommends that one rain gauge station cover an area of 250Km^2 for areas with similar terrain characteristics to the study area.

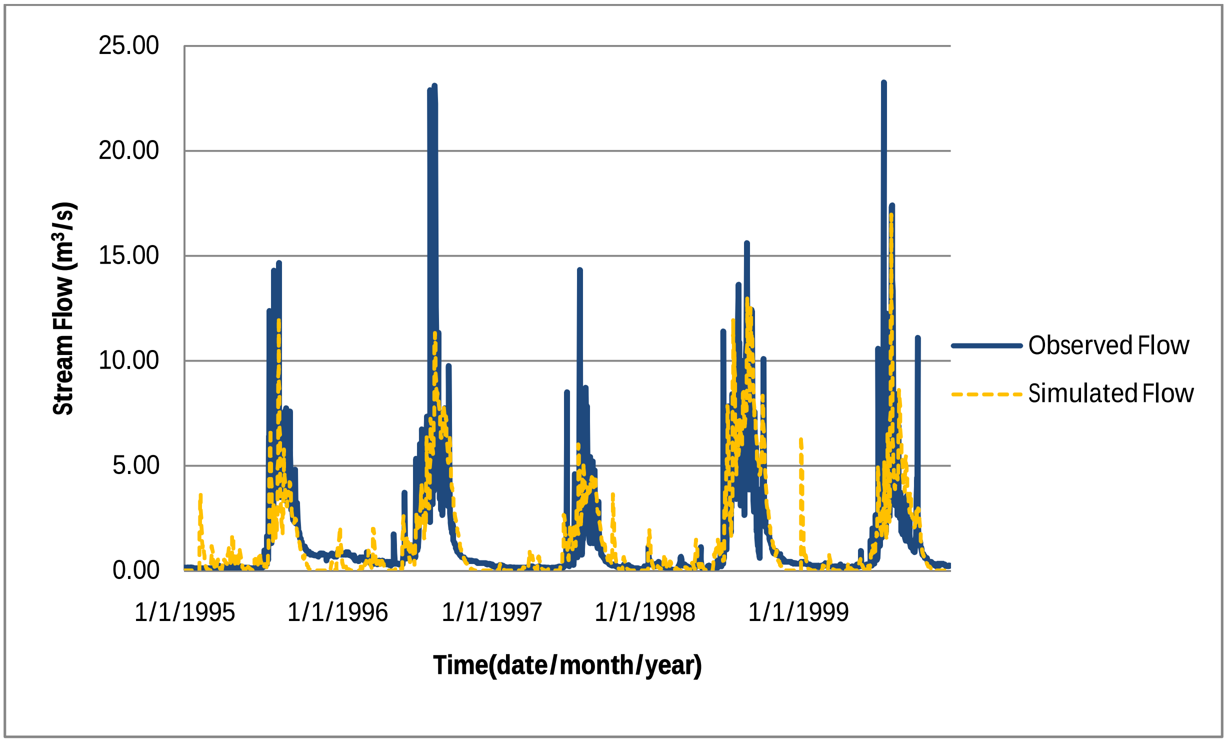


Figure 11. Observed and simulated hydrograph after daily calibration

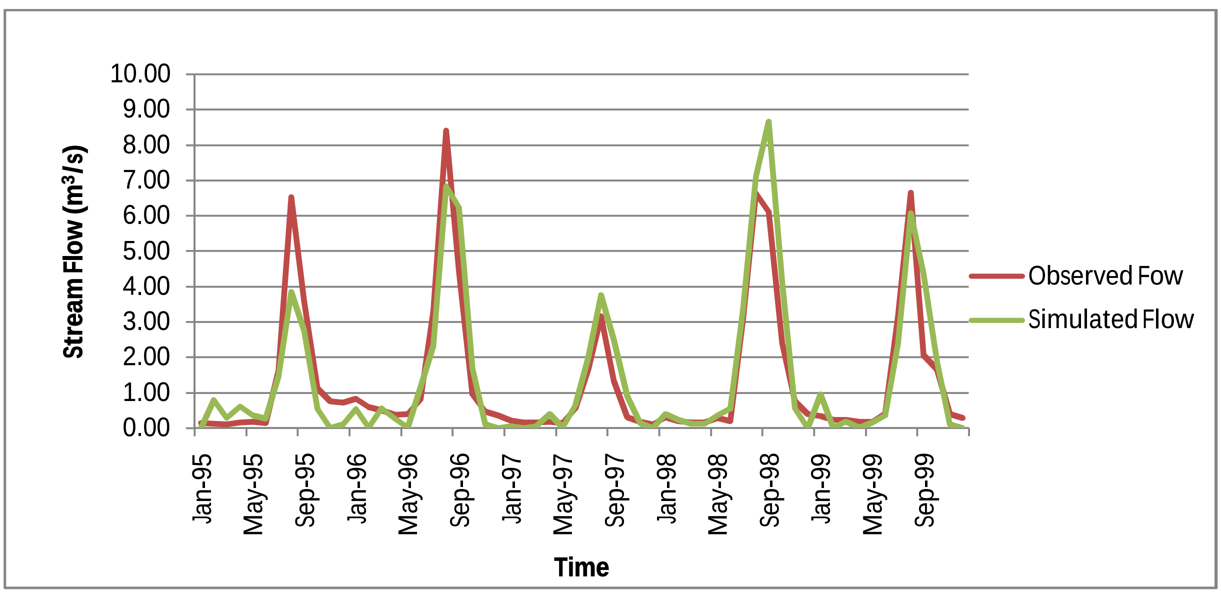


Figure 12. Observed and simulated hydrograph after monthly calibration

The daily calibration result showed that the regression coefficient (R^2) was 0.57; Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.55 and Index of Volumetric Fit (IVF) was

102.62 %. In addition, based on monthly calibration the result showed that the regression coefficient (R^2) was 0.85; Nash-Sutcliffe Efficiency Coefficient was 0.84 and Index of Volumetric Fit was 102.8% (figure 13). These indicated that the model performance was very good and highly acceptable.

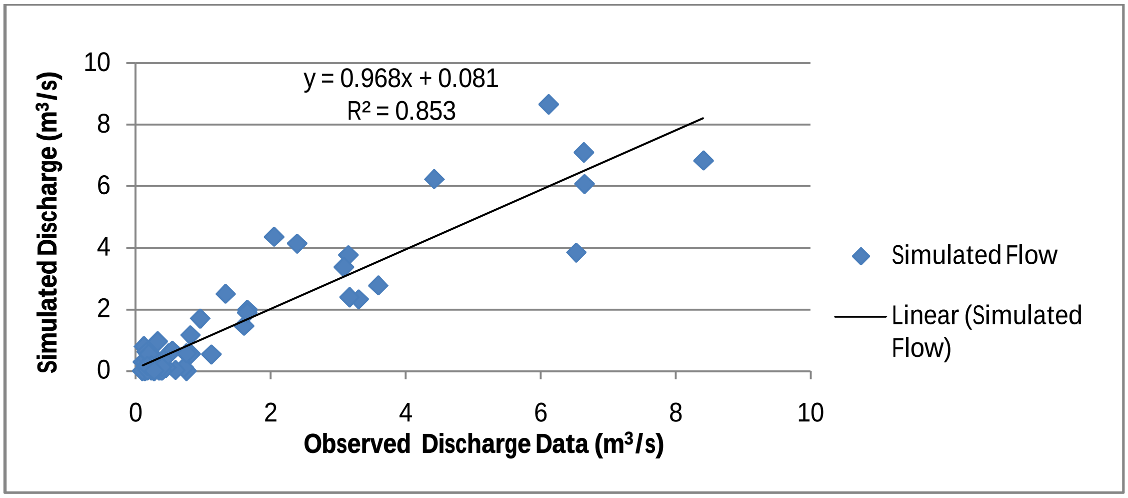


Figure 13. Scattered plot & correlation between simulated & observed monthly flow during calibration

4.1.4. Model Validation

The validation process was performed by simply executing the model for the different period using the previously calibrated input parameters. Figure 14 and figure 15 showed the daily and monthly graphical performance evaluation of SWAT model during validation period respectively. Both the daily and monthly graphs implied that the model simulation is best fitted with the observed flow measurement.

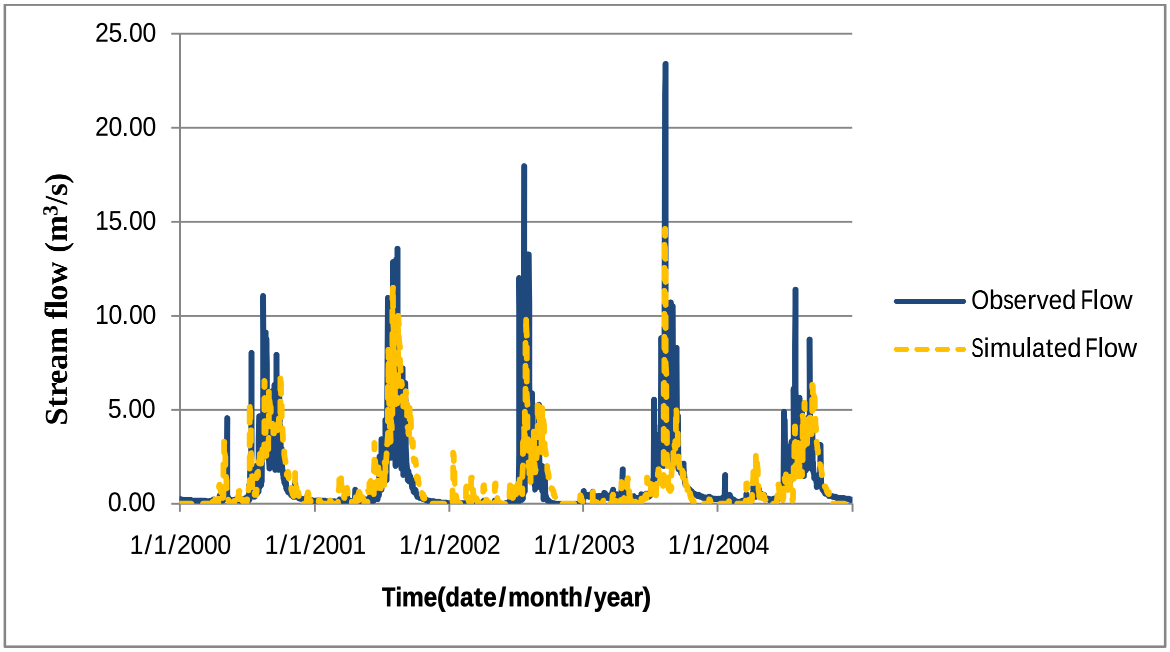


Figure 14. Observed and simulated hydrograph during daily model validation

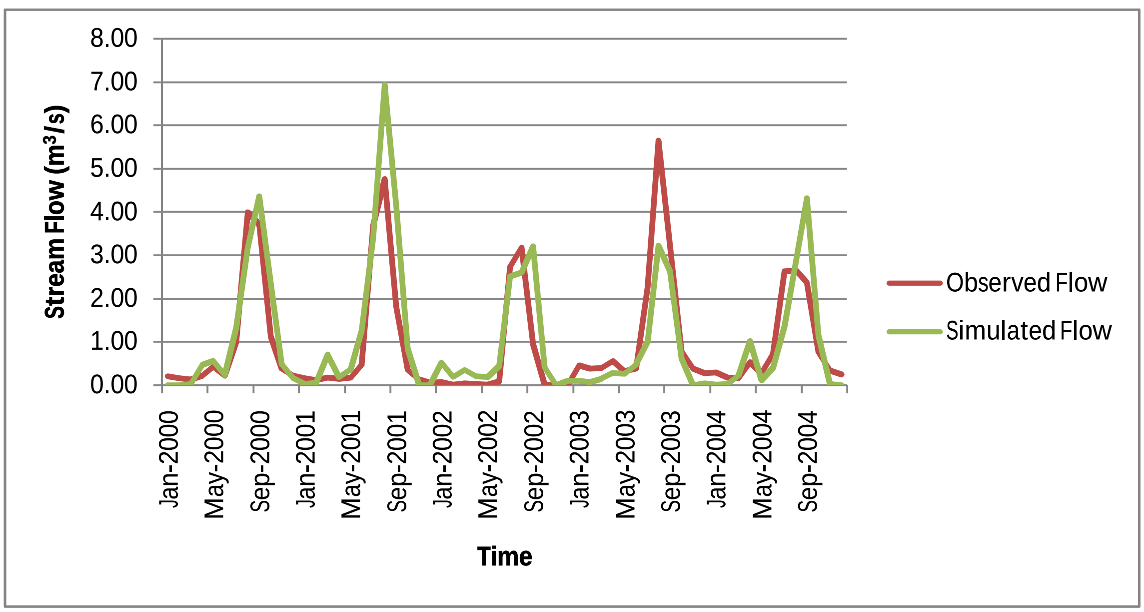


Figure 15. Observed and simulated hydrograph during monthly model validation

The three goodness-of-fit measures were also calculated for the validation period. The daily calibration result showed that the regression coefficient (R^2) was 0.44; Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.4 and Index of Volumetric Fit (IVF) was 108.9 %.

