JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

ASSESSMENT OF SURFACE WATER POTENTIAL AND CURRENT WATER DEMAND: THE CASE OF HOLETTA RIVER CATCHMENT, AWASH RIVER BASIN, ETHIOPIA

BY: FIKADU GUDETA FETULA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

MARCH, 2020
JIMMA, ETHIOPIA

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MAIN ADVISOR: - DR.-ING. FEKADU FUFA (PH.D.)
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MARCH, 2020
JIMMA, ETHIOPIA

DECLARATION

I hereby declare that the Thesis entitled "**Assessment of Surface Water Potential and Current Water Demand: The Case of Holetta River Catchment, Awash River Basin, Ethiopia**" is my original work, which I submit for partial fulfillment of the degree of Master of Science in Hydraulic Engineering to school of graduate studies, Hydrology and Hydraulic Engineering Chair, Jimma Institute of Technology, Jimma University. The Thesis conducted under the guidance of a main advisor, Dr.-Ing. Fekadu Fufa (Ph.D.), and co-advisor, Mr. Megersa Kebede (M.Sc.).

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Co-advisor	Signature	Date

APPROVAL SHEET

The undersigned certify that, the Thesis entitled "**Assessment of Surface Water Potential and Current Water Demand: The Case of Holetta River Catchment, Awash River Basin, Ethiopia**" is the work of Fikadu Gudeta Fetula. We hereby recommend for the acceptance by a school of Graduate Studies of Jimma University in partial fulfillment of the requirements for Degree of Masters of Science in Hydraulic Engineering.

Dr.-Ing. Fekadu Fufa ……………………. ……………
Main-advisor Signature Date

Megersa Kebede (M.Sc.) ……………………. ……………
Co-advisor Signature Date

As the member of Board of Examiners of the M.Sc. Thesis Open Defense Examination, we certify that we have read, evaluated the Thesis prepared by Fikadu Gudeta Fetula and examined the candidate. We recommended that the Thesis could be accepted as fulfilling the Thesis requirement for the Degree of Masters of Science in Hydraulic Engineering.

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Chairperson Signature Date

ABSTRACT

Nowadays, the need of water for different purpose is dramatically increasing. The source of this water may be surface water or ground water. There are various ways how to allocate the available water, but the challenge is to find an optimal way. An important purpose of water management is to balance the demand for water with its availability, through suitable water allocation arrangements. Therefore, assessing the surface water potential of a river catchment and allocating the available water resources becomes crucial concern of different researchers. Currently the surface water potential of Holetta river catchment is not studied well and users of the river are facing the problem of sharing the available water during dry season due to scarcity. This paper was initiated with an objective of assessing surface water potential and current water demand of Holetta River catchment. Soil and Water Assessment Tool (SWAT) was used to determine the surface water potential. Sensitivity analysis, model calibration and validation were done by using SWAT_CUP SUFI2 algorithm while Water Evaluation and Planning (WEAP) tool was used to determine water demand for the current year 2019 G.C. Statistical model performance measures, coefficient of determination (R^2) and Nash–Sutcliffe simulation efficiency (NSE), indicated good performance of the model simulation on monthly time step both on calibration and validation with a value of 0.89 and 0.74 for calibration and 0.87 and 0.65 respectively for validation. PBIAS value during calibration and validation were -7.3 and -6.4 respectively indicating model over prediction. The catchment receives mean annual precipitation of 1213.5 mm. The monthly surface runoff volume for the months of January, February, March, April, May, and December were 0.582, 1.192, 2.556, 1.947, 2.080 and 0.342 Mm^3 respectively which accounts a total surface runoff volume of 8.699 Mm^3. Four demand sites were considered and given equal priorities regardless of the differences in financial returns expected from each site. The WEAP21 model result showed that the current water demand, during dry season, for irrigation, livestock, urban and rural domestic demand sites were 6.6, 0.012, 1.767 and 4.698 Mm^3 respectively which accounts a total water demand of 13.077 Mm^3. The current base year 2019 water allocation result revealed that the demand is much higher than the available water and hence, there is unmet demand with a deficit volume of 1.046, 0.93, 0.497, 0.921, 0.073, and 0.911 Mm^3 respectively in the dry months. Therefore, to overcome water scarcity during the dry season, it is important to store the available water in the rainy season by constructing artificial water storage.

Key words: *Arc SWAT, DEM, Holetta River, Surface water, Water Demand, WEAP*

ACKNOWLEDGEMENTS

First and for most I would like to thank the ‘Almighty God’ for his help in all my life. I sincerely like to thank my main advisor Dr.-Ing. Fekadu Fufa and Mr. Megersa Kebede (co-advisor) for their valuable and fruitful comments.

I sincerely thank my family for their valuable advice and help from the beginning to the end of this work.

I would like to forward my thanks to Jimma University, Institute of Technology, especially faculty of civil and environmental engineering hydrology and hydraulic engineering chair.

My deepest gratitude also goes to my colleague Mr. Tariku Fikadu and all my friends whose names are not listed here.

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ACRONOMYS

95PPU	95 Percent Prediction Uncertainty
a.m.s.l	Above Mean Sea Level
AnnAGNPS	Annualize Agricultural Non-Point Source Model
ARBA	Awash River Basin Authority
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DMC	Double Mass Curve
ENMSA	Ethiopian National Metrological Service Agency
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GLUE	Generalized Likelihood Uncertainty Estimation
GTP	Growth and Transformation Plan
HARC	Holetta Agricultural Research Center
HEC-HMS	Hydrologic Modelling System
HRUs	Hydraulic Response Units
IWRM	Integrated Water Resource Management
Lcpd	Liter per capita per day
LULC	Land Use Land Cover
MCM	Million Cubic Meter
MODSIM	Modular Simulation Model
MoWR	Ministry of Water Resources
NSE	Nash-Sutcliffe Efficiency
parasol	Parameter Solution
PRMS	Precipitation Runoff Modeling System
RF	Rain Fall
RIBAS1M	River Basin Simulation Model
RO	Runoff
SCS-CN	Soil Conservation Service Curve Number
SEI	Stockholm Environmental Institute
SUFI2	Sequential Uncertainty Fitting Version 2

SWAT	Soil and Water Assessment Tool
SWAT_CUP	Soil and Water Assessment Tool- Calibration Uncertainty Program
TLU	Tropical Livestock Units
UNEP	United Nations Environmental Program
USDA	United States Department of Agriculture
WEAP	Water Evaluation and Planning
WGEN	Weather Generator
WHO	World Health Organization

1. INTRODUCTION

1.1 Background

Water is the prime requirement for the existence of life and thus it has been man's endeavor from time immemorial to utilize the available water resources. Ethiopia is endowed with enormous surface and ground water resources. There are many perennial rivers in the country. A number of lakes and reservoirs also exist in different parts of Ethiopia. Knowing the potential and availability of surface water is vital in wise use of the water resource, designing economical and suitable hydraulic structure for water supply, hydropower, irrigation and other purpose (Mahtsente *et al*., 2017).

Water resource development is the basic strategy to come up with sustainable growth of agriculture, rural development and overall economic progress. The optimal allocation of scarce water resources for different purposes is essential. There are 12 river basins in our country, Ethiopia. Out of these, two are dry, two are water surplus and eight of them are water deficit basins (Dereje, et al., 2015).

The rapidly growing demand of water resources in the world is the main problem for efficient and sustainable utilization of the limited water resources. The increasing pressure on the world′s fresh water resources which is enforced by population growth and can lead to conflicts between demands for different uses to satisfy their water requirement. Water demand is the volume of water requested by users to satisfy their needs. In a simplified way water demand is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Peter, 2003).

There are various ways how to allocate the available surface water resources among different users, but the challenge is to find an optimal allocation that, firstly, adheres to laid-down legal and other regulations, and secondly, that satisfies the water demand of all users as much as possible (Pieter, 2003).

An Integrated Water Resource Management (IWRM) at river basin level ensures that social, environmental, technical dimensions as well as economic implications of water allocations are taken into consideration. Water resource assessment and demand identification is the component of Integrated Water Resource Management. Therefore, knowing the available water resources at a river basin and specifically at small watershed level and its corresponding demand locally as well globally is a basic tool in implementing the integrated water resource management approach efficiently (Tilahun, 2015).

The water resources availability assessment requires detailed understandings of hydrological processes. However, studying the complexity of hydrological processes, needed for sustainable catchment management, is mostly based on understanding rainfall characteristics and catchment properties. Forecasting the water demand of different sectors and end users in specific watershed is a key for decision making in Integrated Water Resources Planning and Management (Munyaneza, *et al*., 2014).

Various hydrological models have been developed across the world to assess the impact of climate and soil properties on hydrology and water resources. The inputs used by different models are rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other physical parameters. SWAT and WEAP models are the common and have the capability of modelling the hydrology of complex and large basins as well as specific river catchment (Gayathri K Devi, *et al*., 2015).

Therefore, the general objective of the study was estimating the surface water potential of the Holetta river catchment and its current water demand for optimal water resources using ArcSWAT and WEAP models respectively.

1.2 Statement of the problem

Water is the major requirement for the existence of life but, its scarcity is now a worldwide issue which makes the management of water resources a complex task. Dealing with the limited water resources requires the development of comprehensive framework including technical, political and institutional dimensions to maintain water quantity and meeting the rapidly growing demand for the limited water resources (Dereje, *et al*., 2018).

Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Surface water courses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water potential resources is a key aspect of water resource assessment and evaluation (Tadesse, 2006).

Knowing the potential and availability of surface water is vital in wise use of the water resource, designing economical and suitable hydraulic structure for water supply, hydropower, irrigation and other purpose (Mahtsente *et al*., 2017).

Currently, the growth of population demands for increased domestic water supplies and, at the same time, results in a higher consumption of water due to expansion in agriculture and industry. As a result, proper utilization of water resources which requires assessment and management of the quantity water resources both spatially and temporally is very crucial. On other hands the need of water for different purpose is dramatically increasing due to increase in population, climate change hazard, expansion in industry, increase in modern irrigation systems and socioeconomic development (Dereje, *et al*., 2015).

Holetta river is the sub-basins of Awash river basin which is found in the upper Awash River basin. It is the main source of surface water in the study area and is Perennial river having many users. The hydrology of Holetta River and its seasonal variability is not fully studied yet. In addition to this, due to the problem of sharing the available surface water and increase in water demand for different purposes, the major users of the river are facing a problem of allocating and sharing the available water during the dry season (Mahtsente *et al*., 2017).

Therefore, this study was intended to estimate the available surface water of Holetta river catchment and its current demand using ArcSWAT and WEAP models with the following objectives.

1.3 Objective of the Study

1.3.1 General objective

The general objective of the study was to assess the available surface water potential of Holetta river catchment and its current water demand using ArcSWAT and WEAP models respectively.

1.3.2 Specific objectives

The specific objectives of the study are;

1. To evaluate SWAT model performance
2. To assess the available surface water of Holetta river catchment using ArcSWAT

3. To quantify current water demand for irrigation, domestic, livestock and environment WEAP model; and
4. To assess unmet water demand in the catchment

1.4 Research Questions

The study answers the following questions

1. Does the SWAT model perform well?
2. What is the available surface water potential of Holetta river?
3. What amount of water is required by the water sharing sectors/end users?
4. Is there unmet water demand in the catchment?

1.5 Significance of the Study

Now upon completion, this study has a significant importance in determining the available water of the river and in identifying users of the available water. In addition, water requirement of the selected demand sites using Holetta river as a source has been estimated. This reduces conflicts that may rise among end users due to competition on water resources in the study area. The study can also be used as a reference for any other studies that will be conducted in the catchment.

1.6 Scope of the study

This specific study focuses on assessing the surface water potential and current water demand of Holetta river catchment. Specifically, it focuses on estimation of available annual surface water and current water demand for domestic, environment, livestock and irrigation. The study is limited to Holetta river catchment which is found in the upper Awash river basin Ethiopia, having a watershed area of 393.25 km^2.