In addition, based on the result of monthly validation, the regression coefficient was 0.73; Nash-Sutcliffe Efficiency Coefficient was 0.67 and Index of Volumetric fit was 108.9% (figure 16). These results indicated that the model performance was good in the acceptable limit.

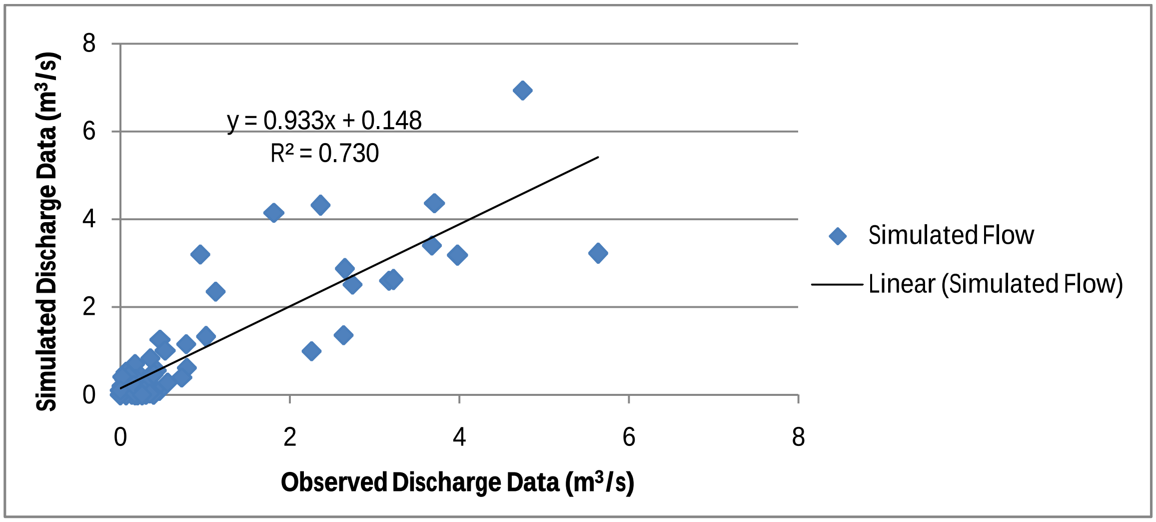


Figure 16. Scattered plot & correlation between simulated & observed monthly flow during validation

4.1.5. Runoff Estimation for Holetta Catchment

The Holetta catchment was divided into six subbasins. Only one of the subbasin was gauged which is found in the upper part of the catchment. The calibration and validation of SWAT model was performed at subbasin one. Then, regionalization approach was used to estimate runoff for the ungauged subbasin's of the catchment.

In this study, Spatial Proximity method was used to estimate runoff at subbasins 2, 3, 4 and 5 where majority of the users located. Figure 17 and figure 18 showed the daily simulation result of SWAT model. Figure 19 and figure 20 showed the monthly simulation result of SWAT model at the subbasins. The mean flow (m^3/s) at the subbasin 2, 3, 4 and 5 was shown in table 5.