2. LITERATURE RIVIEW

2.1 World Water Resources

The total quantity of water in the world is estimated to be 1386 million cubic kilometers (M km^3). About 96.5% of this water is contained in the oceans as saline water. Some of the water on the land amounting to about 1% of the total water is also saline. Thus, only about 35 M km^3 of fresh water is available. Out of this about 10.6 Mkm^3 is both liquid and fresh and the remaining 24.4 Mkm^3 contained in frozen state as ice in the Polar Regions and mountain tops and glaciers (Subramanya, 2008).

Very little of the earth's abundant water is actually accessible and suitable for human needs. At the continental level, Africa's 3931 km^3 of renewable water resources represent about nine percent (9%) of the world's total fresh water resources. Africa is the second world's driest continent, after Australia, but also the world's populous continent after Asia (UNEP, 2010).

The scarce water resource of the world is facing a challenge resulting from social and environmental impacts. Challenges faced by more and more countries in their struggle for economic and social development are increasingly related to water. Water shortages, quality deterioration and flood impacts are among the problems which require greater attention and action. Integrated Water Resources Management (IWRM) is a process which can assist countries in their endeavor to deal with water issues in a cost-effective and sustainable way (Agarwal, *et al*., 2000).

Table 2.1: Estimated world water quantities (UNESCO, 1975)

Item	Area (M km^2)	Volume (M km^3)	Percent total water	Percent fresh water
1. Oceans	361.3	1338.0	96.5	--
2. Ground water				
a) fresh	134.8	10.530	0.76	30.1
b) saline	134.8	12.870	0.93	--
3. Soil moisture	82.0	0.0165	0.0012	0.05
4. Polar ice	16.0	24.0235	1.7	68.6
5. Other ice and snow	0.3	0.3406	0.025	1.0
6. Lakes				
a) Fresh	1.2	0.0910	0.007	0.26
b) saline	0.8	0.0854	0.006	--
7. Marshes	2.7	0.01147	0.0008	0.03
8. Rivers	148.8	0.00212	0.0002	0.006
9. Biological water	510.0	0.00112	0.0001	0.003
10. Atmospheric water	510.0	0.01290	0.001	0.04
Total:				
a) All kinds of water	510.0	1386.0	100.0	
b) Fresh water	148.8	35.0	2.5	100

The source of surface water resource is rainfall. As rainfall reaches the earth's surface, it meets the first separation point. At this point part of the rain water returns directly to the atmosphere, which is called evaporation from interception (I). The remaining rain water infiltrates in to the soil until it reaches the maximum capacity of infiltration, which is called infiltration (F). If there is enough rainfall /if rainfall continues and exceed the interception and infiltration, then overland flow (surface runoff) (Q_s) is generated (Tilahun, 2015).

The overland flow is a fast runoff process, which generally carries soil particles. A river that carries a considerable portion of overland flow has a brown muddy color and carries debris. The infiltration reaches the soil moisture. From the soil moisture part of the water returns to the atmosphere through transpiration T. If the soil moisture content is above field capacity (or if there are preferential pathways), part of the soil moisture percolates towards the groundwater. The reverse process of percolation is capillary rise. The percolation feeds the groundwater and renews the groundwater. On average the percolation minus the capillary rise equals the seepage of groundwater Q_g to the surface water.

The seepage water is clean and does not carry soil particles. A river that has clear water carries water that stems from groundwater seepage. This is the slow component of runoff. During the rise of a flood in a river when the water color is brown, the water stems primarily from overland flow. During the recession of the flood, when the water is clear, the river flow stems completely from groundwater seepage. The water that is consumed by the vegetation through transpiration is called "green water". It is an important water resource for agriculture, nature and livestock. The surface water and groundwater which are intimately intertwined are the "blue water". Although the ground water and surface water cannot be separated and although surface water consists to a large extent of groundwater, they are often dealt with separately. This is because they have quite different characteristics (time scales, quantities, availability) and because they obey different laws of motion (Pieter, 2003).

2.2 Water Resources of Ethiopia

2.2.1 Surface Water Resources

Surface water is the water stored or flowing on the earth's surface. The surface water system continually interacts with the atmospheric water system and subsurface water system through a process of evaporation and infiltration and seepage respectively (Peter, 2003).

Surface water occurs in two kinds of water bodies. This are water courses, such as rivers, canals, estuaries and streams and stagnant water bodies, such as lakes, reservoirs, pools, tanks, etc. The first group of water bodies consists of conveyance links, whereas the second group consists of storage media. Together they add up to a surface water system.

Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Surface water courses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation (Tadesse, 2006).

The amount of water available in storage media is rather straightforward as long as a relation between pond level and storage is known. The surface water available in channels is more difficult to determine since water flows. The water resources of a channel are defined as the total amount of water that passes through a given period of time. In a given cross section of a channel the total available amount of surface water runoff over a time step Δt is defined as the average over time of the discharge.

$$R = \frac{1}{\Delta t}\int_{t}^{1+\Delta t} Q\, dt \qquad \text{Equation (2.1)}$$

Where; R is surface water runoff, Q is channel discharge and Δt is time step. The discharge Q is generally determined on the basis of water level recordings in combination with a stage discharge relation curve, called a rating curve (Pieter, 2003).

Ethiopia is often called the water tower of Northeast Africa. It has 12 catchment areas, 8 of which are River Basins, 1 Lake Basin and 3 Dry Basins. Almost all of the basins branch out from the central ridges that separate the Rift Valley from the highlands of Ethiopia to all directions out of the country. Rivers originates from the eastern part of the country drain in to the Indian Ocean while those originate from the western part drain into the Mediterranean Sea Basin (Henock, 2015).

The majority of Ethiopian lakes are rich in fish. Most of the lakes except Ziway, Tana, Langano, Abbaya and Chamo have no surface water outlets, i.e., they are endhoric. Lakes Shala and Abiyata have high concentrations of chemicals and Abiyata is currently exploited for production of soda ash. The geographical location of Ethiopia and its endowment with favorable climate provides a relatively higher amount of rainfall in the region. Much of the water, however, flows across the borders being carried away by the Transboundary Rivers to the neighboring countries. Ethiopia has 12 river basins. The total mean annual flow from all the 12 river basins is estimated to be 124.25 billion cubic meters. It has often been advocated that the most logical unit for water resources planning and optimum utilization of available water resources is the river basin. All major river basins in Ethiopia have an integrated development master plan study, and their potential in terms of economic development be known (Seleshi, *et al*., 2007).

The idea of a river basin, despite its physical or natural attributes, is more than an engineering concept and encompasses the magnitude and dynamics of a resource that must be harnessed for the common good (Molle, 2006).

Figure 2.1: River basins of Ethiopia (Seleshi, *et al.,* 2007)

Table 2.2: Surface water potential and coverage area of Ethiopian river basins (Seleshi, *et al*., 2007)

S.No.	River Basin Name	Area (Km^2)	Surface runoff (Bm^3)
1	Tekeze	82,350	8.2
2	Abay	199,812	54.8
3	Baro Akobo	75,912	23.6
4	Omo-Gibe	79,000	16.6
5	Rift valley	52,739	5.6
6	Mereb	5,900	0.65
7	Afar/Denakil	74,002	0.86
8	Awash	112,696	4.9
9	Aysha	2,223	-
10	Ogaden	77,121	-
11	Wabi-Shebelle	202,697	3.16
12	Genale-Dawa	171,042	5.88

Integrated water resources management is a process which encourages the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. The overall aim of the national water resources management policy is to improve and promote all national efforts towards the efficient, equitable, and optimum utilization of the available water resource of Ethiopia for significant Socio-Economic development on substantial basis (MoWR, 2002).

2.3 Water Demand

Demand for water is the amount of water required at a certain point for certain purpose. An important purpose of water management is to match or balance the demand for water with its availability, through suitable water allocation arrangements. Water demand forecasting is a process achieved through several techniques and is typically used to predict future water requirements for different uses including hydropower, domestic and agriculture water demands. (Pieter, 2003).

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Peter, 2003).

Water allocation is not an issue when water availability far surpasses the demand. In such situations all demands can be satisfied, and in fact there is no need for a regulated allocation of water. In many catchment areas and parts of river basins, however, water availability is frequently less than the demand for it. It is then necessary to find a suitable allocation of the scarce water. Water allocation is not only concerned with the physical allocation of water. More broadly it is about satisfying conflicting interests depending on water. These may be functions derived from water such as navigation (navigability, minimum water levels), hydropower (head difference), environment (a water regime of water level fluctuation), and recreation (availability of water but non-consumptive). These functions are only to a certain extent consumptive, but can be conflictive in their timing and spatial distribution. Also flood protection is a function of the water resources system that related to the water resources. Flood protection through the construction of storage dams can have a positive impact on water availability for other functions (hydropower), but can have negative impacts on others (on the environment). Finding a suitable allocation key for water can be quite complex, since a large number of parameters have to be considered (Pieter, 2003).

The amount of water that people use depends on minimum needs, amount of water available for use, level of economic development and extent of urbanizations. There are three categories of fresh water use globally: for agriculture, industry and domestic (personal, household and municipal) of which agriculture dominates (Gleik, 1996; Tilahun, 2015).

2.3.1 Domestic water demand

Humans need fresh water for three major uses. This include domestic use such as drinking, washing, cooking and general hygiene, agricultural uses and industrial use for non-agricultural commercial activities. The domestic water demand is determined based on the population and the minimum standard required per person per year (Dereje, *et al*., 2015).

The available water resource that is easily accessible may be demanded for various purposes. One of the main water demands is the domestic water demand. Domestic water demand includes water that is needed for basic needs such as drinking, cooking, washing clothes and utensils and house sanitation. It is difficult to determine the exact amount of this water demand category as it accounts minor water wastages. Different countries have different consumption requirement for domestic use. International organizations and water providers adopt an overall basic water requirement of 50 liter per capita per day (Lpcd) as a minimum standard to meet four basic needs: drinking, sanitation, bathing and cooking (Gleik, 1996).

Ethiopia developed a new and continuous Growth and Transformation Plan of different phases. According to the GTP-1 of Ethiopia, urban and rural water demands were 20 and 15 liters per capita per day respectively. In this phase there is scarcity of water demanded by both rural and urban residents due to economic development and as result the country developed the second GTP. In this plan, about 25 liters and 40-100 liters per capita per day of water is recommended for rural and urban respectively (GTP-2, 2015)

2.3.2 Agricultural water demand

Currently the need of water for irrigation purpose is dramatically increasing due to increase in modern irrigation systems and uneven distribution of rain fall spatially and temporally. Ethiopia has a substantial irrigation potential identified from both available irrigable land and water resources. Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Seleshi, *et al*., 2007).

According to the Ministry of Water, Irrigation and Energy of Ethiopia irrigation command areas can be categorized into three groups based on the irrigable areal extent. The first group is small scale irrigation areas of less than 200 ha, medium-scale between 200 and 3000 ha and large scale above 3000 ha.

2.3.3 Industrial water demand

Industries that produce various products use water in their production process and their water requirement depends on amount of water for all levels of production. Industrial water demand is normally considered in urban areas where industries are found. There is no direct relationship between industrial water demand population since amount of water required for each industry depends up on the process they intended to perform and hence its calculation is done separately (Dereje, *et al*., 2015).

2.4 Water Allocation

Available water resources can be used by different regions and groups or individuals. Water allocation is the process of developing, managing and sharing of the available and scarce water resources among different regions and competing users based on the procedures and principles of Integrated Water Resources Management for sustainable development. It is a process made primarily when the natural distribution (spatially and temporally) and availability of water is unable to satisfy the needs of all water users in terms of quantity, quality, timing of availability, or reliability.

An important purpose of water resource management is to match and balance the demand for water with its availability, through suitable water allocation arrangements. In many catchment areas and parts of river basins water availability is frequently less than the demand for it and as a result, it is essential to find a suitable allocation of the scarce water. Water allocation is not only concerned with the physical allocation of water. More broadly it is about satisfying conflicting interests depending on water (Pieter van der Zaag, 2003).

According to Awash River Basin Authority (2017) report optimal water allocation plays a great role in sustainable water resources and scarce water resources management. Currently optimal water allocation is increasing and developed from single water source to multiple, from single objective oriented to multi-objective, from temporal allocation to spatial, from water quantity and quality to water quantity-quality coupling.

2.5 Hydrological Models

The knowledge and understanding that the scholars has about the world is often represented in the form of models. The main aim of the scientific method is to simplify and explain the complexity and confusion of the world through models.

Different scholars and individuals have defined hydrological models in many ways and perspectives. A model is a simplified representation of real-world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are principally used for forecasting system behavior and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management (Sorooshian, *et al.*, 2008).

According to Chow *et al.* (1988) hydrological model is an approximation of the complex reality using a system concept. A system is a group of interacting or inter-dependent components forming a complex whole. The overall intent of the hydrologic system analysis is to study the system function and predict its output. The models treat the hydrological cycle as a system that comprises its different components as inputs like precipitation and outputs like runoff, using a set of equations that links the inputs and outputs.

In other words, hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. They relate the unknown parameter which is output to known variable which the model input. Hydrological modeling is a process of determining the operation of the hydrological system in the transformation of rainfall in to runoff. They are chiefly used for hydrologic forecast and for understanding hydrological processes. The overall intent of the hydrologic system analysis is to study the system function and forecast its output (USDA-SCS, 1972).

Several hydrologic models are widely used for the assessment of the water resource. Rainfall runoff models have broadly used in hydrology over the last century for a number of applications, and play an important role in optimal planning and management of water resources in catchments (Loughlin, 1999).

Determination of runoff generation has a great role in understanding catchment hydrology. Some of the tasks of predicting rainfall runoff models are of a purely hydrological nature, such as real time flood forecasting, design flood estimation, and assessment of the reliability of natural water resources (Kumela, 2011).

Stochastic models use local hydrometric data to forecast flows. These models allow for some randomness that results in different outputs and are based on analysis of past events, commonly rainfall and river discharge (Tessema, 2011). These models try to establish a linkage between numerous phenomena from historical data without internal description of the physical processes involved in. One of the common uses of this type of model is for forecasting inflows into a reservoir system.

In other hands, Deterministic models generate a single output of runoff for a given rainfall under the same physical environments. They can be classified as lumped, Distributed and Semi distributed model. In lumped model a variable or parameter is assumed to have an average value for the whole catchment, and in distributed models all variables and parameters have different values that account for the spatial variation in the catchment. Semi-distributed models use multiple lumped units in a catchment either as sub basins or HRU. Their hydrological process description is based on the conceptual type (Merritt, *et al*., 2003).

Currently there are numerous hydrological models to model the hydrological process of a river basin as well as a specific river catchment. Among those models the following are recently developed or regularly updated ones and were taken in to comparison.

Hydrologic Modelling System (HEC-HMS): HEC-HMS was developed by US Army Corps of Engineers Hydrologic Engineering Center, and is designed for both continuous and event-based hydrologic modelling. It provides several different alternatives to the users for modelling numerous components of hydrologic cycle. Firstly, it was developed to simulate the precipitation-runoff processes of dendritic watershed systems but later it was enhanced to solve widest possible range of problems including large river basin water supply, flood hydrographs, and small urban or natural watershed runoff (USACE-HEC, 2010). HEC-HMS does not simulate most of the components of land phase of the hydrologic cycle like groundwater flow, it needs other HEC family software to delineate the catchment and it needs less data than SWAT model.

Precipitation Runoff Modeling System (PRMS): is a modular designed, physically-based, distributed- parameter watershed model developed to evaluate the effects of various combinations of precipitation, climate and land use on stream flow, sediment yields, and general basin hydrology. PRMS simulates snowpack formation and melt, and is well suited for simulating stream flow and its hydrologic components from snowmelt dominated basins. It is suitable for coupling with other models but it may subject to computational instability problem due to its governing equations requiring numerical approximation for their solutions (Dhami and Pandey, 2013).

Annualized Agricultural Non-Point Source Model (AnnAGNPS): is a watershed-scale, continuous simulation model modeled to forecast the impact of watershed management on water, sediment, nutrients and pesticides in agricultural watershed. This model is the next generation of the AGNPS 5.0 single event model developed by USDA-ARS and Natural Resources Conservation Services (NRCS). It integrates numerous components of other models, like the revised universal soil loss equation, Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model, the groundwater loading effects (Bingner *et al*., 2011). AnnAGNPS model is similar to SWAT model but it has a spatial limitation and does not consider point source.

TOPMODEL: It is a semi distributed conceptual rainfall runoff model that takes the advantage of topographic information related to runoff generation. But the TOPMODEL was considered as physically based model as its parameters can be measured theoretically (Beven, et al., 1984). In other words, it can be defined as a variable contributing area conceptual model. It can be used in single or multiple sub catchments using gridded elevation data for the catchment area. It helps in the prediction of hydrological behavior of basins. The major factors considered in this are the catchment topography and soil transmissivity (Gayathri K Devi, *et al*., 2015).

Modular Simulation Model (MODSIM): is a generic river basin management decision support system based on simulation of river network flow and reservoir operations. It was originally developed by Dr. John Labadie of Colorado State University in the late 1970s and later enhanced to MODSIM that allow the model to simulate physical operation of the reservoirs and water demand. It has been linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources, as well as water quality simulation models for assessing the effectiveness of pollution control strategies (H.Assata, *et al*., 2008).

River Basin Simulation Model (RIBAS1M): is a generic model package for simulating river basins under various hydrological conditions. The model package links the hydrological water inputs at various locations with the specific water users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure and operational and demand management, and to see the results in terms of water quantity and flow composition. RIBAS1M can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account. Irrigation demand can be calculated based on cropping patterns, irrigation practices and meteorological data. Surface and groundwater resources can be allocated. Minimum flow requirements and flow composition can be assessed (H.Assata, *et al*., 2008).

Generally, there are a number of water resources assessment and water demand assessment models like Precipitation Runoff Modeling System (PRMS), WinSRM, SWAT, Water Resources Graphical Interface – Simulation Tool (WARGI-SIM), Water Evaluation and Planning (WEAP) and etc.

The main task is choosing the best model that is more flexible and that can fit the specific criteria of the hydrologist and researchers. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for graphical user interface, computer operation system, input/output management and structure, or users add on expansibility. Among the various project-depended selection criteria, there are four main common, fundamental ones that must always be considered (Cunderlik, 2003). These are required model outputs which is important for the needed purpose and therefore to be estimated by the model, hydrologic processes that need to be modeled to estimate the desired outputs, availability of input data and price. Finally, SWAT and WEAP models were selected and used to assess surface water potential and current water demand of Holetta river catchment respectively.

2.5.1 Soil and Water Assessment Tool

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed by Dr. Jeff Arnold for the United States Department of Agriculture (USDA) - Agricultural Research Service (ARS) (Neitsch *et al*., 2005). The Arc SWAT ArcGIS extension is a graphical user interface for the Soil and Water Assessment Tool (SWAT) model. It is a comprehensive, continuous-time, process based and semi-distributed conceptual river basin model (Arnold, *et al*., 1998).

SWAT is a theoretical model that operates on a daily time step. In order to adequately simulate hydrologic processes in a basin, the basin is divided into sub basins through which streams are routed. The subunits of the sub basins are referred to as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous. The model calculations are performed on HRU basis and flow variables are routed from HRU to sub basin and subsequently to the watershed outlet. The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. Soil water balance is the primary consideration by the model in each HRU, which is represented as (Arnold, *et al*., 1998).

$$SW_t = SW_o + \sum_{i=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \quad \text{Equation (2.2)}$$

Where, SW_t is final water content of soil (mm), (SW_o) initial water content of soil on day I (mm), (R_i) rainfall amount on day I (mm), (Q) amount of surface runoff on day I (mm), (ET_i) amount of evaporation on day I (mm), (P_i) percolation on day I (mm) and (QR_i) is amount of return flow on day I (mm).

2.5.2 Water Evaluation and Planning

WEAP is short for Water Evaluation and Planning System. It is a computer tool for integrated water resources planning developed by Stockholm Environment Institute (SEI, 2005). It is a PC-based surface and groundwater resource simulation tool, reliant on water balance accounting principles, which can test alternative sets of supply and demand conditions. The user can project changes in water demand, supply, and pollution over a long-term planning horizon to develop adaptive management strategies.

Water Evaluation and Planning (WEAP) is a micro-computer tool for integrated water resources planning that provides a comprehensive, flexible and user-friendly framework for policy analysis (Jack Sieber & David Purkey, 2015).

The WEAP model provides an integrated assessment of climate, hydrology, water resources allocation, and watershed management. It also addresses several issues such as water resources, water demands analysis in different sectors, provides priorities in water allocation, reservoir operation, and management. It solves the water allocation challenges at user-defined periods, either monthly or yearly based on linear programming structures (Adgolign, *et al.*, 2016).

It is comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Sieber , 2012).

WEAP is designed as a comparative analysis tool. A base case is developed, and then alternative scenarios are created and compared to this base case. Incremental costs of water sector investments, changes in operating policies, and implications of changing supplies and demands can be economically evaluated (Yates D., *et al.*, 2005).

Appropriately WEAP was designed for what-if analysis of various policy scenarios and long-range planning studies. Adaptive agriculture practices such as changes in crop mix, crop water requirements, canal linings; changes in reservoir operations; water conservation strategies; water use efficiency programs; changes in instream flow requirements; implications of new infrastructure development and is applicable for detailed water demand modelling *(*H.Assata*,* *et al*., 2008).

2.6 Previous Studies using SWAT and WEAP

In Ethiopia, previously SWAT was used as a hydrological assessment tool to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with different soil, land use, and management conditions over long periods of time.

Setegn (2008) used SWAT model in the Northern high lands of Ethiopia for modeling of Hydrology and Sediment Yield in Lake Tana Basin, Blue Nile, Ethiopia. The study tasted the performance and feasibility of SWAT model to examine the influence of topography, land use, soil and climatic condition on stream flow, soil erosion and sediment yield. The model was successfully calibrated and validated on four tributaries of Lake Tana as well as Anjeni watershed using SUFI-2, GLUE, and Parasol algorithms. There was a good agreement between the measured and simulated flows and sediment yield with higher values of coefficients of determination and NSE.

Ayana *et al*. (2012) applied SWAT model to simulate the sediment yield from Fincha watershed, located in Western Oromiya Regional State, Ethiopia to examine the applicability of SWAT in watershed with a high sediment runoff modulus. From the result obtained the model has a good capability of predicting sediment yields and hence can be used as a tool for water resources planning and management in the watershed.

Recently, Firisa (2017) also applied SWAT model to Sor watershed which is located in Illubabor zone of Oromiya regional state near Metu town to assess the surface water potential. The result was calibrated using stream flow data at the outlet of Sor River and it has showed good performance.

WEAP21 model had also been used for several water related studies over the world including our country, Ethiopia. For instance, it was used to model surface water resources allocation in Didessa sub-basin, west Ethiopia and showed good performance (Adgolign, *et al*., 2016).

WEAP was also used to evaluate the likely impact of a number of possible development scenarios in lake Tana Catchment, Ethiopia, on lake water levels (Alemayehu, *et al.*, 2010). In our neighboring country, Kenya, WEAP21 model was also applied to simulate water demand of Mara River Basin, Kenya (Marcellus, *et al.*, 2018).

From this point of view, SWAT model can be applied for small as well as large area for the assessment of the surface water potential and as well WEAP model have good performance history in simulating water demand.

There are also other researchers who used SWAT and WEAP in combination to assess the surface water potential and water demand of the watershed. Tilahun Araya tried to use both models to assess the Surface Water Potential and Water Demand in Genale Dawa River Basin (Tilahun, 2015). Dereje also used SWAT and WEAP model to assess and analyze Surface water potential and demand scenarios In Omo-Gibe River Basin (Dereje, 2015).