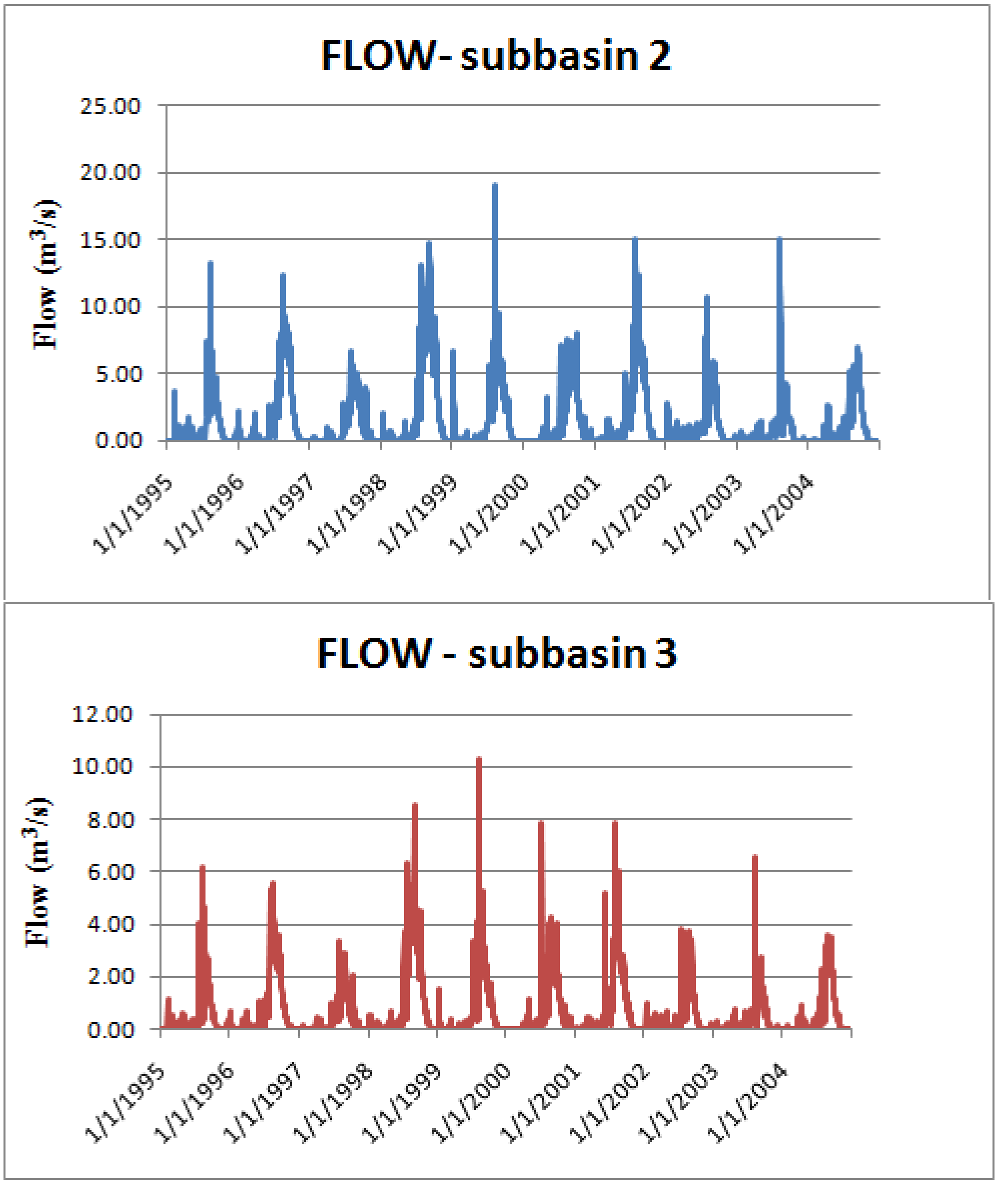


Figure 17. Daily SWAT simulation result at subbasins 2 and 3

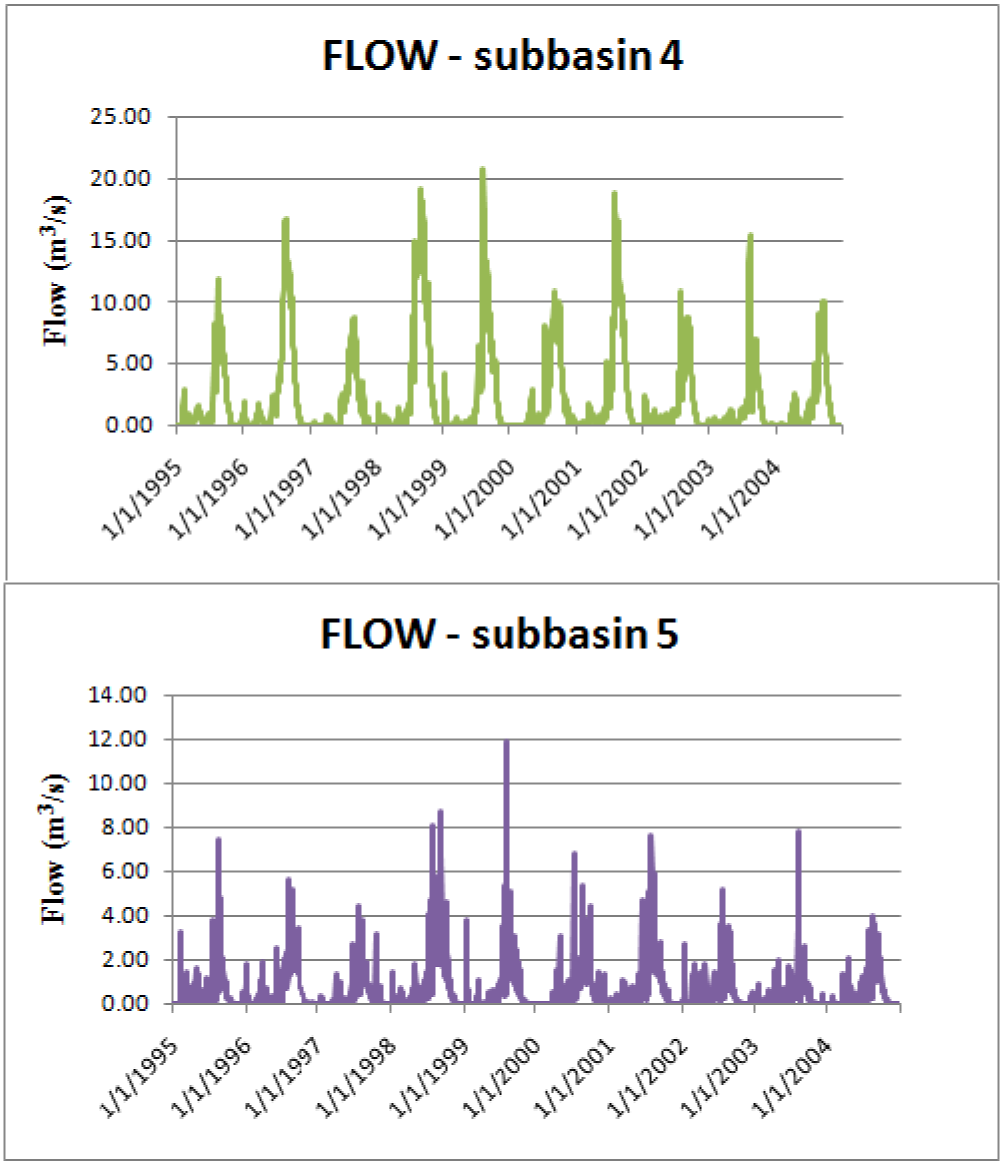


Figure 18. Daily SWAT simulation result at subbasins 4 and 5

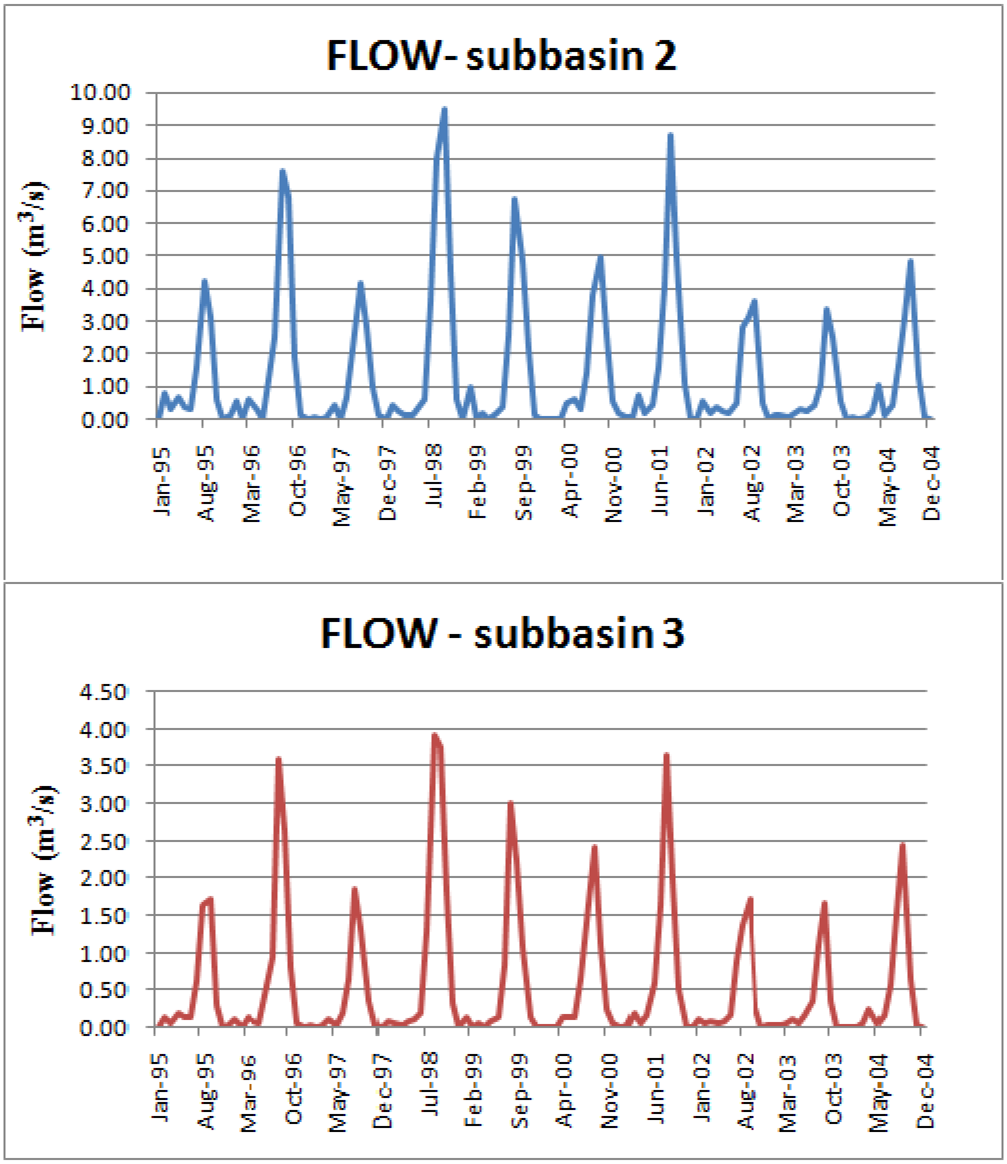


Figure 19. Monthly SWAT simulation result at subbasins 2 and 3

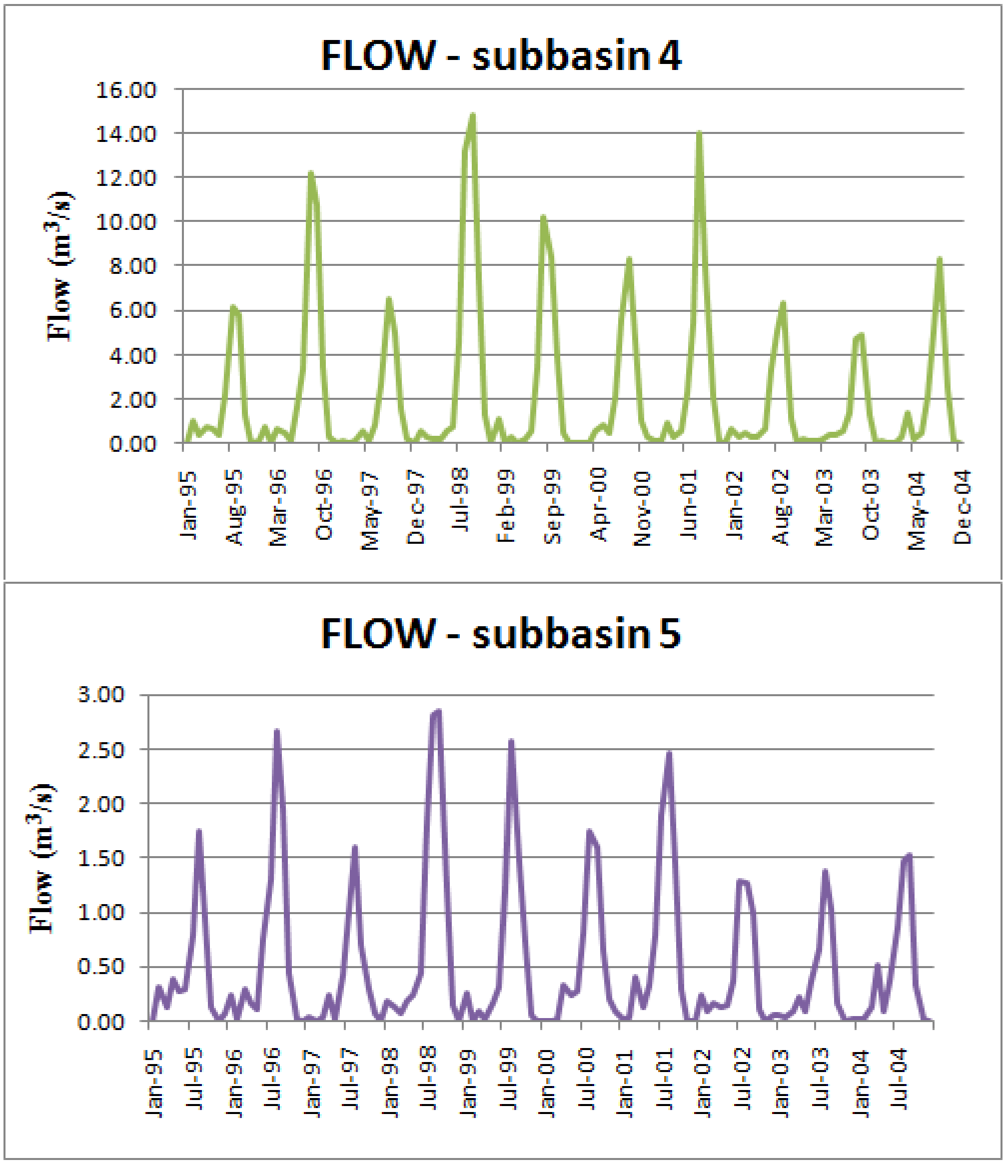


Figure 20. Monthly SWAT simulation result at subbasins 4 and 5

Table 5. Summary of mean flow (m^3/s) at the subbasins

Subbasin	Mean daily flow (m^3/s)	Mean monthly flow (m^3/s)	Mean annual flow (m^3/s)
2	1.358	1.351	1.358
3	0.564	0.561	0.564
4	2.109	2.099	2.109
5	0.525	0.522	0.525

4.2. Questionnaire Analysis

The survey form was used to identify information which includes the number of Holetta River consumers, major crops grown by irrigation, the total area coverage, conflict between users and water management system in the catchment. Over all 100 respondent were interviewed, 60 of them were from farmers, 10 from Holetta Agricultural Research Centre, 10 from Tsedey farm , 10 from *Kebele* and 10 from Agricultural office .Then, the questionnaire was analyzed with Excel software and simple statistical description method was used. The majority of downstream users of Holetta River were from four *Kebele*s. These are *Medi Gudina, Dewana Lafto, Tulu Wato Dalecha* and *Hamus Gebeya*. For detail questionnaire survey only one *kebele* was selected which is *Medi Gudina*. Tsedey Farm is located at subbasin 2 and 3; HARC and *Medi Gudina kebele* located at subbasin 2 whereas *Dewana Lafto*, T*ulu Wato Dalecha* and *Hamus Gebeya* located at subbasin 3, 4 and 5(see figure 21).

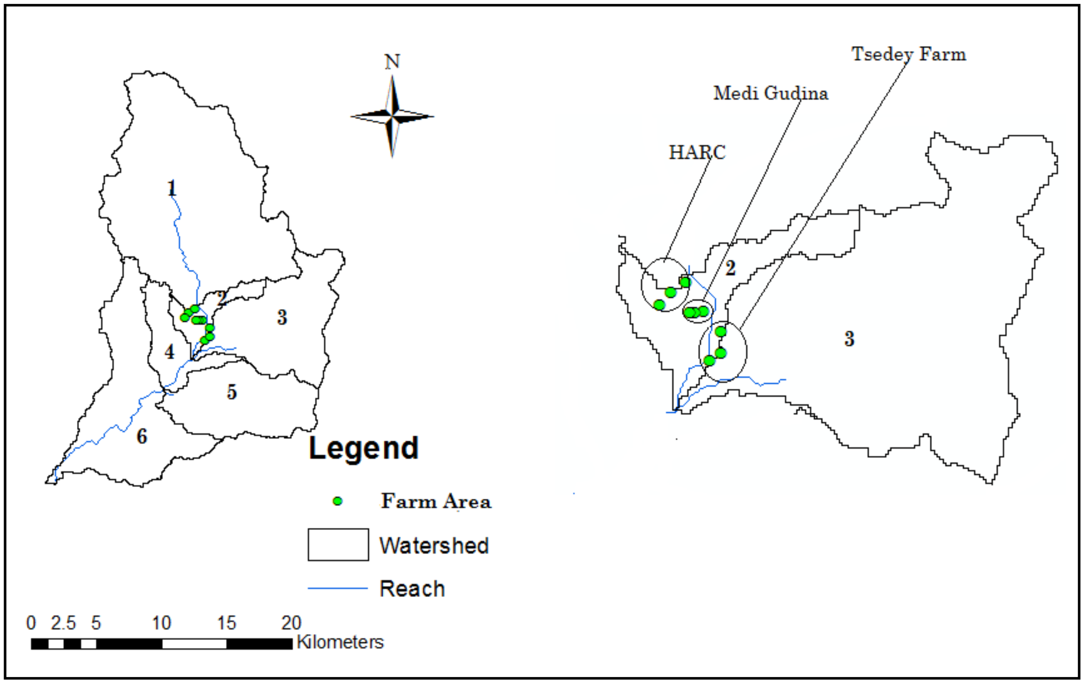


Figure 21. Location of users of Holetta River

According to the collected data, majority of users have been using the river more than ten years and 51.67% of the users use the river for 30- 50 years. All the farmers respondent reply that they use the Holetta River for irrigation, livestock and human consumption but the main use of the river is for irrigation. Holetta Agricultural Research Center and Tsedey Farm use the river only for irrigation purpose.

In the survey, it was planned to determine the major crops grown in the study area. The major crops grown are potato, tomato, cabbage, carrot, onion, and lettuce. The farmers respond showed that the three major crops are potato with 96.67%, cabbage with 91.67% and tomato with 56.67%. They use furrow irrigation to grow these crops during the off-season mainly from January to June. The area of irrigated land for each crops were about 0.25 hectares. The survey also indicated that the major crops for HARC are potato, cabbage, barely, and apple. Potato, tomato, and cabbage are the major crops for Tsedey farm. Figure 22 explained the major crops for the three users of Holetta River.

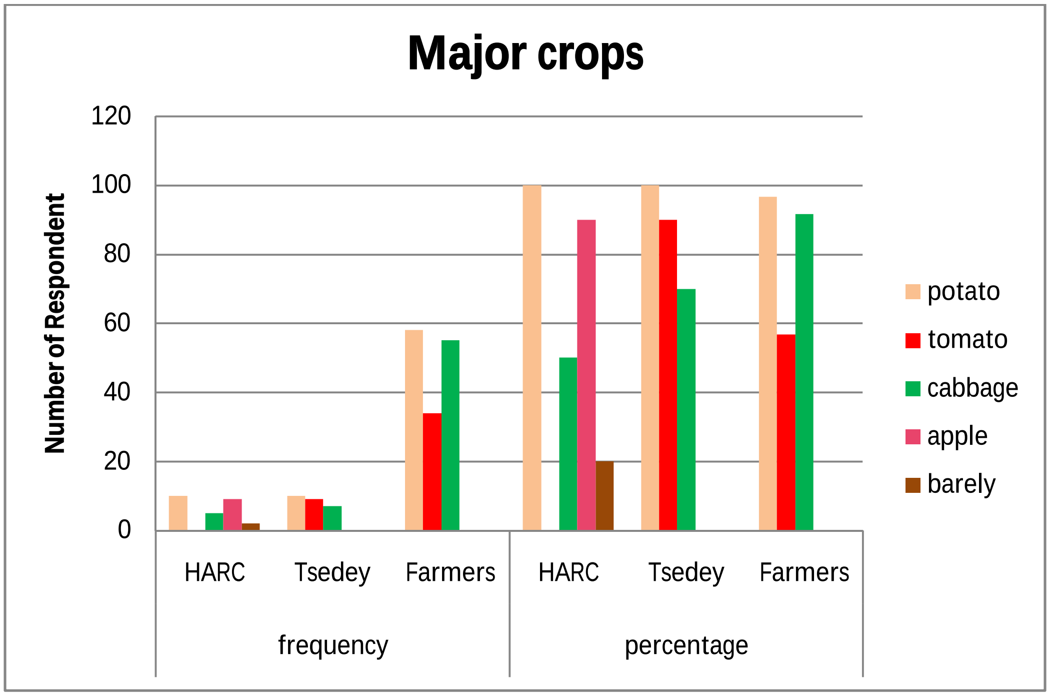


Figure 22. Summary of major crops for the three users of Holetta River

All the farmers respond that the only source of water for irrigation is the river and there is no alternative means, but there are springs and wells for human consumption. About 63.33 % of the farmers agreed that there is conflict between the users. On contrary, 36.67 % of the farmers replied that there is no conflict. HARC and Tsedey Farm respondents believed that there is a conflict between users of Holetta River. They also mentioned that this conflict mostly occurs at the turning points and during allocation of the water. Even though it is not well established, there is an irrigation committee, which settles these conflicts.

During the survey, attempts were made to collect information about the number of households and livestock that use Holetta River at subbasin 2. According to the survey from Agricultural office and *kebele*, about 371 households use the river for irrigation purpose and 300 households use for human consumption (figure 23 and figure 24).

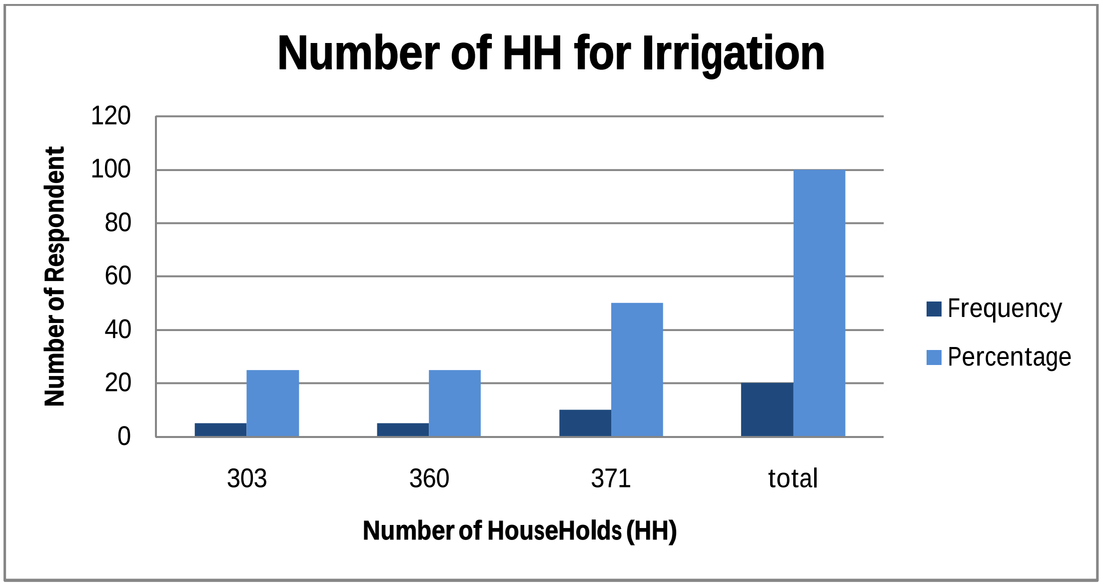


Figure 23. Summary of irrigation users of Holetta River

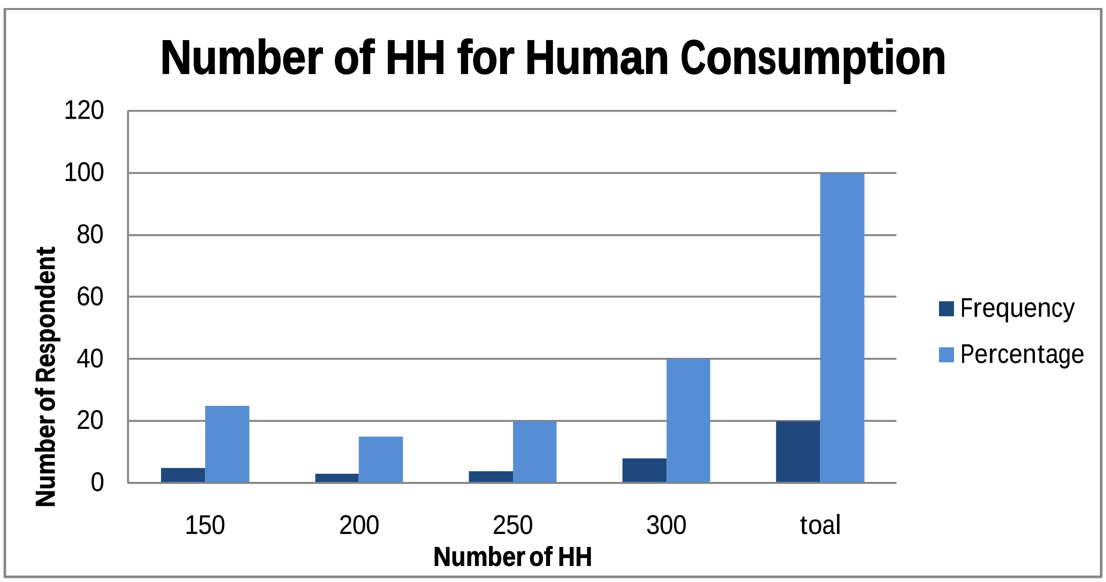


Figure 24. Summary of human consumption users of Holetta River

The collected data indicated that some of the livestock exist in the subbasin 2 were ox, cow, sheep, goat, horse and donkey. According to the survey, the approximate number of livestock summarized in table 6.

Table 6. Summary of livestock which users Holetta River

Type of livestock	Number
Ox	154
Cow	250
Sheep	500
Goat	200
Horse	33
Donkey	34

4.3. CROPWAT Model Analysis

Reference evapotranspiration, effective rainfall, crop pattern data, and soil data were used CropWat model analysis. The major crops identified from the survey analysis were used in the calculation of crop water requirement.

4.3.1. Reference Evapotranspiration

First monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data (1994-2004) was fitted in CropWat model. Then, the model calculated crop evapotranspiration values based on the FAO Penman-Montieth equation and figure 25 showed the calculated reference evapotranspiration. The detail description of reference evapotranspiration is attached in appendix I -8.

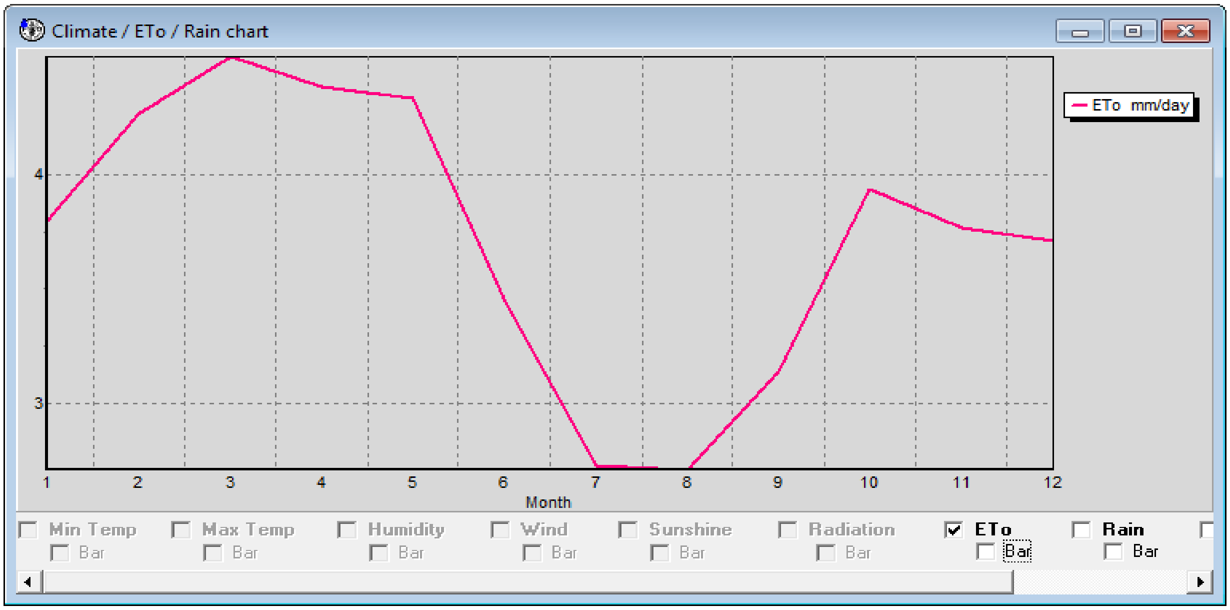


Figure 25. Reference Evapotranspiration (ETo) used by CropWat8.0

4.3.2. Effective Rainfall

To account for the losses due to runoff or percolation, a choice was made from the four methods given in CropWat 8.0 (Fixed percentage, dependable rain empirical formula, USDA Soil Conservation Service). Rainfall data from 1994-2004 was taken to calculate effective rainfall and dependable rain empirical formula has been used (figure 26).

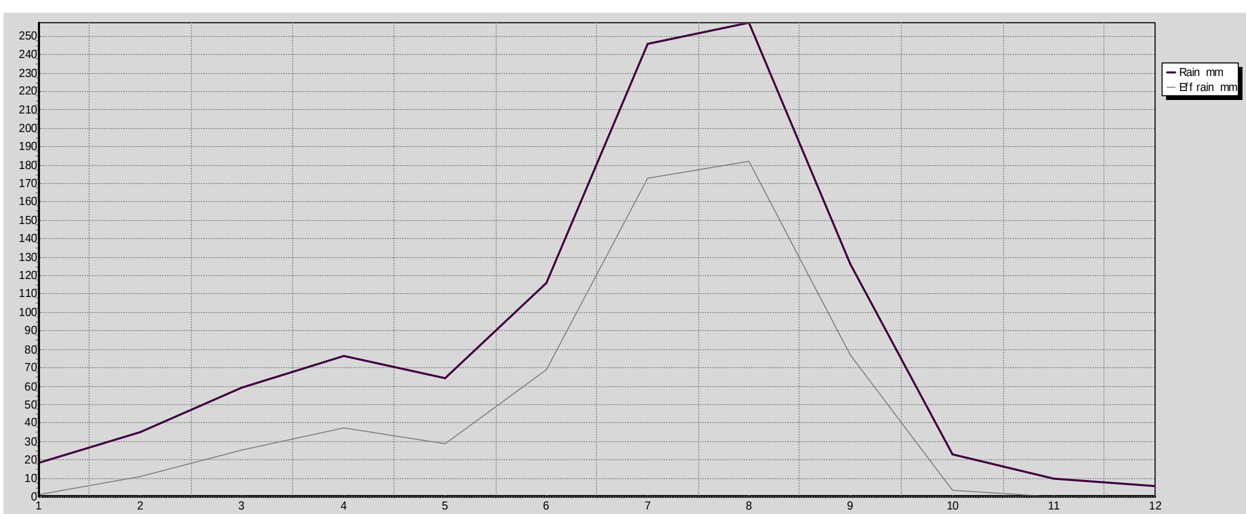


Figure 26. Rainfall Vs Effective rain calculated by CropWat 8.0

4.3.3. Crop and Soil Data

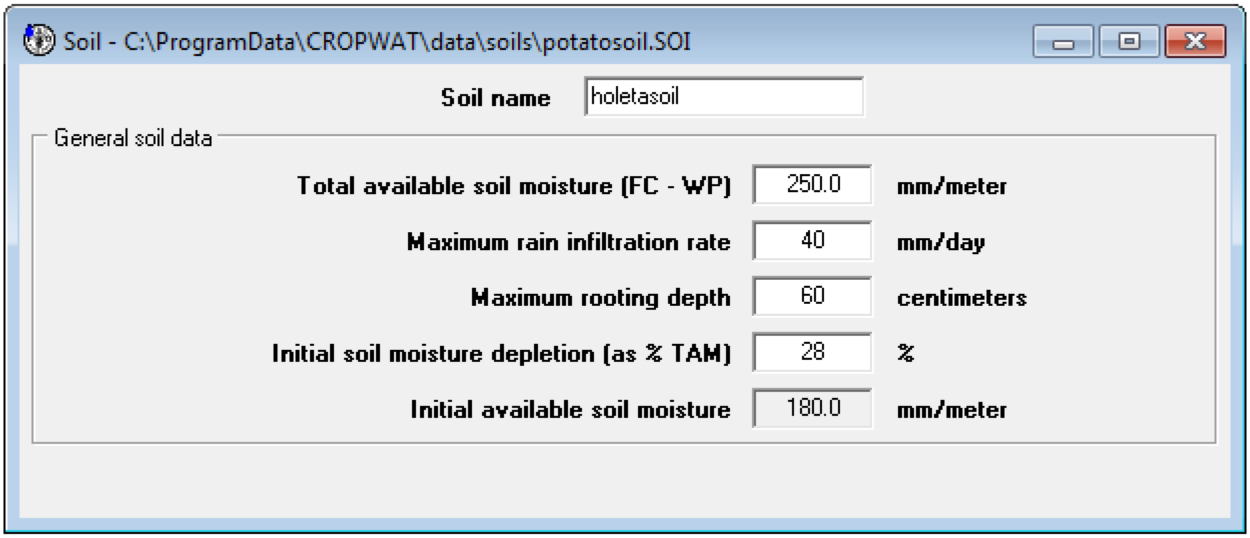
Crop water requirement and irrigation requirements were calculated only for the major crops in the study area. The major crops are Potato, Cabbage, Apple and Barely for Holetta Agricultural Research Canter; Potato, Cabbage and tomato for Tsedey farm and farmers. The development stages, Kc factor and root depth of each crop was taken from FAO-24 (Doorenbos and Pruitt, 1992) and FAO-33 (Doorenbos and Kassam, 1986). The summary of crop data used in the model was shown in table 7.