Setogn and Muhammed also applied SWAT and WEAP models to assess surface water potential and water demand in Tekeze River Basin, Northern Ethiopia, and Baro-Akobo river basin, Ethiopia respectively (Setogn, 2015; Muhammed, 2016).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted at Holetta river catchment, which is situated in the upper part of Awash River basin, in the central part of Oromiya regional national state, Ethiopia. It is about 45 km in the west direction from Addis Ababa, capital of Ethiopia. The study area lies at an altitude of 2069 - 3378 m above sea level and located at a latitude range of 8°56'N to 9°13'N and longitude range of 38°24'E to 38°36'E having a drainage area of 393.25 km^2.

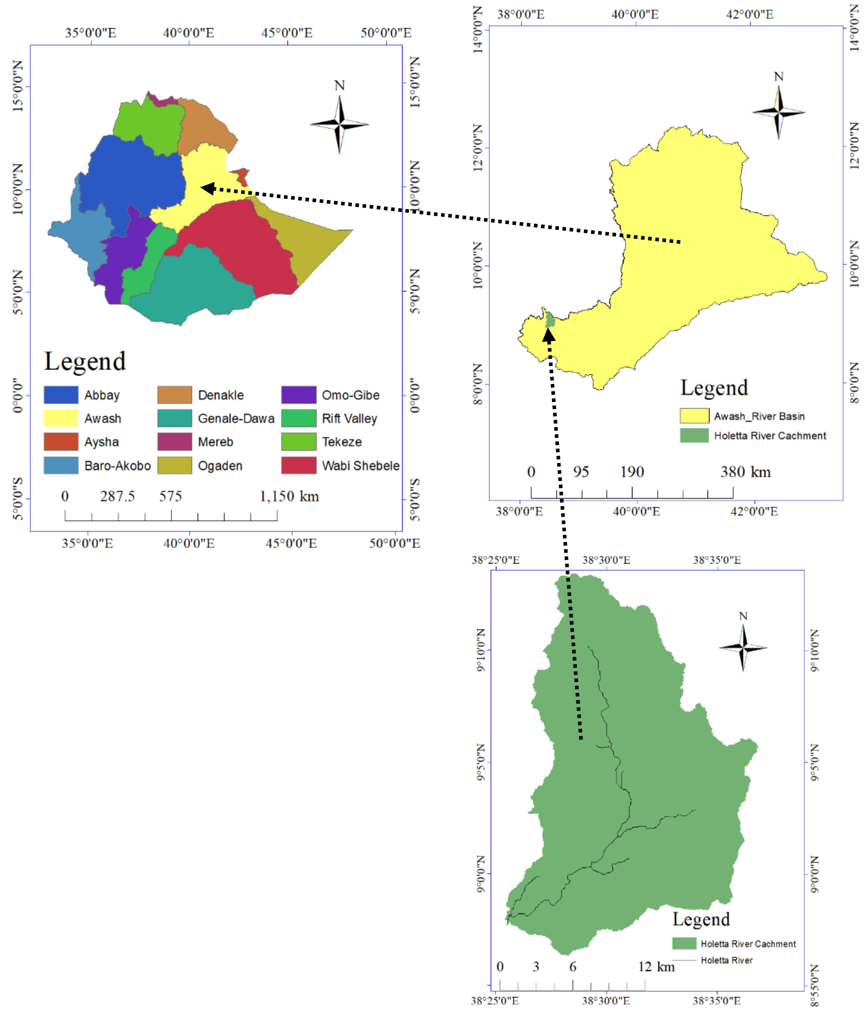


Figure 3.1: Location map of Holetta river catchment

3.1.2 Climate

Climatic elements such as precipitation, temperature, relative humidity, sunshine hours and wind are affected by geographic location and altitude. Seasonal classification over the study area is thus mainly based on the average rainfall distribution pattern over the year.

The study area is characterized by three distinct seasons and are locally known as Bega, Belg and Kiremt. Bega season consists October to January, Belg consists February to May and kiremt consists June to September. Generally, the rainfall pattern in the area has two distinct peaks during a year that is a short rainy season in months of February to May and long Rainy Seasons in moths of June to September and has the mean annual rainfall of 1213.5 mm.

The study area lies in Temperate (Woina Dega) of 54 % and cool temperate (Dega) of 46 % climatic zones. The minimum temperature occurs in the months of November and December while the maximum temperature occurs in the months of February and May having mean annual temperature of 16.2 ºC.

4.1.4 Population

Knowing the population dynamics of the study area is extremely important in wise use of available water resources. According to the Ethiopian Central Statistical Agency report (CSA 2017), the projected population of Holetta town which is the capital of wolmera district is 40,528 and that of wolmera district is 107,762 which in together accounts a total population of 148,290 by the end of the year 2017.

4.1.5 Land use land cover

The major land use land cover types of the catchment are agricultural land, natural forest, grass land, settlement, and wet land (water bodies). Forests and woodlands occur on the better-drained soils of mountains and sides of the valleys, and grasslands inhabit areas of heavy clay soil of the valley bottom.

4.1.6 Soil Classification

Based on SWAT soil classification, the soil type in the study area is classified as Eutric vertisols, Vertic cambisols, Chromic luvisols and Humic 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 dries; 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 (Kramer, 2000).

4.2 Data Collection

Before all, for any water resources assessment all necessary data have to be collected and processed. One of the most important data for assessment of surface water potential of a certain river catchment is rainfall data of the area over a several successive years. Rain fall data and other Meteorological data including maximum and minimum temperature, relative humidity, sunshine hours and wind speed from selected meteorological stations and nearby rain gauge stations was used. Digital Elevation Model (DEM) of the Awash River basin were used to delineate the watershed area as an input for Arc GIS and Arc SWAT software. All the necessary data type and their respective sources are listed in the following table.

Table 3.1: Data type and source

Data type	**Source**
Meteorological	National Metrological Service Agency of Ethiopia
Hydrological data	Ministry of Water, Irrigation and Electricity (Hydrology department)
Land Use Land Cover Data and Soil Data/Map	Ministry of Water, Irrigation and Electricity
Population Data	Central Statistical Agency
Irrigation Project data	Ministry of Water, Irrigation and Electricity
Awash DEM	Ministry of Water, Irrigation and Electricity (GIS Department)

4.2.1 Meteorological Data

One of the most important and preliminary data for any water resources assessment is meteorological data of the study area over a long period of time. Meteorological data includes precipitation, maximum and minimum temperature, relative humidity, solar radiation and wind speed. For this particular study all weather data parameters were collected from four meteorological stations and analyzed in the format that is suitable for model.

Table 3.2: Geographical locations of meteorological stations

Station Name	Longitude	Latitude	Elevation (m)	Collected Weather parameters
Holetta	38.500	9.075	2400	✓ precipitation ✓ maximum and minimum temperature ✓ relative humidity ✓ sunshine hours and wind speed
Addis Alem	38.38333	9.042	2372	✓ precipitation
Wolenkomi	38.25467	9.001833	2165	✓ precipitation
Kimoye	38.33783	9.008	2150	✓ precipitation

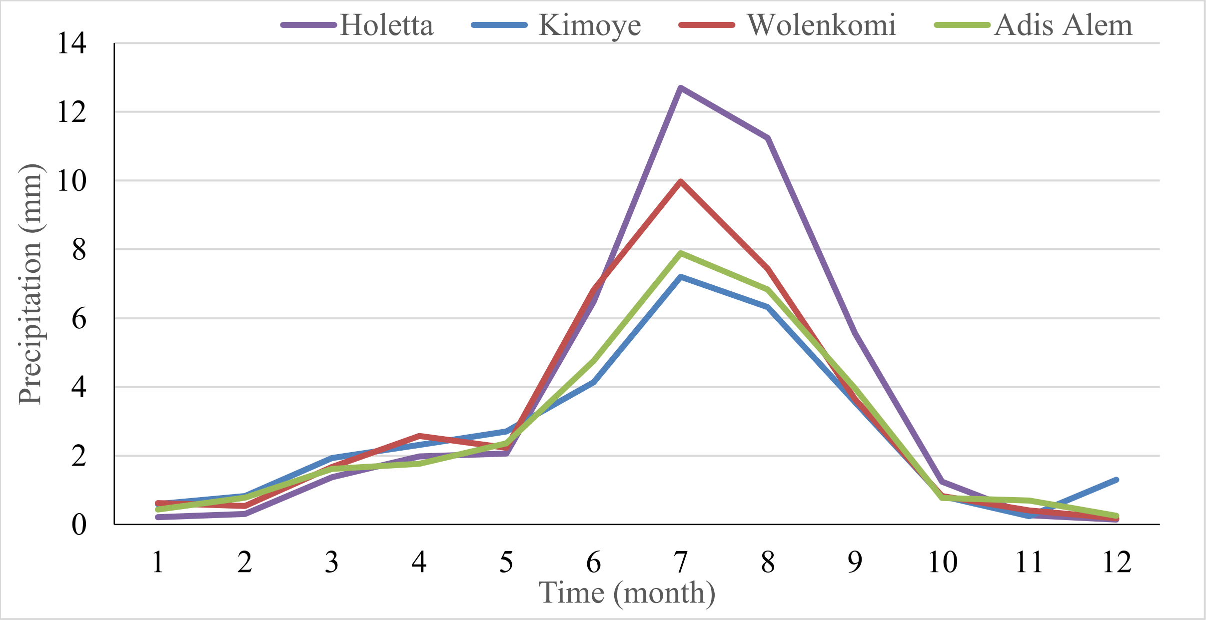


Figure 3.2: Plot of mean monthly precipitation of meteorological stations

3.2.1 Hydrological Data

Stream flow data of Holetta river was collected from Ministry of Water, Irrigation and Electricity (Hydrology department) that is recorded at Holetta gauging station near Holetta. Seventeen years (1993-2009) data was collected and used for model calibration and validation.

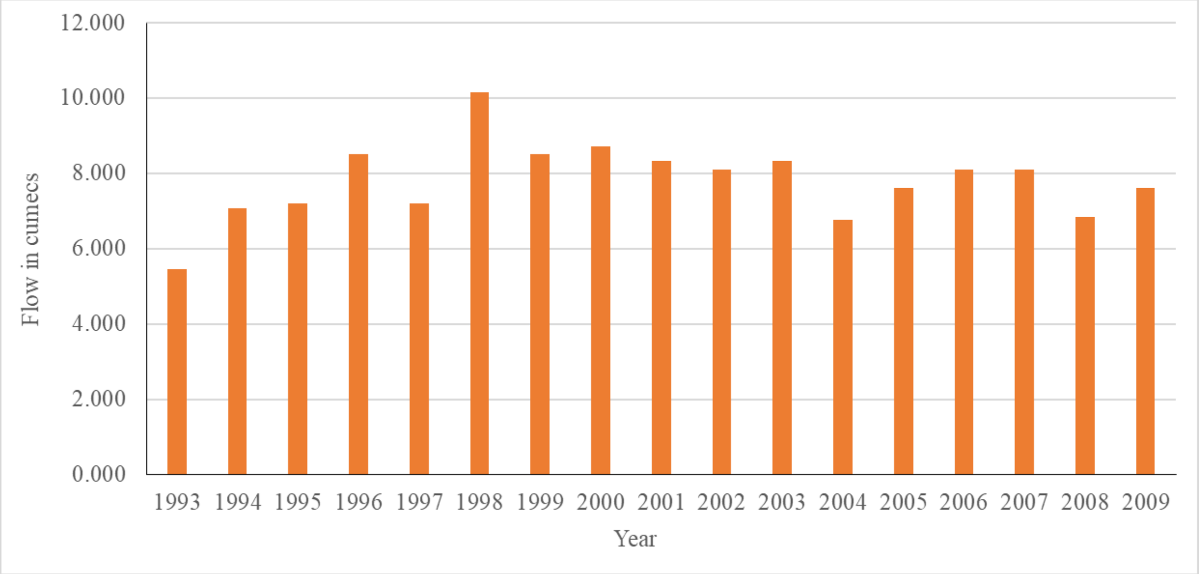


Figure 3.3: Mean annual flow graph of Holetta river

4.3 Data Analysis and Processing

The outcome of any hydrological models depends on the quality and completeness of data. One of the most important tasks and first step in any hydrological and meteorological study is accessing and analyzing reliable data. The incompleteness of precipitation data may be due to damaged measuring instruments, measurement errors and geographical paucity of data (data gaps) or changes to instrumentation over time, a change in the measurement site, a change in data collectors, the irregularity of measurement, or severe topical changes in the climate of a zone.