Table 7. Summary of crop and soil data for the major crops at Holetta watershed

No	Crop	Planting Date	Total growing period/ days	Kc				Soil water depletion	root depth (cm)
				Initial	Dev't	Mid stage	Late stage		
1	Potato	15/01	110	0.5		1.15	0.75	50%	60
				25	30	35	20		
2	Cabbage	15/01	105	0.7		1.05	0.95	35%	50
				25	35	30	15		
3	Tomato	15/01	145	0.6		1.15	0.8	40%	100
				30	40	45	30		
4	Apple	15/06	365	0.6		0.95	0.75	50%	150
				30	120	170	45		
5	Barely	15/01	120	0.3		1.15	0.25	100% critical depletion	110
				15	25	50	30		

The soil data required by the CropWat model includes, total available soil moisture, maximum rain infiltration rate, maximum root depth, initial soil moisture depletion and initial available soil moisture. The soil data used in the model was the same for all crops except the maximum root depth. The summary of soil data was shown in table 8.

Table 8. Summary of soil data used in CropWat model



4.3.4. Crop Water Requirement and Irrigation Requirement

In order to estimate the water demand for agricultural use/ irrigation for each crop, evapotranspiration, effective rainfall, data of crop type, area coverage and soil data were fitted in CropWat model. The water demand of irrigation is assumed to occur during the growing season. All calculation procedures as used in CropWat 8.0 are based on the FAO-56 guidelines (Allen et al., 1998). The crop water requirement (CWR) and irrigation requirement (IR) of each crop for the entire growing period was summarized below. Table 9 described the total crop water requirement and irrigation requirement for each crop and table 10 showed the irrigation requirement for a month of January to May.

Table 9. Estimation of total crop water requirement and irrigation requirement

crop	CWR (mm)	Effective rain(mm)	Net IR (mm)
potato	440.1	78.3	360.9
cabbage	425.4	73.5	350.6
tomato	600.8	116.8	480.8
apple	668.7	103.6	565.0
barely	466.2	86.7	378.7

Table 10. Estimation of irrigation water requirement (mm/month) for each crop

Month	Potato	cabbage	tomato	barely	apple
January	32	45.3	38.7	19.1	125
February	69.7	82.50	68	95	114.5
March	138.1	122.70	122.5	144.3	121.7
April	110.8	100.30	122.7	104.9	102.5
May	10.2		118.3	15.4	101.3

4.4. Water Demand Analysis

The result of CropWat model and survey analysis was used as an input for the calculation of water demand. The CropWat calculated the irrigation water requirement of the major crops in the area. The survey analysis indicated the area coverage and number of users of Holetta River.

Based on the result of CropWat model and survey analysis, the irrigation water demand for the three major users of Holetta River was calculated. The period was taken only for the dry seasons, from January to May. Table 11 to table 13 showed the monthly irrigation requirement of major crops in million cubic meters (MCM) for HARC, Tsedey Farm, and farmers respectively.

- **For HARC**

Table 11. Monthly irrigation requirement (MCM) for each major crops of HARC

Crop Type	Area(ha)	total IR(MCM)				
		January	**February**	**March**	**April**	**May**
potato	6	0.00192	0.004182	0.008286	0.006648	0.000612
cabbage	3	0.001359	0.002475	0.003681	0.003009	
apple	6	0.0075	0.00687	0.007302	0.00615	0.006078
barely	5	0.000955	0.00475	0.007215	0.005245	0.00077
total	**20**	**0.01173**	**0.01828**	**0.02648**	**0.02105**	**0.00746**

- **For Tsedey Farm**

Table 12. Monthly irrigation requirement (MCM) for each major crops of Tsedey Farm

Crop type	Area(ha)	Total IR(MCM)				
		January	**February**	**March**	**April**	**May**
potato	7	0.00224	0.004879	0.009667	0.007756	0.000714
cabbage	5	0.002265	0.004125	0.006135	0.005015	
tomato	6	0.002322	0.00408	0.00735	0.007362	0.007098
total	**18**	**0.006827**	**0.013084**	**0.023152**	**0.020133**	**0.007812**

- **For farmers from *Medi Gudina Kebele***

Table 13. Monthly irrigation requirement (MCM) for each major crop of farmers

Crop type	Area (ha)	Total IR(MCM)				
		January	**February**	**March**	**April**	**May**
potato	92.75	0.02968	0.064647	0.128088	0.102767	0.009461
cabbage	92.75	0.042016	0.076519	0.113804	0.093028	
tomato	92.75	0.035894	0.06307	0.113619	0.113804	0.109723
total	278.25	**0.10759**	**0.20424**	**0.35551**	**0.3096**	**0.11918**

The three other *kebele* farmers only differ based on the area of irrigated land. *Dewana Lafto Kebele* has 94 ha of irrigated land, *Tulu Wato Dalecha* has 150 ha and *Hamus Gebeya* has 218 ha. Therefore, the irrigation requirement for these kebele's was summarized in table 14.

Table 14. Total monthly irrigation requirement (MCM) for the four kebele farmers

Kebele	Total IR (MCM)				
	January	**February**	**March**	**April**	**May**
Medi Gudina	0.10759	0.204236	0.355511	0.3096	0.119184
Dewana Lafto	0.03633	0.068987	0.120127	0.10459	0.040182
Tulu wato Dalecha	0.058	0.1101	0.19165	0.1669	0.06425
Hamus Gebeya	0.084293	0.160026	0.278545	0.242533	0.093188
Total	**0.286213**	**0.543348**	**0.945832**	**0.823622**	**0.316804**

Then, the total monthly irrigation requirement (IR) for all the three major users was added and summarized (see table 15). Based on the analysis, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865, and 0.332 MCM for January, February, March, April, and May respectively.

Table 15. Total monthly irrigation requirement (MCM) for all major users of Holetta River

Total IR for the three (MCM)				
January	**February**	**March**	**April**	**May**
0.304774	0.5747088	0.99546775	0.8648068	0.33207550

Tsedey Farm and HARC use the river only for irrigation purpose but the farmers' further use the river for human consumption and livestock. Therefore, the water demand for human consumption and livestock was calculated for the farmers.

Water demand for livestock and human consumption was estimated by multiplying the number of user/consumer by standard consumption

$$CR = \frac{N * q * t}{1000} \quad \text{................. equation 12}$$

Where, CR is human and livestock consumptive requirement (m^3);

N is the consumer size (number); q is the consumptive rate (lt/day) and,

t is the number of days

Based on the above formula, the monthly human consumption at *Medi Gudina Kebele* was calculated and showed in table 16 to table 18. The monthly livestock consumption at the same *Kebele* was calculated and showed in table 19 to table 21. The total human consumptive requirement was 0.00279, 0.0025, 0.00279, 0.0027, and 0.0279 MCM for January, February, March, April, and May respectively. According to the result, total livestock consumptive requirement was 0.0059, 0.0053, 0.0059, 0.0057, and 0.0059 MCM for January, February, March, April and May respectively.

- ***For human consumption at Medi Gudina Kebele***

Table 16. Human consumptive requirement for January, March and May

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
no of HH	300	31	1500	15	**697.5**	**0.0006975**
no of members	5					
lts/day	15					

Table 17. Human consumptive requirement for February

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
no of HH	300	28	1500	15	**630.0**	**0.00063**
no of members	5					
lts/day	15					

Table 18. Human consumptive requirement for April

Description	Quantity	t (days)	N (number)	q (lt/day)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
no of HH	300	30	1500	15	**675.0**	**0.000675**
no of members	5					
lts/day	15					

➢ ***For livestock consumption at Medi Gudina Kebele***

Table 19. Livestock consumptive requirement for January, March and May

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	31	214.83	
Cow	250	130	31	1007.5	
Sheep	500	7.5	31	116.25	
Goat	200	7.5	31	46.5	
Horse	33	45	31	46.035	
Donkey	34	45	31	47.43	
total				**1478.545**	**0.001478545**

Table 20. Livestock consumptive requirement for February

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	28	194.04	
Cow	250	130	28	910	
Sheep	500	7.5	28	105	
Goat	200	7.5	28	42	
Horse	33	45	28	41.58	
Donkey	34	45	28	42.84	
total				**1335.46**	**0.001335460**

Table 21. Livestock consumptive requirement for April

Type of livestock	N (number)	q (lts/head/day)	t (days)	consumptive requirement CR(m3) = N*q*t/1000	consumptive requirement CR (MCM)
Ox	154	45	30	207.9	
Cow	250	130	30	975	
Sheep	500	7.5	30	112.5	
Goat	200	7.5	30	45	
Horse	33	45	30	44.55	
Donkey	34	45	30	45.9	
total				**1430.85**	**0.001430850**

Monthly value of irrigation requirement, human consumptive requirement and livestock consumptive requirement was added in order to get the overall water demand of the three major users of Holetta River. Finally, the total water demand requirement of each month for all the three users was summarized in table 22.

Table 22. Overall summary of total water demand and supply at Holetta watershed

	January	**February**	**March**	**April**	**May**
Total IR for the three(MCM)	0.30477425	0.5747088	0.99546775	0.86480675	0.3320755
Human consumptive requirement CR(MCM)	0.0027900	0.002520	0.0027900	0.0027	0.0027900
Livestock consumptive requirement CR(MCM)	0.00591418	0.00534184	0.00591418	0.0057234	0.00591418
Total (MCM)	**0.313**	**0.583**	**1.004**	**0.873**	**0.341**

The total water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM for January, February, March, April, and May respectively. The available river flow from January to May was taken from the result of SWAT simulation at subbasins 2, 3 , 4 and 5. The flow taken is the in flow (m^3/s) at each subbasins. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April, and May respectively. From the five months, the demand and the supply showed a gap during February, March and April. This indicated that there is shortage of supply during these months with 0.59 MCM (table 23).

Table 23. The summary of available flow and water demand in the study area

	January	**February**	**March**	**April**	**May**
Flow (MCM)	0.749	0.419	0.829	0.623	0.471
Total Water demand (MCM)	0.313	0.583	1.004	0.873	0.341
Difference	0.436	-0.164	-0.175	-0.25	0.13

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The study was conducted to estimate runoff at Holetta catchment and to model rainfall runoff relation in the area. The study also analyzed the water demand and the gap between the river water supply and demand.

The rainfall runoff process of the catchment was modeled by SWAT. According to SWAT classification, the watershed was divided in to 6 subbasins and 33 hydrological response units (HRUs). Only subbasin one was gauged which is found in the upper part of the area. Therefore, sensitivity analysis, calibration, and validation of the model were performed at this subbasin and then the calibrated model was used to estimate runoff for the ungauged part of the catchment. The result of sensitive analysis showed that 26 parameters were sensitive; out of 26, eight of them are the most sensitive ones. These parameters were used for model calibration.

The performance of the model was evaluated by statistical and graphical method. The statistical methods used were coefficient of determination (R^2), Nash-Sutcliffe Efficiency Coefficient (NSE) and Index of Volumetric Fit (IVF). The result showed that R^2, NSE, and IVF were 0.85, 0.84 and 102.8 respectively for monthly calibration and 0.73, 0.67 and 108.9 respectively for monthly validation. Therefore, this indicated that SWAT model performed well for simulation of the hydrology of the watershed.

After modeling the rainfall runoff relation and studying availability of water at the Holetta River, the water demand in the area was assessed. CropWat model was used to calculate the irrigation water requirement for major crops and the area coverage was determined from questionnaire. The study identified the three major users of Holetta River that is Holetta Research Center, Tsedey Farm and village farmers. Based on the analysis, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865, and 0.332 MCM for January, February, March, April, and May respectively. In addition to irrigation, the farmers use the river for livestock and human consumption. Therefore, the study also included the water demand for livestock and human's use. According to the result, livestock consumptive requirement was 0.0059, 0.0053, 0.0059, 0.0057 and 0.0059 MCM for January, February, March, April and May respectively. The human consumptive requirement was 0.00279, 0.0025, 0.00279, 0.0027, and 0.00279 MCM for January, February, March, April, and May respectively. Overall, the water demand in the area was 0.313, 0.583, 1.004, 0.873, and 0.341 for January, February, March, April, and May respectively. The available river flow from January to May was taken from the result of SWAT simulation at subbasins 2.3.4 and 5. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April, and May respectively. From the five months, the demand and the supply showed a gap during February, March and April. Therefore, it is possible to conclude that there is shortage of river water supply during February, March, and April comparing the water demand with the available river flow at the same months. The total shortage of supply during these months was 0.59MCM.

In addition to shortage of water supply, the analysis of the questionnaire indicated that there is a conflict between users at diversion points and during water allocation. There is an irrigation committee to settle this conflict but the conflict become more and more concerning issue in the area.

5.2 Recommendations

Soil and Water Assessment Tool (SWAT) model was used to estimate runoff at Holetta catchment and the performance was evaluated based on statistical and graphic methods. Even though the model performance was good, the accuracy was highly dependent on quality of data. The Holetta catchment has only one gauging station and the total area is 403.47 km^2. Therefore, in order to improve data quality, it is better to have at least two gauging station in the catchment. In addition to this, in poorly gauged areas, use of satellite data is very advantageous.