3.3.1 Filling Missed Data

In order to have full, adequate, and reliable information missed data have to be filled by using different approaches. Incomplete and inconsistent hydro-meteorological data are the main causes of inadequate and unstable design of hydraulic structures. The collected meteorological and hydrological data have some missed value and were filled by Arithmetic mean method. Arithmetic mean method is the simplest and commonly used method to fill in missing meteorological data in meteorology and climatology (Chow, 1988). The missed data were obtained by computing the arithmetic mean of the data corresponding to the nearest weather stations.

3.3.2 Data consistency test

Recorded data may not be consistent due to instrument error, personal error or other natural hazardous. For result accuracy and proper assessment of any water resource the collected data have to be checked for consistency. Double Mass Curve (DMC) technique is the best method and was used to check the consistency of the collected data. It is characterized by low data requirements and high transferability.

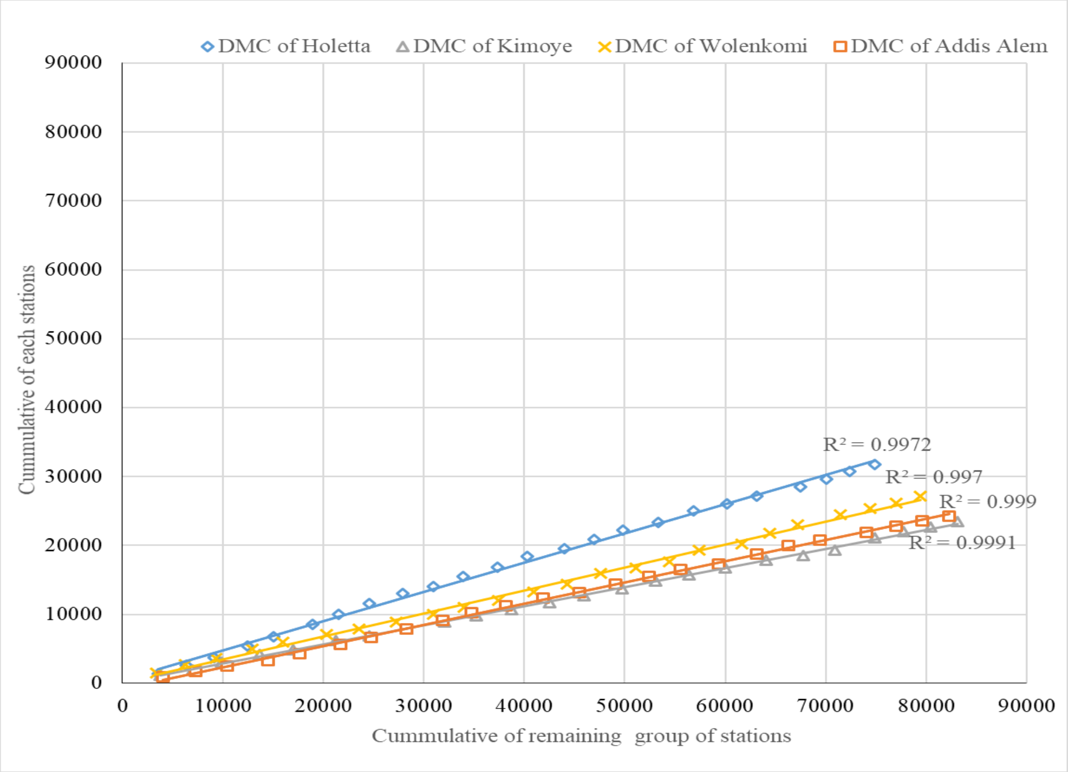


Figure 3.4: Double mass curve of meteorological stations

3.4 Materials and Tools

For the assessment of surface water potential of Holetta river catchment and water demand different materials were used. Seventeen years stream flow data of Holetta river from 1993 to 2009, twenty-four years (1993-2016) meteorological data, irrigation data, and population data was used. The software that were used includes Arc SWAT 2012, ArcGIS 10.1, WEAP21 model, SWAT_CUP and data preprocessing programs (pcpSTAT and Dew02).

3.5 Methods

This study aims to assess the surface water potential of Holetta river and its demand. In order to achieve this objective, specific methods and approaches were followed. Data collection, analyzing data, model selection, model setup, sensitivity analysis, model calibration and validation and finally model output analysis and interpretation was carried out to attain the general and specific objective of this study.

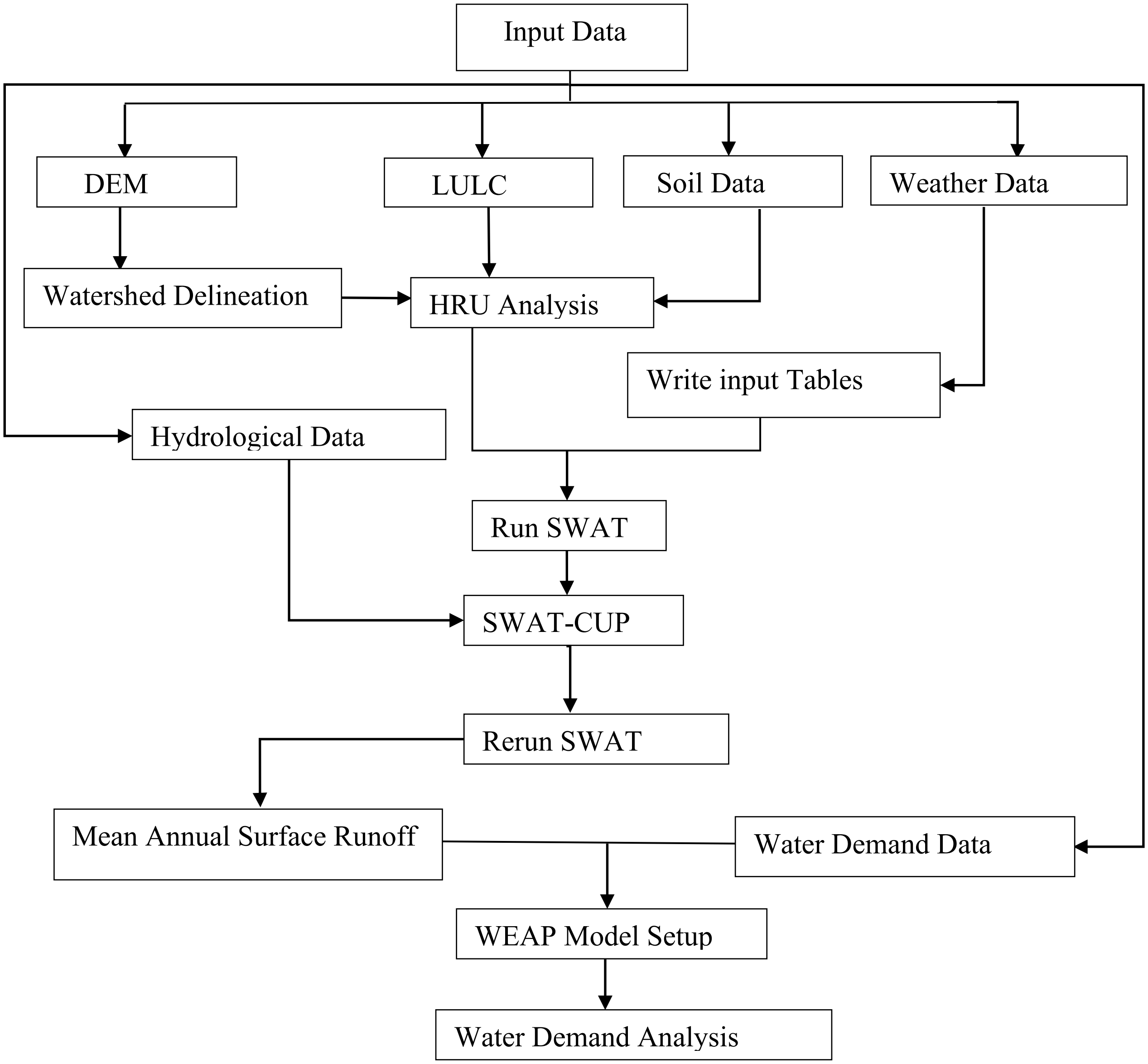


Figure 3.5: Flow chart of study method

3.6 SWAT Input Data

3.7.1 Digital Elevation Model (DEM)

A 30m by 30m Digital Elevation Model of Awash river basin was collected from Ministry of Water, Irrigation and Electricity (GIS Department) and was used to delineate the Holetta river catchment in SWAT model.

3.7.2 Land use land cover map

The land use land cover of Awash river basin was clipped and dissolved to Holetta catchment. The clipped land use land cover of Holetta river catchment was used for ArcSWAT land use classification. According to SWAT land use classification, the study area has four land use categories. Most of the catchment area is covered by agricultural land as the study area is found in both rural and urban area.

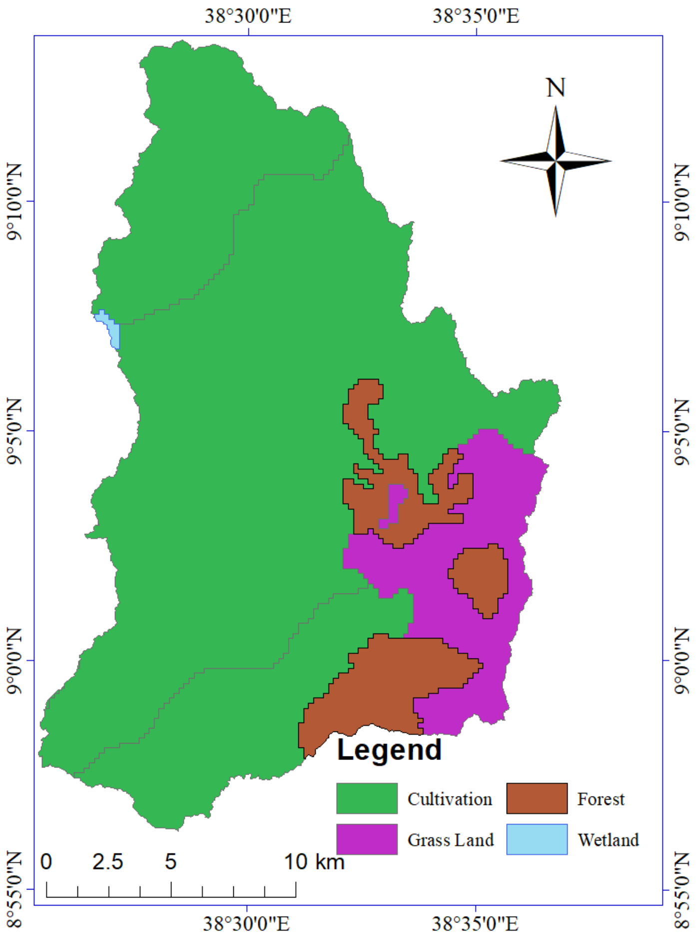


Figure 3.6: Land use land cover map of Holetta river catchment

Table 3.3: Holetta land use land cover and areal coverage

Land use land cover name	SWAT LULC code	coverage Area (km^2)
Cultivation	AGRR	320.7
Grass Land	PAST	40.56
Natural Forest	FSRE	36.56
Wetland	WETL	0.638

3.7.3 Soil map

The soil map of Awash river basin was clipped and dissolved to Holetta catchment by ArcGIS 10.1 version. The clipped soil map of Holetta river catchment was used for SWAT soil classification. According to SWAT soil classification, the study area has four soil categories.

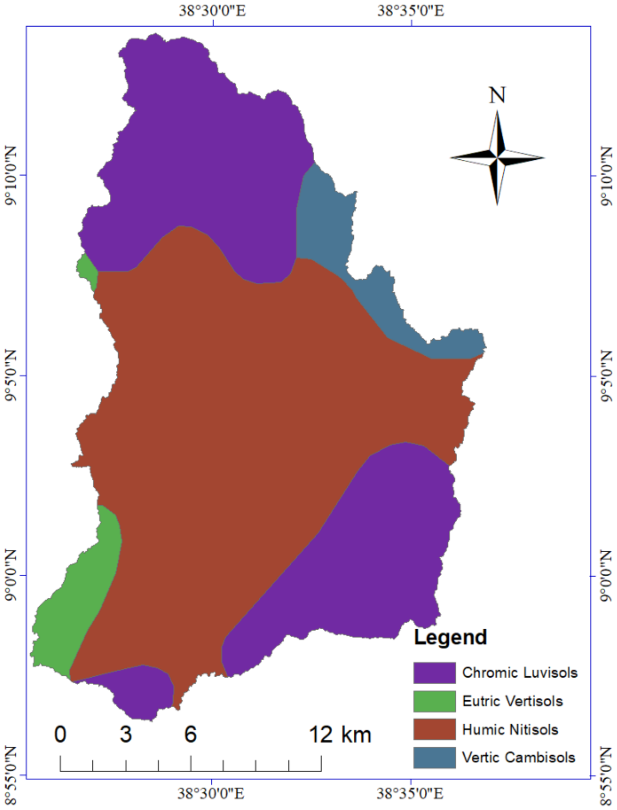


Figure 3.7: Soil map of Holetta river catchment

Table 3.4: Holetta SWAT soil classification and areal coverage

Soil Name	SWAT soil code	coverage Area (km^2)
Chromic Luvisols	CHLUVISOLS	144.89
Eutric Vertisols	EUVERTISOLS	15.413
Humic Nitisols	HUNITISOLS	219.193
Vertic Cambisols	VTCAMBISOLS	19.032

Humic Nitisol is the dominant soil type in the study area covering an area of 219.193 km^2. This type of soil normally consist clay and are hard when dry. Nitisols are well grained, deep, free-draining soils and permeable to water which makes it good for cultivation.

3.7.4 Land Slope Classification Map

The slope of watershed has a great role in the contribution of precipitation to direct surface runoff. In SWAT model the slope of Holetta watershed was classified in to three slope class by selecting multiple slope discretization. The slope class ranges are from 0-10%, 10-20% and 20-9999.

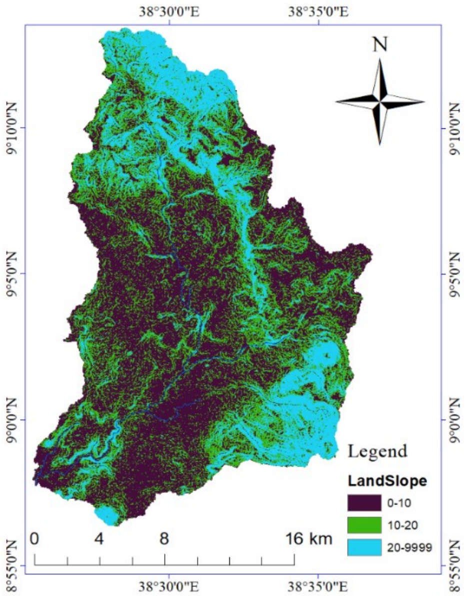


Figure 3.8: Slope classification map

3.7.5 Weather Data

The SWAT model requires a daily time step meteorological data that could either be read from a measured data set at a gauging station or be generated by a weather generator model which includes all the meteorological parameters such as rain fall, maximum and minimum temperature, relative humidity, solar radiation and wind speed. Those weather parameters were prepared in the format for SWAT model in which the model understands and access from the database. For the assessment of surface water potential of Holetta river catchment daily precipitation data of 24 successive years (1993-2016) were collected from Holetta, Addis Alem, Wolenkomi and Kimoye meteorological stations. Holetta meteorological station which is located in the study area was used as a weather generator station for SWAT model as it contains all weather data. All other three remaining nearby rain gauge stations was used for precipitation data only.

SWAT comprises the WXGEN weather generator model to generate climatic data or to fill in gaps in measured records. The incidence of precipitation on a given day has a major influence on relative humidity, temperature and solar radiation for the day. The weather generator first independently generates precipitation for the day. Once the total amount of precipitation for the day is generated, firstly the distribution of rainfall within the day is figured. Maximum and minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently (Neitsch, *et al*., 2005).

3.8 Surface Water Assessment

For the assessment of surface water potential of Holetta river catchment Soil and Water Assessment Tool was selected and used. In order to determine water balance components of the watershed the following procedures were followed.

3.8.1 SWAT model setup

Since Soil and Water Assessment Tool (SWAT) is an ArcGIS extension, firstly ArcGIS of different versions have to installed. After successful installation and SWAT database preparation new SWAT project setup was carried out and project directory was selected in which the whole work was executed. In addition to SWAT project setup it incorporates different user interfaces like Watershed Delineator, HRU Analysis, Write Input Tables, Edit SWAT Input, and SWAT Simulation.

3.8.2 Watershed Delineation

After new SWAT project directory was selected and saved, automatic SWAT watershed delineation becomes active. In its definition watershed is a hydrologically isolated region. DEM setup, Stream Definition, Inlet and Outlet Definition, Watershed Outlets Selection and Definition and Calculations of Sub basin Parameters were the activities carried out in watershed delineation. Digital Elevation Model of Awash river basin was used.

3.8.3 Hydrological Response Units Analysis

In order to adequately simulate hydrologic processes, the watershed is divided into sub-watersheds through which streams are routed. The sub-units of the sub-watersheds are referred to as hydrologic response units (HRUs) which are the unique combination of soil, land use, and slope characteristics and are considered to be hydrologically homogeneous. They are the smallest unit of calculation in SWAT made up of overlying elevation, soil, land-use, and slope. Both sub-watersheds and HRUs are user defined, providing model users with some control over the resolution considered in the SWAT model (Neitsch, *et al*., 2005). Accordingly, under HRUs analysis eleven sub-basins and seventy-eight HRUs are analyzed and land use/soils/slope definition was defined successfully.

After HRU analysis was successfully done, Write Input tables become active where all the SWAT input data are written to the SWAT data base for model further processing. In Edit SWAT Input the user can edit the SWAT database in the form that the model understands the codes.

SWAT simulation is the final stage that becomes active after all stages have been successfully completed. Setting the default simulation and SWAT Run was successfully carried out at this stage. SWAT check, reading model outputs, auto and manual calibration were also performed here.

3.9 SWAT Hydrological Process

SWAT model process and simulate the hydrology of a given watershed in to two phases. These are the land and water (routing) phases of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticides loadings to the main channel. The water or routing phase of the hydrologic cycle defines the transport of water, sediment and nutrient through the channel to the outlet of the sub-basin. Soil water balance is the primary consideration by the model in each HRU, which is represented as (Arnold, *et al*., 1998).

$$SW_t = SW_o + \sum_{i=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \qquad \text{Equation (3.2)}$$

Where SW_t is final water content of soil (mm), SW_o initial water content of soil on day I (mm), R_i rainfall amount on day I (mm), Q amount of surface runoff on day I (mm), ET_i amount of evaporation on day I (mm), P_i percolation on day I (mm) and QR_i is amount of return flow on day I (mm) and t - is time (days).

SWAT model simulates surface runoff volume and peak runoff rates for each HRUs in the watershed. The Soil Conservation Service (SCS) curve number (USDA-SCS, 1972) method was applied to estimate surface runoff using daily rainfall data and is given by the equation:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)} \qquad \text{Equation (3.3)}$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), S is the retention parameter (mm).

The retention parameter varies spatially in the watershed due spatial variation of soil, land use, management practice and slope and is given by the equation:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad \text{Equation (3.4)}$$

Where, CN- is average curve number of the watershed.

Initial abstractions (I_a), which includes surface storage, interception and infiltration prior to runoff and retention parameter (S) can be related to each other by the equation:

$$I_a = 0.2S \qquad \text{Equation (3.5)}$$

Hence, equation 3.2 becomes;

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{\left(R_{day} - I_a + S\right)} \qquad \text{Equation (3.6)}$$

Hydrological process of SWAT model consists of simulation, sensitivity analysis, calibration and validation from which the later three processes were performed and analyzed by a separate software called SWAT Calibration and Uncertainty Program (SWAT_CUP).

3.10 SWAT_CUP Software

Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats. SWAT-CUP is an interface software that was developed for Soil and Water Assessment Tool. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT (Abbaspour, 2015).

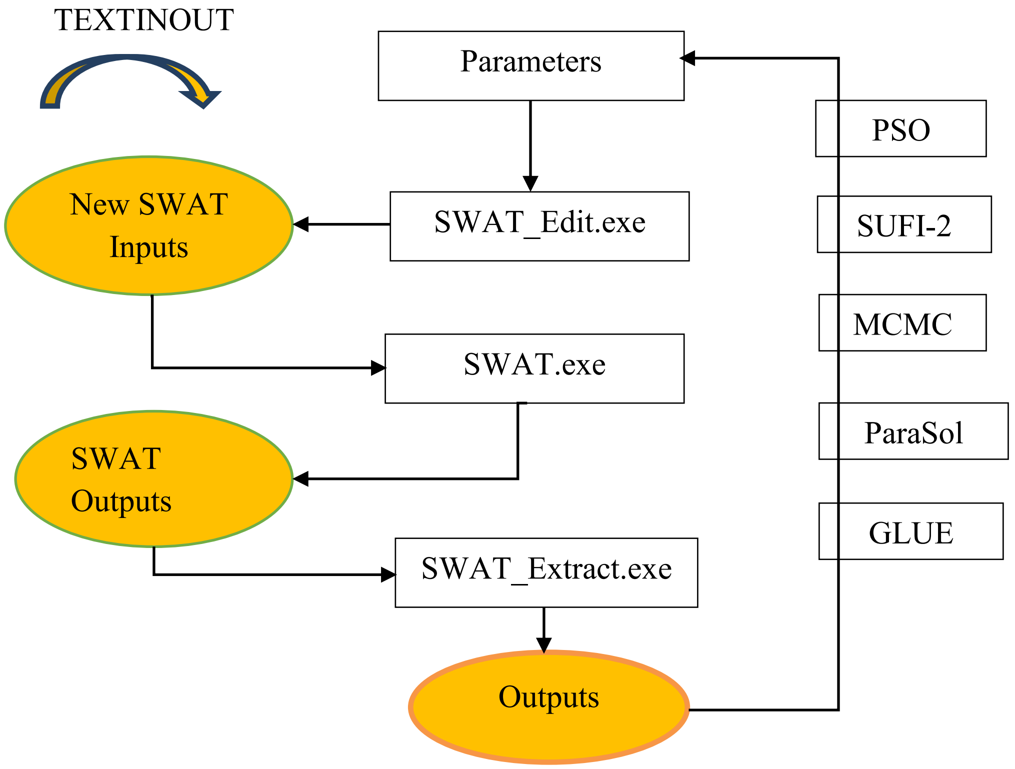


Figure 3.9: SWAT_CUP optimization programs

3.10.1 Sensitivity Analysis

Sensitivity analysis refers to the identification of the most important influence factor in the model. It is important from two perspective points of view: primarily, the parameters represent processes, and sensitivity analysis provides information on the most important processes in the study area. Secondly, sensitivity analysis helps to decrease the number of parameters in the calibration procedure by eliminating the parameters identified as not more sensitive in affecting model output. Two general types of sensitivity analysis are usually performed. These are one-at-a-time (OAT) or local sensitivity analysis, and all-at-a-time (AAT) or global sensitivity analysis. In OAT all parameters are held constant while changing one to identify its effect. But, in AAT all parameters are changing and about 500 – 1000 runs are required (Abbaspour, *et al*., 2017).

Accordingly, a number of flow parameters were selected and based on global sensitivity analysis rank finally seven highly sensitive flow parameters was used in SWAT model calibration and validation.