The SWAT model perform well for simulation of the hydrology of the watershed, therefore it can be used for further study to estimate sediment yield in the area and to evaluate the effect of different catchment changes on the river.

The water demand analysis showed that there was shortage of river water supply for February, March, and April. During these months, there was also conflict between users at diversion and water allocation. Therefore, in order to solve water shortage, alternative source of water supply like ground water and water harvesting technologies should be studied and integrated water management system should be implemented. In addition to this, to improve the efficiency of irrigation water, different irrigation methods like drip irrigation should be improved in the area.

In order to minimize the conflict, well established irrigation committee including all the users with a clear guide and management rules is required and water allocation system should be developed. In addition to this, water management and irrigation training should be improved in the area in order to establish river management system and to properly use the scarce water resource.

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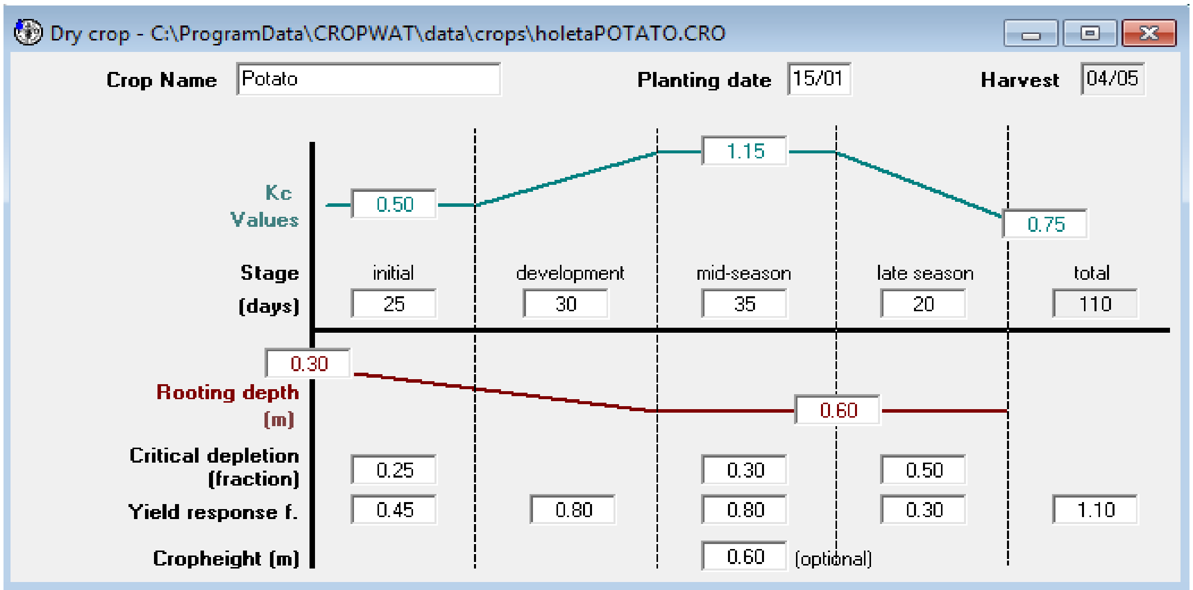
APPENDICES

Appendix I - 1. Effective rainfall for Holetta watershed

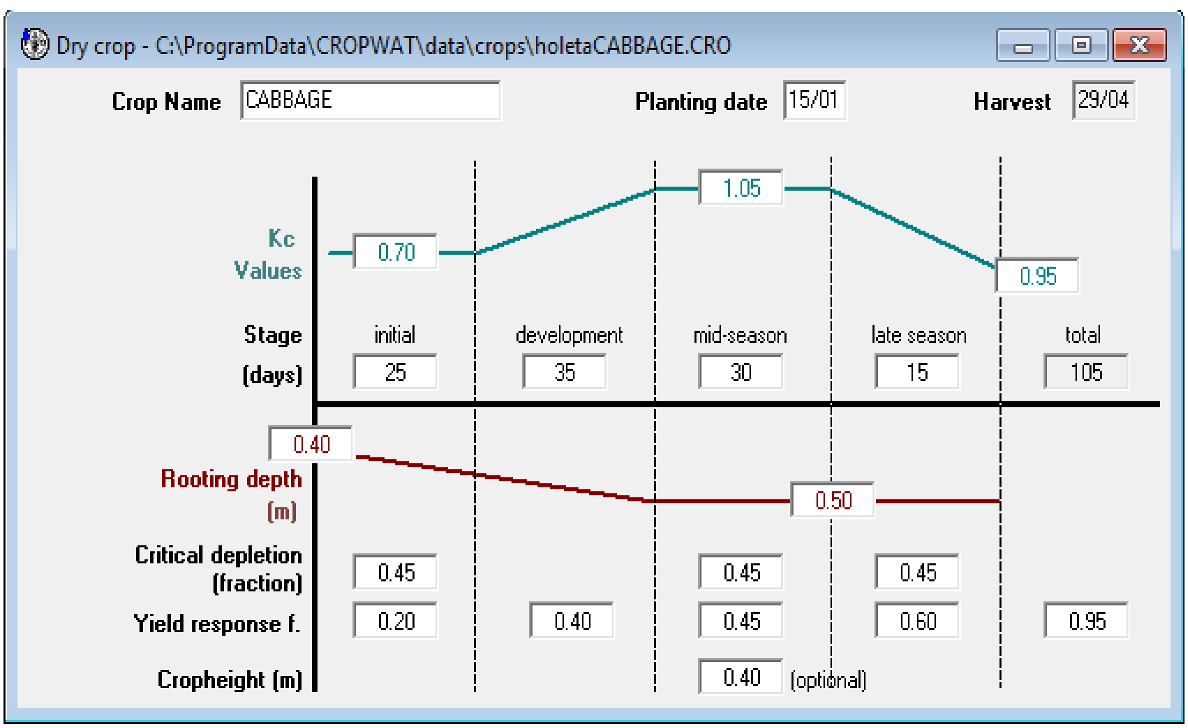
Monthly rain - C:\ProgramData\CROPWAT\data\rain\holetaAverage.CRM

Station: holeta   Eff. rain method: FAO/AGLW formula

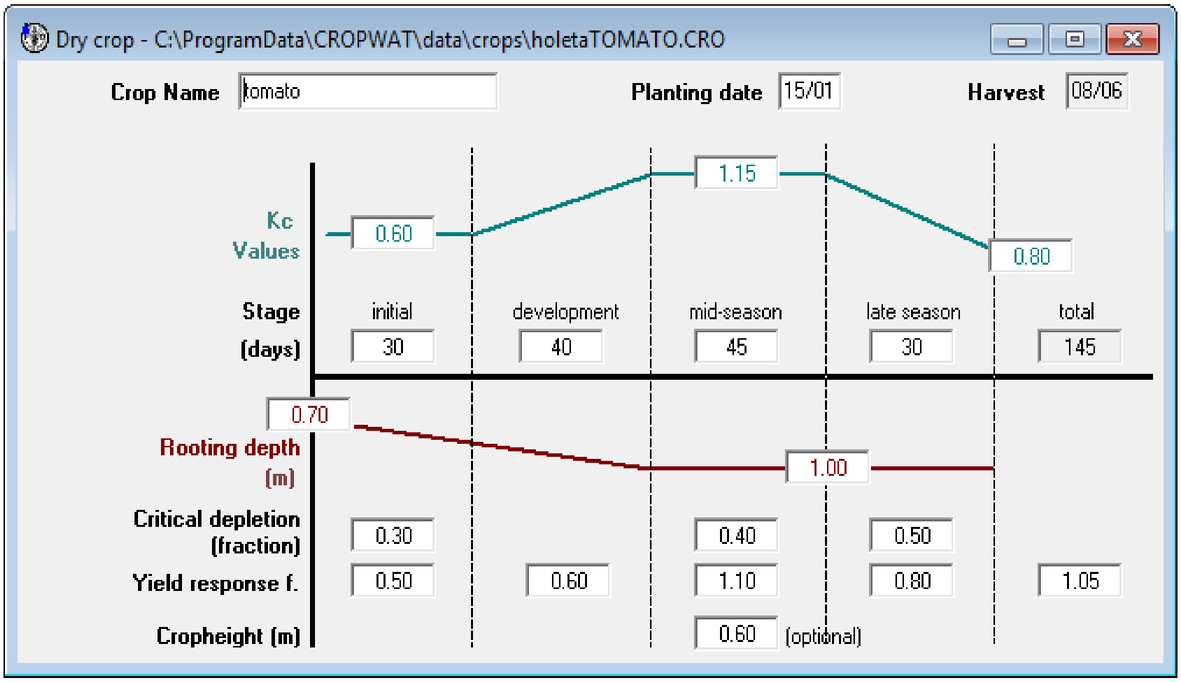
	Rain	Eff rain
	mm	mm
January	18.4	1.0
February	35.0	11.0
March	58.9	25.3
April	76.5	37.2
May	64.5	28.7
June	115.9	68.7
July	245.8	172.6
August	257.3	181.8
September	126.3	77.0
October	22.8	3.7
November	9.7	0.0
December	5.6	0.0
Total	**1036.7**	**607.2**



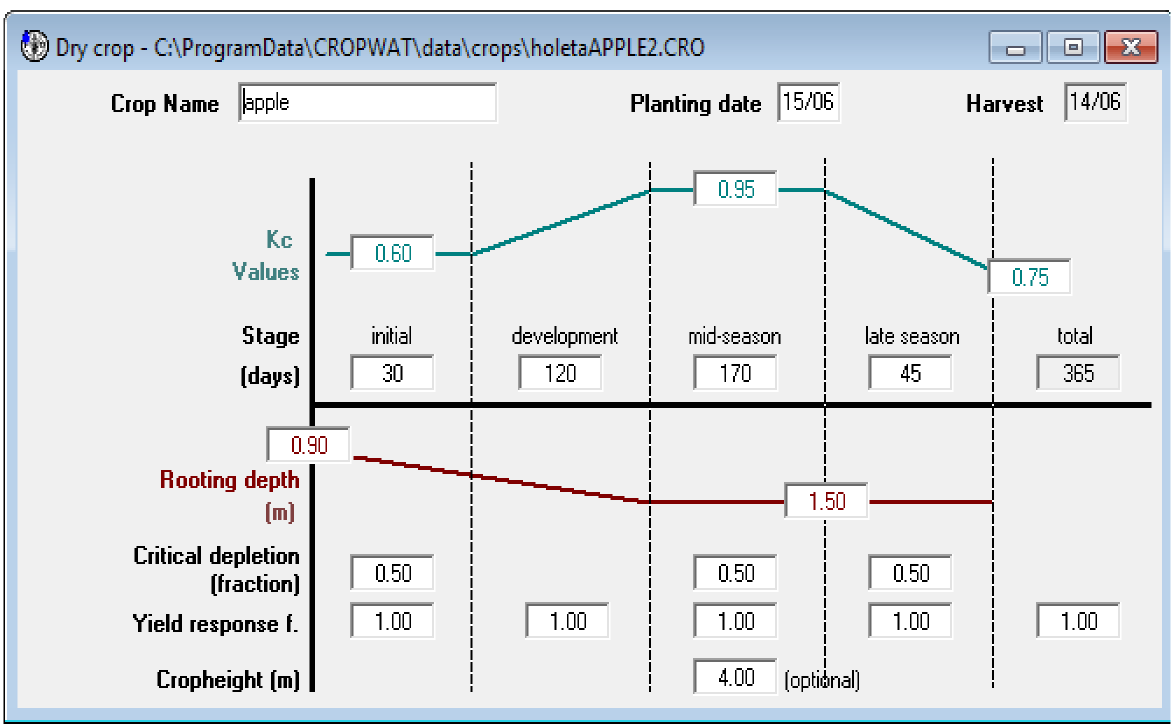
Appendix II - 1. Summary of crop data for Potato