3.10.2 SWAT Model Calibration

SWAT model Calibration was performed by using SWAT_CUP SUFI-2 algorithm. Calibration is inherently subjective and, therefore, intimately related to model output uncertainty. Parameter estimation through calibration is concerned with the problem of making inferences about physical systems from measured output variables of the model.

Calibration involves comparison of the model output that is generated with the use of historical meteorological data and recorded stream flow data. The result of SWAT model for Holetta river was calibrated with the help of SWAT_CUP SUFI-2 algorithm.

For the calibration process it was suggested that 60% of the available data were sufficient while the remaining 40% were used for model validation process (Abbaspour, 2015). Accordingly, the record year 1993 and 1994 were used as a model warm-up period and the nine years stream flow data starting from 1st January 1995 to 31st December 2003 were used for calibration process.

3.10.3 SWAT Model Validation

After model calibration was successfully carried out, stream flow data of six years starting from 1st January 2004 to 31st December 2009 were used for validation. The statistical model performance measures used in calibration process were also applied in validating the stream flow data of Holetta river.

3.10.4 Model Performance Evaluation

Model performance evaluation were carried out to evaluate the performance of SWAT model whether it performs good or not. There is certain criterion of evaluating the goodness of fit measures between the observed and simulated values during model calibration and validation. Regression Coefficient (R^2) and Nash-Sutcliffe Efficiency (E_{NS}) were used to evaluate the model performance.

The Regression Coefficient (R^2): Coefficient of determination which describes the proportion of the total variance in the observed data that can be explained by the model is the first criterion to evaluate the model performance. The closer the value of R^2 to 1, the higher is the agreement between the simulated and the measured flow and is calculated as follow:

$$R^2 = \frac{[\sum(X_i - X_{av})(Y_i - Y_{av})]^2}{\sum[X_i - X_{av}]^2 \sum[Y_i - Y_{av}]^2} \qquad \text{Equation (3.7)}$$

Where: X_i is measured value, X_{av} is average measured value, Y_i simulated value, Y_{av} is average simulated value and subscript i stands for the i^th measured or simulated data, the same holds true for equation 3.2.

Nash-Sutcliffe Efficiency (E_{NS}): It indicates the degree of fitness of observed and simulated data and given by:

$$E_{NS} = 1 - \frac{\sum(X_i - Y_i)^2}{\sum(X_i - X_{av})^2} \qquad \text{Equation (3.8)}$$

The value of E_{NS} ranges from 1 (best) to negative infinity. If the measured value is the same as all simulated value, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between measured and simulated values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash & Sutcliff, 1970).

3.11 Water Demand Assessment

Water is the prime requirement for sustainable development of the society and environment. With increase in population, expansion in urbanization, economic growth, rapid industrial expansion, need of modern irrigation systems and high livestock production demand for water has increased over the last years (GWP, 2000).

Usually, water demand has been differentiated according to broad water usage: namely, residential, agricultural, commercial, industrial and recreational and environmental. Residential water demand covers uses of water by households, both inside and outside the confines of the residence and typically includes washing, cooking, bathing, laundry and gardening. Agricultural water demand is taken to cover all irrigation and livestock purposes. Commercial water use consists of water used by warehouses, stores and shopping centers, restaurants, hotels and related activities, cinemas, offices, and educational, entertainment and health establishments. Industrial water demand is focused on cooling, processing and manufacturing operations, power generation, sewerage, cleanup and sanitation, and fire protection. while, recreational and environmental relates to all end-uses other than residential that have value derived from utility provision direct to the consumer (Worthington, 2010).

Forecasting the water demand of different sectors and end users in specific watershed is a key for decision making in Integrated Water Resources Planning and Management. Generally, the water demand in the watershed are irrigation water demand, livestock and environmental water demand.

Holetta river is the source of water in the study area and mainly used by Holetta Agricultural Research Center (HARC), Tsedey Farm and farmers of four kebeles found at the downstream of the river. Holetta Agricultural Research Center and Tsedey farms use the river for irrigation purpose only while the farmers of the four kebeles use the river for livestock and human consumption in addition to small traditional irrigation.

3.12 WEAP Model Setup

The first task in WEAP model is establishing a new, blank working area and hence, the new blank project area was created by using Area, create area menu option. Initially blank area option was selected and from the world map, the geographic area of this particular study area was selected by drawing a rectangle around the area that represent the study area.

After a new blank project area was created, the vector maps of the study area that was previously prepared by GIS was added to the WEAP21 model and saved. Under the general menu, the current account year and time-step per year was set to 2018 and 12 respectively starting from the calendar month, January.

The Holetta river schematic was drawn manually following the natural river starting from the head of the river from where the water flows to the downstream end and named as Holetta River. All the demand sites were created and the related data were entered. The next step undertaken in WEAP21 model was connecting all the demand sites to the supply sources. In this case, the supply source is Holetta river. Transmission link was used to connect the supply source to the demand sites. In the reverse side, return flow link was created by connecting flow from the demand sites to the river. The final step was running the model and reading the result.

3.13 Current Water Demand in the Area

3.13.1 Domestic Water Demand

Domestic water demand includes water that is needed for basic needs such as drinking, cooking, washing clothes and utensils and house sanitation. It is difficult to determine the exact amount of this water demand category as it accounts minor water wastages. Different countries have different consumption requirement for domestic use. According to World Health Organization, about 100 liters per person per day is required to meet the basic needs (WHO, 2003).

Ethiopia developed a new and continuous Growth and Transformation Plan of different phases. According to the GTP-1 of Ethiopia, urban and rural water demands were 20 and 15 liters per capita per day respectively. In this phase there is scarcity of water demanded by both rural and urban residents due to economic development and as result the country developed the second GTP. In this plan, about 25 liters and 40-100 liters per capita per day of water is recommended for urban and rural respectively (GTP-2, 2015).

Accordingly, 25 liters per capita per day and 100 Lpcd was taken into account for rural and urban, since the study area lies both in urban and rural area. The amount of water required for domestic purpose was obtained by multiplying the population number by the per capita water demand.

3.13.2 Livestock Water Demand

Ethiopia is home to about 35 million tropical livestock units (TLU), and on average, about 25 liters of water per day is required by an individual tropical livestock unit. Note that one

Tropical Livestock Unit is equivalent to an animal of 250 kg live weight. Drinking water, water contained in feeds and metabolic water are the three sources of water for livestock. The water requirement of domestic animals varies between species, between breeds or varieties within species and individuals within breeds and also largely vary according to other factors such as food intake, quality of the food and air and water temperature (Zinash, *et al*., 2003).

There are different livestock types in the catchment and those are cows, ox, sheep, goats, horses, donkeys and mule, in which sheep dominates. The current livestock number in the catchment were about 2616 units. The amount of water required for each livestock was taken as 25 liters per livestock per day by adopting the maximum average water demand for the livestock as recommended by Zinash *et al*. 2003.

Table 3.5: Current livestock water requirement

Livestock type	TLU	Per capita water demand of TLU (l/d)	Total population	Water demand (l/d)	Total water demand	
					(m^3/d)	(m^3/year)
Cattle	0.7	25	854	14,945	14.945	5,454.93
Donkeys	0.4	25	434	4,340	4.34	1,584.10
Horses	0.4	25	84	840	0.84	306.60
Mules	0.4	25	14	140	0.14	51.10
Sheep	0.1	25	833	2,083	2.0825	760.11
Goats	0.1	25	397	993	0.9925	362.26
Total livestock water requirement in (m^3/year)						8,519.10

3.13.3 Environmental Flow Requirement

Any withdrawal of water for consumptive use is likely to have a related impact on the sustenance of instream ecosystem services. From the total available water resources in specific river some amount of water is required to sustain environmental values and benefits (J. Pittock & B. A. Lankford, 2010).

Instream flow is required to reserve and sustain the natural ecosystem in a given area and is the one that must have to be released. In order to maintain healthy, productive and sustainable and groundwater systems, it is essential to give great recognition to the environmental flow water requirement. For this particular study, the minimum flow (base flow), determined by the flow duration curve, in the river during dry season was taken as the volume of water required for the sustainability of ecosystem and environment.

3.13.4 Irrigation Water Demand

Agriculture is the dominant activity in Ethiopia and as a result Agricultural sector is the leading sector in the Ethiopian economy. Most of the country's land is still under rainfed irrigation system. Due to limited water storage structures and high spatial and temporal variations in rainfall, there is no enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage in the country (Seleshi, et al., 2007).

All the irrigation land, including Holetta Agricultural Research Center, Tsedey Farm and small village farmers irrigable area accounts about 890 hectares were considered as one demand site in the catchment in WEAP21 model. CROPWAT version 8.0 for windows software, which was developed by Food and Agricultural Organization of United Nations, was used to determine the monthly variation in percentage and the crop water requirement for five selected dominant crops (potato, tomato, cabbage, pepper and maize) in the study area.

3.13.5 System Losses

In any hydrological system, all the available water does not reach fully the demand sites. This indicates that there is a wastage of water (system loss) in that system, whether it is major or minor losses and it is difficult to calculate the exact amount of water that was lost in the system. For this particular study, system loss was taken as 20 percent of the total water required for domestic, commercial and institutional water demand and industrial water demand

3.14 WEAP Model Input and Assumptions

In WEAP, models are called areas and the background vector data of the Holetta river catchment shape file which was created by ArcGIS software during watershed delineation, was added to the WEAP21 model. Once the vector layer was added under schematic view bar, the years, time-steps and units were adjusted. The time steps per year was set to be 12 and the time step boundary “based on calendar month”, starting with the month of January was selected.

In this study, only the current water demand was determined in which the year 2019 was used as the current account year and four demand sites (excluding environmental flow requirement) were considered. The four major demand sites in the catchment are irrigation demand site, urban domestic demand site, rural domestic demand and livestock.

Modeling assumptions: regardless of the differences in financial returns from each demand sites, all demand sites were given equal priority in water allocation.

4. RESULT AND DISCUSSIONS

4.1 Sensitivity Analysis

Groundwater delay (GW_DELAY), SCS runoff curve number ‘f’ (CN2), Moist bulk density (SOL_BD), Available water capacity of the soil layer (SOL_AWC), Saturated hydraulic conductivity (SOL_K), Manning's "n" value for the main channel (CH_N2), Baseflow alpha factor (ALPHA_BF), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Groundwater "revap" coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN), Effective hydraulic conductivity in main channel alluvium (CH_K2), Average slope length (SLSUBBSN), Manning's "n" value for overland flow (OV_N), Maximum canopy storage (CANMX), Soil evaporation compensation factor (ESCO) and Baseflow alpha factor for bank storage (ALPHA_BNK) were considered for sensitivity analysis and based on Global sensitivity analysis seven of them were found highly sensitive to flow and they are used for calibration and validation of SWAT model. Table 4.1 shows the seven sensitive flow parameters in rank order from high to low and their respective fitted values. (see Appendix I)

Table 4.1: Result of sensitivity analysis

Parameter Name	t-Stat	p-value	Min. value	Max. value	Fitted value	Rank
R__CN2.mgt	18.3603	0.0000	-0.200000	0.200000	0.140000	1
R__SOL_AWC(..).sol	-3.8807	0.0008	0.000000	1.000000	0.716667	2
R__CH_N2.rte	1.1497	0.2626	0.000000	0.300000	0.185000	3
R__REVAPMN.gw	1.0681	0.2971	0.000000	500.000000	308.333313	4
V__GW_REVAP.gw	0.4753	0.6393	0.020000	0.200000	0.077000	5
V__GWQMN.gw	0.3021	0.7654	0.000000	2.000000	0.633333	6
R__SOL_K(..).sol	-0.1204	0.9052	-0.800000	0.800000	0.080000	7

In the simulation of sensitivity analysis, SCS runoff curve number (R_CN2.mgt) and SOL_AWC were found as the most sensitive parameters to affect the stream flow. This was due to the higher sensitivity of the CN2 is attributed to the higher influence of runoff generation and SOL_AWC represent the soil moisture characteristics which influence the surface runoff.

To identify the relative significance of each parameter t-test was used. Based on t-stat and p-value the sensitive parameters have been identified. The larger (absolute value) t-stat and the smaller (absolute value) p-value, the more sensitive the parameter. (see appendix I).