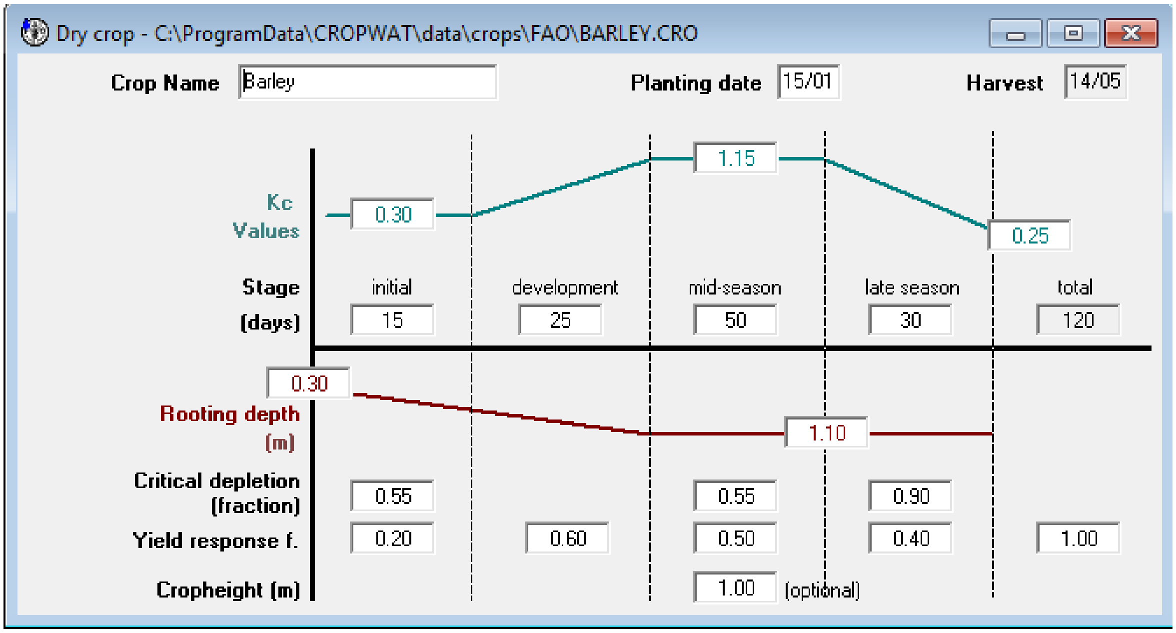
Appendix II - 2. Summary of crop data for Cabbage



Appendix II - 3. Summary of crop data for Tomato

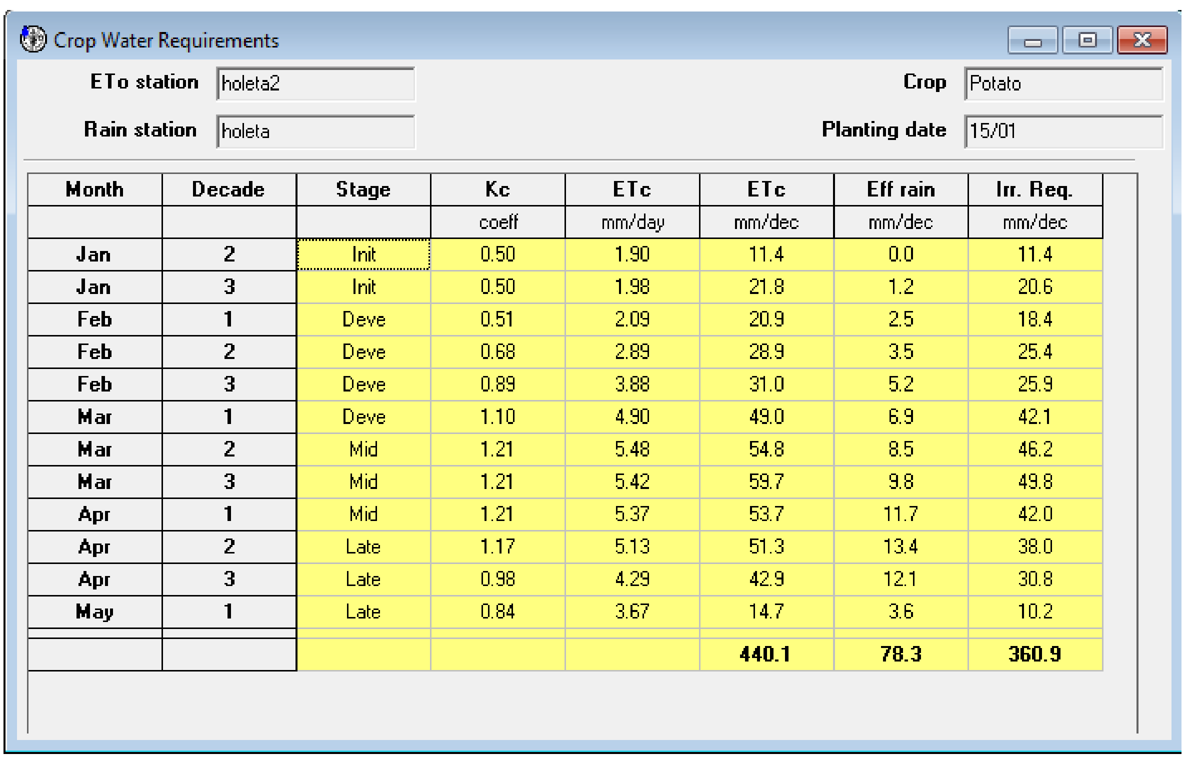


Appendix II - 4. Summary of crop data for Apple



Appendix II - 5. Summary of crop data for Barely

Appendix I - 2. Summary of crop water requirement for Potato



Crop Water Requirements

ETo station: holeta2 | Crop: Potato

Rain station: holeta | Planting date: 15/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.50	1.90	11.4	0.0	11.4
Jan	3	Init	0.50	1.98	21.8	1.2	20.6
Feb	1	Deve	0.51	2.09	20.9	2.5	18.4
Feb	2	Deve	0.68	2.89	28.9	3.5	25.4
Feb	3	Deve	0.89	3.88	31.0	5.2	25.9
Mar	1	Deve	1.10	4.90	49.0	6.9	42.1
Mar	2	Mid	1.21	5.48	54.8	8.5	46.2
Mar	3	Mid	1.21	5.42	59.7	9.8	49.8
Apr	1	Mid	1.21	5.37	53.7	11.7	42.0
Apr	2	Late	1.17	5.13	51.3	13.4	38.0
Apr	3	Late	0.98	4.29	42.9	12.1	30.8
May	1	Late	0.84	3.67	14.7	3.6	10.2
					440.1	**78.3**	**360.9**

Appendix I - 3. Summary of crop water requirement for Cabbage

Crop Water Requirements

ETo station: holeta2 | Crop: CABBAGE

Rain station: holeta | Planting date: 15/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.70	2.66	16.0	0.0	16.0
Jan	3	Init	0.70	2.77	30.5	1.2	29.3
Feb	1	Deve	0.70	2.89	28.9	2.5	26.5
Feb	2	Deve	0.79	3.36	33.6	3.5	30.1
Feb	3	Deve	0.89	3.88	31.0	5.2	25.9
Mar	1	Deve	0.99	4.41	44.1	6.9	37.2
Mar	2	Mid	1.09	4.94	49.4	8.5	40.9
Mar	3	Mid	1.10	4.95	54.4	9.8	44.6
Apr	1	Mid	1.10	4.90	49.0	11.7	37.3
Apr	2	Late	1.09	4.79	47.9	13.4	34.5
Apr	3	Late	1.03	4.51	40.6	10.9	28.5
					425.4	**73.5**	**350.6**

Appendix I - 4. Summary of crop water requirement for Tomato

Crop Water Requirements

ETo station: holeta2 | Crop: tomato

Rain station: holeta | Planting date: 15/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.60	2.28	13.7	0.0	13.7
Jan	3	Init	0.60	2.37	26.1	1.2	25.0
Feb	1	Init	0.60	2.47	24.7	2.5	22.2
Feb	2	Deve	0.64	2.74	27.4	3.5	23.9
Feb	3	Deve	0.78	3.38	27.0	5.2	21.9
Mar	1	Deve	0.91	4.05	40.5	6.9	33.6
Mar	2	Deve	1.07	4.82	48.2	8.5	39.7
Mar	3	Mid	1.20	5.36	59.0	9.8	49.2
Apr	1	Mid	1.21	5.37	53.7	11.7	42.0
Apr	2	Mid	1.21	5.32	53.2	13.4	39.8
Apr	3	Mid	1.21	5.30	53.0	12.1	40.9
May	1	Late	1.21	5.27	52.7	9.0	43.7
May	2	Late	1.14	4.93	49.3	7.3	42.0
May	3	Late	1.01	4.10	45.1	12.5	32.6
Jun	1	Late	0.90	3.39	27.1	13.2	10.6
					600.8	**116.8**	**480.8**

Appendix I - 5. Summary of crop water requirement for Barely

Crop Water Requirements

ETo station holeta2 **Crop** Barley

Rain station holeta **Planting date** 15/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.30	1.14	6.8	0.0	6.8
Jan	3	Deve	0.31	1.23	13.5	1.2	12.3
Feb	1	Deve	0.58	2.37	23.7	2.5	21.3
Feb	2	Deve	0.95	4.04	40.4	3.5	36.8
Feb	3	Mid	1.21	5.26	42.1	5.2	36.9
Mar	1	Mid	1.22	5.42	54.2	6.9	47.3
Mar	2	Mid	1.22	5.52	55.2	8.5	46.7
Mar	3	Mid	1.22	5.47	60.2	9.8	50.3
Apr	1	Mid	1.22	5.42	54.2	11.7	42.5
Apr	2	Late	1.15	5.07	50.7	13.4	37.3
Apr	3	Late	0.85	3.71	37.1	12.1	25.1
May	1	Late	0.53	2.29	22.9	9.0	13.9
May	2	Late	0.30	1.30	5.2	2.9	1.5
					466.2	**86.7**	**378.7**

Appendix I - 6. Monthly rainfalls in Holetta watershed (1994 - 2004)

Year	Monthly total rainfall (mm)											
	Jan	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1994	0.0	2.3	86.7	45.9	29.8	107.3	216.4	209.3	149.7	0.0	36.6	0.0
1995	0.0	84.6	41.9	122.8	81.3	86.4	191.9	262.7	82.1	3.9	0.0	0.0
1996	62.6	8.5	96.1	58.4	45.4	192.6	249.8	236.4	120.7	5.3	1.4	0.0
1997	15.3	0.0	21.1	77.4	13.5	131.0	233.5	206.6	42.5	53.5	23.6	0.0
1998	54.6	42.3	25.7	65.7	80.4	141.5	341.6	238.1	168.3	67.4	0.8	0.0
1999	77.3	4.6	34.0	16.6	54.6	98.9	272.8	307.7	88.9	65.4	0.0	0.0
2000	0.0	0.0	12.5	123.8	50.8	89.8	187.1	260.6	120.5	9.5	38.9	0.0
2001	7.9	10.6	130.7	48.6	101.2	176.5	301.6	161.2	103.2	24.2	0.0	0.0
2002	72.6	25.7	56.9	38.1	49.4	123.2	273.1	194.0	77.4	0.0	0.0	0.0
2003	17.5	11.3	33.3	84.2	13.6	117.1	194.0	237.2	107.4	10.0	0.0	0.0
2004	12.7	0.8	42.5	155.1	27.0	121.4	204.0	226.6	119.7	3.6	0.7	0.0
Average	29.1	17.3	52.9	76.1	49.7	126.0	242.3	230.9	107.3	22.1	9.3	0.0

Appendix I - 7. Yearly evapotranspiration calculation for Holetta catchment (1994 - 2004)

	1994											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	24.1	25.1	24.4	24.1	25.1	21.4	19	19.3	20.6	22.4	22.4	23.1
T min.(^{o}C)	1.6	3.9	8	7.9	7.4	8.1	9.9	9.1	6.6	2.5	2.7	0.5
RH (%)	39	41	54	57	49	74	82	83	73	50	51	44
U2 (km/hr)	4.24	4.73	4.95	5.15	5.38	3.29	2.97	2.18	2.97	4.21	4.17	4.47
n (hrs)	9.8	9.3	7.21	6.47	7.43	4.33	2.47	2.86	5.46	8.81	8.73	9.83
Ep(mm/day)	10.71	11.25	10.66	8.94	10.7	5.63	4.06	4.61	7.44	10.87	9.02	10.05
ETo (mm/day)	3.86	4.29	4.13	4.05	4.34	2.93	2.41	2.5	3.13	3.9	3.59	3.7

	1995											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	24	24.3	24.5	22.5	24	23.6	19.4	19.7	20.6	22.6	23.4	23.2
T min.(^{o}C)	1.4	5.7	7	9.8	7.6	6.5	8.6	9.1	6.3	3.4	1.7	3.3
RH (%)	44	50	53	66	56	63	80	81	73	52	46	48
U2 (Km/hr)	4.42	4.45	5.26	4.43	4.75	3.83	2.79	2.3	2.46	4.13	3.87	3.82
n (hrs)	10.39	8.62	8	4.86	7.6	6.5	2.68	3.02	4.54	8.2	9.29	8.82
Ep(mm/day)	11.22	10.3	10.7	7.39	9.61	7.9	4.49	4.44	5.37	9.62	10.35	9.37
ETo (mm/day)	3.95	4.03	4.33	3.45	4.09	3.6	2.47	2.56	2.9	3.81	3.7	3.46

Appendix I -7 (continued)

	1996											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	21.8	24.9	24.2	23.2	23.1	20.6	19.9	19.5	20.4	22.3	22.5	22.6
T min.(^{o}C)	5.4	3.6	7.7	7.4	7.3	8.2	8.7	8.3	7.1	3.2	2.5	1.7
RH (%)	58	39	55	56	56	74	79	80	74	48	46	41
U2 (Km/hr)	3.3	3.93	4.21	4.79	4.66	3.25	3.27	3.06	2.95	3.79	3.25	4.12
n (hrs)	7.09	8.77	6.76	6.42	5.98	3.97	3.19	2.84	4.4	8.61	8.45	9.15
Ep(mm/day)	8.19	11.03	9.62	8.83	8.57	5.51	5.55	5.06	5.7	9.77	9.4	10.26
ETo (mm/day)	3.13	4.03	3.91	3.91	3.74	2.83	2.62	2.55	2.92	3.8	3.4	3.53

	1997											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	22.9	24.7	25.6	23.8	25.3	23.4	20.1	20.2	22.1	22.5	22.5	23.6
T min.(^{o}C)	5.6	1.1	7.2	8.1	6.6	8.4	8.3	8.4	7.2	6.3	5.6	2.5
RH (%)	54	34	43	56	41	60	77	76	64	59	59	51
U2 (Km/hr)	4.12	5.74	5.19	5.53	5.79	4.58	2.97	2.67	11.72	3.91	3.86	3.97
n (hrs)	6.72	10.27	8.27	6.02	7.88	5.44	3.03	3.06	6.59	6.68	7.42	9.31
Ep(mm/day)	8.25	13.25	12.06	9.41	11.62	8.35	5.36	5.42	8.91	7.86	8.3	9.21
ETo (mm/day)	3.32	4.63	4.56	4.01	4.6	3.55	2.59	2.69	4.39	3.51	3.35	2.7

Appendix I -7 (continued)

	1998											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.8	24.4	24.8	25.7	24.3	23.2	25.9	19.7	20.6	21.5	22.4	22.4
T min.(^{o}C)	6.4	7.8	8.8	8.9	9.1	7.8	12.2	9.3	7.9	6.6	0.7	-1.5
RH (%)	58	55	54	51	55	66	80	82	75	65	46	38
U2 (Km/hr)	4.2	3.82	5.04	5.01	3.93	3.25	2.28	1.85	1.88	2.65	3.78	4.03
n (hrs)	8.04	7.28	6.83	7.1	6.05	5.45	2.41	2.42	4.02	5.56	9.33	10.02
Ep(mm/day)	8.73	9.37	10.2	10.08	8.6	7.52	4.31	4.28	5.41	6.55	9.21	9.91
ETo (mm/day)	3.55	3.72	4.12	4.35	3.76	3.29	2.72	2.42	2.77	3.06	3.6	3.58

	1999											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.2	25.1	23.9	25.6	24.6	23	19	19.5	20.5	20.6	21.9	22.3
T min.(^{o}C)	1.8	1	6.1	5.7	6.6	6.7	8.4	8.1	6.4	5.8	0.1	0.4
RH (%)	45	33	53	39	49	62	77	78	72	68	43	48
U2(km/hr)	4.01	4.69	4.4	5.45	4.64	3.41	2.98	2.66	2.09	2.14	4	3.9
n (hrs)	8.76	9.91	7.26	8.03	6.64	6.27	2.23	4.18	5	4.75	9.81	9.53
Ep(mm/day)	9.47	13.12	9.29	12.33	11.2	8.11	4.74	5.55	5.93	6.1	9.82	9.53
ETo (mm/day)	3.61	4.37	4.01	4.66	4.03	3.47	2.4	2.8	2.95	2.79	3.67	3.47

Appendix I -7 (continued)

	2000											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.3	24.5	25.7	23.8	29.8	21.1	20.2	19	20.1	21.5	22.2	22.8
T min.(^{o}C)	0.3	0.6	3.5	7.1	6.9	6.5	7.7	7.6	6.6	4.7	2.3	1
RH (%)	44	34	36	53	60	73	77	82	78	65	58	51
U2 (km/hr)	4.07	4.62	5.29	5.16	3.62	2.54	3.13	2.53	2.58	17.74	2.97	3.24
n (hrs)	10.17	10.14	9.62	6	6.51	4.93	2.81	2.29	3.94	6.39	7.96	8.94
Ep(mm/day)	11.26	13.39	14.44	10.28	8.51	6.32	5.12	4.67	5.01	6.84	8.04	8.97
ETo (mm/day)	3.79	4.32	4.8	3.99	4.14	2.94	2.57	2.46	2.75	4.65	3.24	3.3

	2001											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23	24.8	22.4	24.3	30.5	21.2	19.9	19.5	20.6	22.8	23	23.4
T min.(^{o}C)	2.8	2.4	7.4	6.4	7	6.8	8	8.3	5.2	3.5	1.2	3.2
RH (%)	55	48	62	52	65	75	81	83	74	60	50	49
U2 (Km/hr)	2.99	4.09	4.11	4.63	3.13	2.35	2.71	2.33	2.91	3.06	3.74	3.85
n (hrs)	8.22	9.3	5.2	8.17	6.63	4.87	3.34	2.46	5.49	7.14	9.48	9.45
Ep(mm/day)	8.74	11.37	8.29	11.05	8.15	5.96	4.38	4.01	5.76	7.9	10.44	9.97
ETo (mm/day)	3.29	4.09	3.42	4.31	4.07	2.92	2.58	2.44	3.11	3.44	3.65	3.54

Appendix I -7 (continued)

	2002											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.1	24.9	24	25.3	25.7	22.9	21	20.3	21.2	23.3	23.9	23.3
T min.(^{o}C)	4.7	4.7	8.1	8.3	9	8	9.1	8.3	6.8	4.2	2.4	6.5
RH (%)	52	40	48	43	39	54	72	80	68	45	39	54
U2 (Km/hr)	3.41	3.99	3.62	5.39	3.64	3.09	2.84	2.21	2.65	3.23	3.62	3.19
n (hrs)	7.99	9.29	7.03	8.85	7.05	5.8	3.42	2.85	5.79	7.85	10.62	6.94
Ep(mm/day)	8.57	11.77	9.14	12.44	10.93	7.34	5.71	5.54	6.89	10.06	11.05	8.36
ETo (mm/day)	3.38	4.12	3.88	4.75	4.07	3.39	2.75	2.54	3.22	3.67	3.85	3.12

	2003											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.4	25.3	23.5	23.3	23.4	21.6	18.1	18.7	19.8	22	22.4	22.2
T min.(^{o}C)	5	5.8	7	9.4	8.4	7.9	9.3	9	7.8	3.8	2.2	2.2
RH (%)	51	51	53	57	57	68	78	80	73	57	52	51
U2 (Km/hr)	3.24	4.49	4.83	4.17	4.74	2.84	2.24	2.07	2.37	3.62	3.7	3.6
n (hrs)	8.44	8.73	7.17	5.72	7.96	4.31	2.02	1.86	3.34	8.17	8.93	8.66
Ep(mm/day)	8.9	17.01	11.86	9.77	13.06	7.39	5.38	4.05	4.55	9.52	9.66	9.29
ETo (mm/day)	3.42	4.13	4.04	3.71	4.1	2.94	2.27	2.3	2.65	3.65	3.52	3.32

Appendix I -7 (continued)

	2004											
Parameters	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
T max.(^{o} C)	23.5	23.9	24.5	22.2	24.2	21.2	19.4	19.1	19.8	20.9	22.5	23
T min.(^{o}C)	5.3	4.5	6.7	9.6	7	8.1	8.7	8.7	7.7	4.3	2.5	3.7
RH (%)	52	45	51	62	48	63	83	85	82	57	52	54
U2 (Km/hr)	3.06	4.36	4.98	3.41	3.98	2.69	2.25	2.18	2.34	2.7	2.61	3.57
n (hrs)	7.27	8.19	6.73	5.29	7.43	3.59	2.47	2.69	3.84	6.3	8.66	8.31
Ep(mm/day)	8.58	11.56	11.37	7.43	9.31	5.31	3.66	3.63	4.08	7.47	8.72	8.5
ETo (mm/day)	3.25	3.95	4.09	3.38	4	2.82	2.38	2.44	2.68	3.15	3.3	3.32

Appendix I -8. Summary of monthly evapotranspiration for Holetta catchment (1994 - 2004)

Year	Jan	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1994	3.86	4.29	4.13	4.05	4.34	2.93	2.41	2.5	3.13	3.9	3.59	3.7
1995	3.95	4.03	4.33	3.45	4.09	3.6	2.47	2.56	2.9	3.81	3.7	3.46
1996	3.13	4.03	3.91	3.91	3.74	2.83	2.62	2.55	2.92	3.8	3.4	3.53
1997	3.32	4.63	4.56	4.01	4.6	3.55	2.59	2.69	4.39	3.51	3.35	2.7
1998	3.55	3.72	4.12	4.35	3.76	3.29	2.72	2.42	2.77	3.06	3.6	3.58
1999	3.61	4.37	4.01	4.66	4.03	3.47	2.4	2.8	2.95	2.79	3.67	3.47
2000	3.79	4.32	4.8	3.99	4.14	2.94	2.57	2.46	2.75	4.65	3.24	3.3
2001	3.29	4.09	3.42	4.31	4.07	2.92	2.58	2.44	3.11	3.44	3.65	3.54
2002	3.38	4.12	3.88	4.75	4.07	3.39	2.75	2.54	3.22	3.67	3.85	3.12
2003	3.42	4.13	4.04	3.71	4.1	2.94	2.27	2.3	2.65	3.65	3.52	3.32
2004	3.25	3.95	4.09	3.38	4	2.82	2.38	2.44	2.68	3.15	3.3	3.32
Mean	3.54	4.09	4.11	3.98	4	3.16	2.54	2.51	2.96	3.45	3.5	3.34
Eto at 80% prob.	**3.85**	**4.27**	**4.52**	**4.39**	**4.34**	**3.46**	**2.73**	**2.71**	**3.14**	**3.94**	**3.77**	**3.71**

Appendix II - 6. Holetta River diversion points

Appendix II - 7. Irrigated lands in the study area

Appendix I - 9. Survey Form

Dear respondent,

This questionnaire is prepared to gather information about your water use practices and management of Holeta River. The data is intended to develop a mechanism to help improve the sustainability of the water sources and to reduce the conflict between major water users of Holeta River. This information will be confidential and will only be used for research purpose, therefore please give your honest opinion. Thank you for your time and cooperation!

Name of Respondent ________________________ Name of Village ______________

Sex ___________________________________ Age _______________________

Occupation _____________________________

PART I

1. Have you been using the Holeta River?

   Yes ☐ No ☐

   If yes,

   - For what Purpose?

   Irrigation ☐ Livestock consumption ☐ Human consumption ☐

   Others ____

   ____

   - For how long have you been using the river? __________________________

   ____

2. Agricultural Water Consumption / Irrigation use,

- What kind of crop /vegetable do you grow using irrigation?

____

____

- What is the major three one's?

____

____

- Which months are you growing these crops with irrigation?

____

____

____

- How much hectares of your land is irrigated/ total area of irrigated land?

____

____

- Do you think the river water supply is adequate?

  1= not adequate at all 2 = less than adequate

  3 = partially adequate 4 = adequate 5 = highly adequate

- Is there any other source of water in this area for irrigation that you use as an alternative? (like wells, protected or unprotected spring, water harvesting structures)

  Yes ☐ No ☐

  If yes, what kind?____

  ____

Annual crop production

No	Major Crop Cultivated	Area of Irrigated land	Type of Irrigation	Season of growing	Annual Yield, Quintal
1					
2					
3					
total					

3. Human Water Consumption,

- How many Household use the river for human consumption?

- How many individuals are there in the household?

- What does the household use water for (e.g. cooking, bathing, washing clothes)?

- How much water does the household use per day?

- Does all the domestic water used by the household come from the river or from other sources?

- What other water sources are available and being used for human consumption (e.g. well, protected or unprotected springs , water harvesting structures)?

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4. Livestock Water Consumption,

Livestock holdings

No	Type of Livestock		Average Number of livestock	Source of water use	
				Holeta River	Other, specify
1	Ox				
2	Cow				
3	Sheep				
4	Goat				
5	Horse				
6	Donkey				
7	Mule				

PART II

1. Is there a conflict between users of Holeta River?

Yes ☐ No ☐

- If yes, what kind?____

____

- What kind of solution have been implemented? ____________________________

____

____

2. Does everyone have equal access to the River water supply ?

1 = Not equal access at all 2 = less equal access

3 = Partially equal access 4 = equal access 5 = Highly equal access

3. Is there any institution or water use committee, which works on river water management?

Yes ☐ No ☐

If yes, who ?____

____

4. Is there any existing River management strategy/ methods in the area ?

Yes ☐ No ☐

If yes, what kind ? ____

____

____

5. Have you received any training on the water management?

1 = No training at all

2 = Simple awareness creation made by the water use committees, government and non government organizations

3 = Relatively intensive teaching provided by government and non government organizations

4 = Extremely intensive advocacy provided by the water use committees, government and non government organizations

6. Do you have any recommendations to make the water sources / river more sustainable?

____

____

____

____

Thank you very much!