4.2 Model Calibration

Model calibration for stream flow was done for average monthly time steps and the initial simulation was done by using the default parameters values provided by SWAT Calibration and Uncertainty Program. At the default calibration stage, the values of coefficient of regression and Nash-Sutcliffe Efficiency for model performance evaluation weren't fulfilled the model performance evaluation criterion ($R^2 > 0.6$ and $E_{NS} > 0.5$) (Santhi C., *et al*., 2001).

Thus, model parameter adjustments were carried out by varying the parameters until the model performance evaluation criterion ($R^2 > 0.6$ and $E_{NS} > 0.5$) were achieved for a realistic hydrologic simulation.

First SWAT model was set to run for a period of seventeen years starting from 1st January 1993 to 31st December 2009 with the initial two years (1993 and 1994) as a model warm-up periods to stabilize the model for further simulation. From the available stream flow data of Holetta river 60 % were used for calibration process (Abbaspour, 2015).

Accordingly, average monthly stream flow data from 1995 to 2002 were used for model calibration process with the seven sensitive flow parameters as described in Table 4.1. Finally, the monthly calibration results for R^2 and E_{NS} were 0.89 and 0.74 respectively which were greater than lower limit of the acceptable value ($R^2 > 0.6$ and $E_{NS} > 0.5$).

The result of the model calibration process showed that the mean of simulated and that of observed stream flow were 8.82 and 8.22 m^3 /sec respectively. Generally, SWAT model showed good performance ($R^2 > 0.6$ and $E_{NS} > 0.5$) and the model slightly over predicted the stream flow of Holetta river.

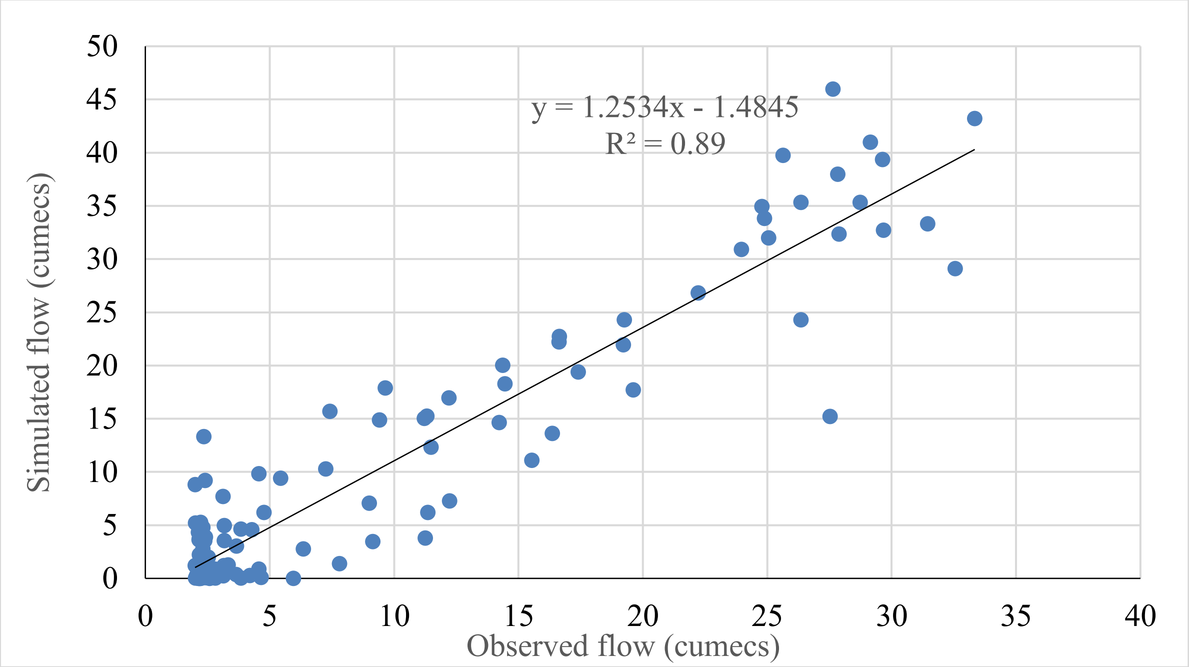


Figure 4.1: Calibration of average monthly observed Vs simulated flows

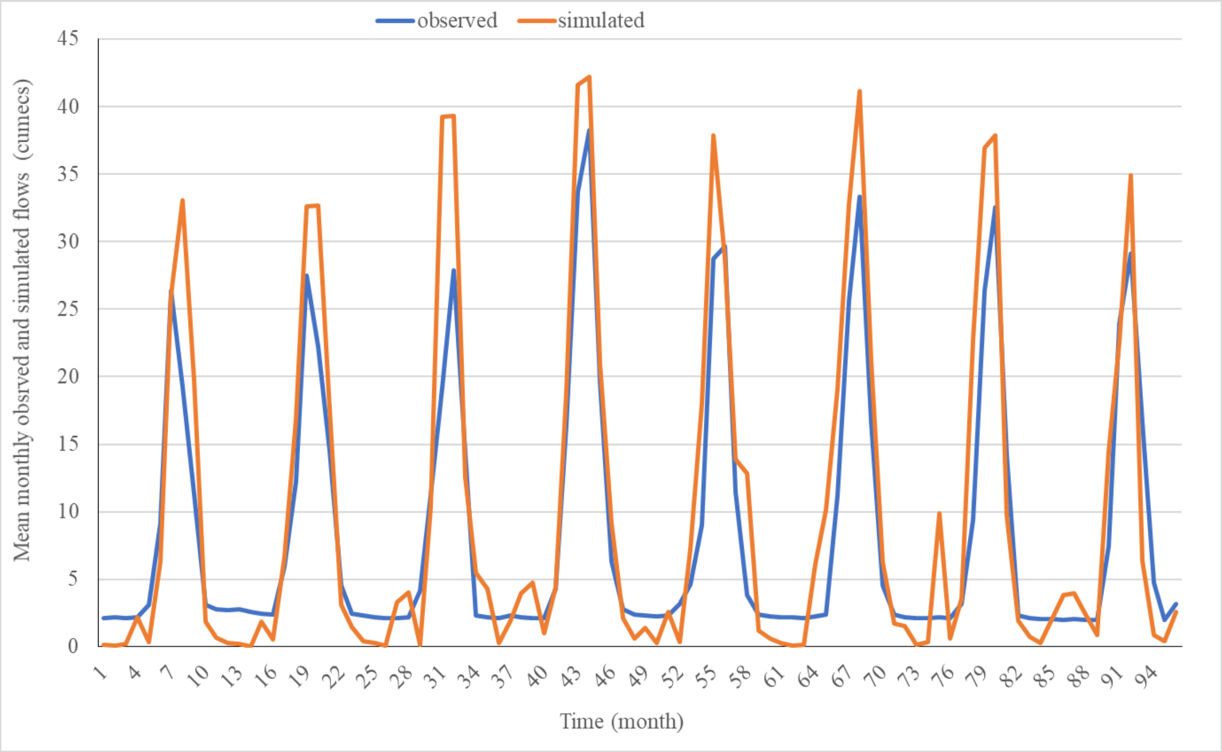


Figure 4.2: Calibration of average monthly observed and simulated flow Vs time

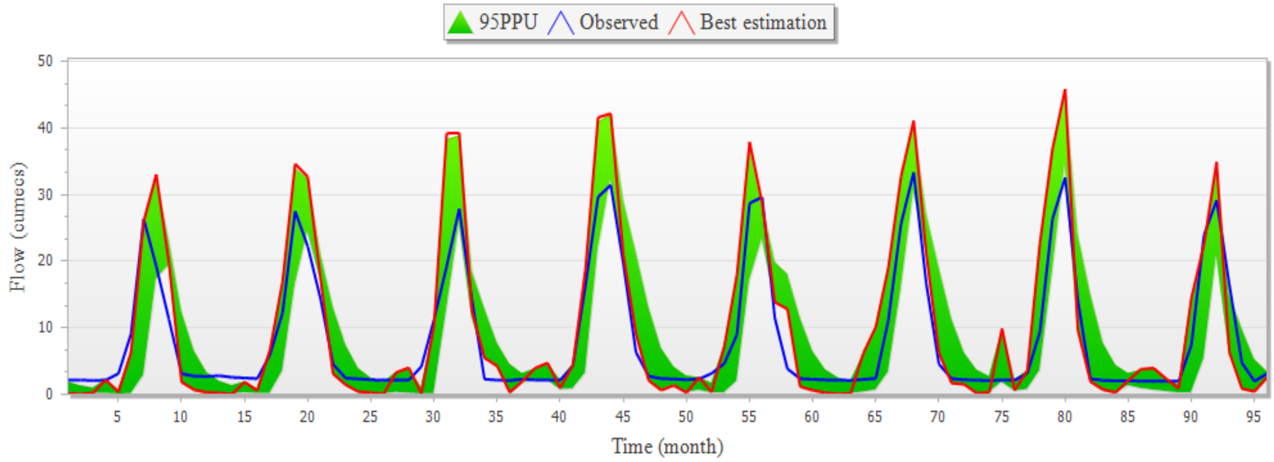


Figure 4.3: Calibration 95ppu plot

4.3 Model Validation

Validation process was performed using seven years stream flow data which is 40 % of the available data. The flow record year starting from 2003 to 2009 were used for validation of the SWAT model (Abbaspour, 2015).

The statistical analysis found that the model had strong predictive capability and showed a good agreement between observed and simulated flow with R^2 and E_{NS} values of 0.87 and 0.65 respectively. Statistical model efficiency criteria fulfilled the requirement of $R^2 > 0.6$ and $E_{NS} > 0.5$ (Santhi C., *et al*., 2001).

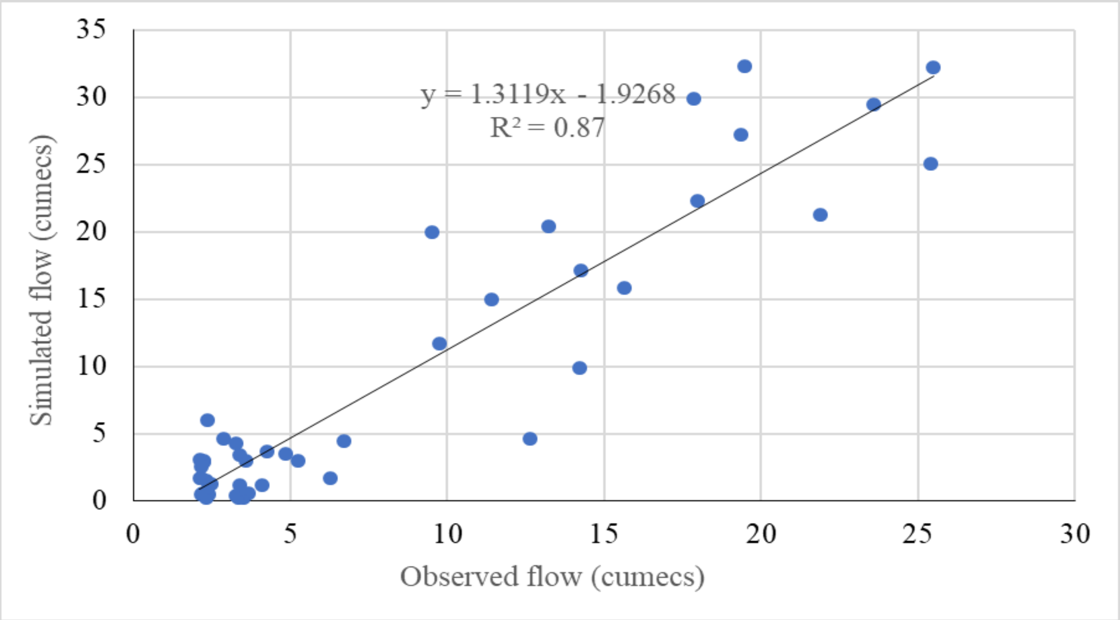


Figure 4.4: Validation average monthly observed Vs simulated flows

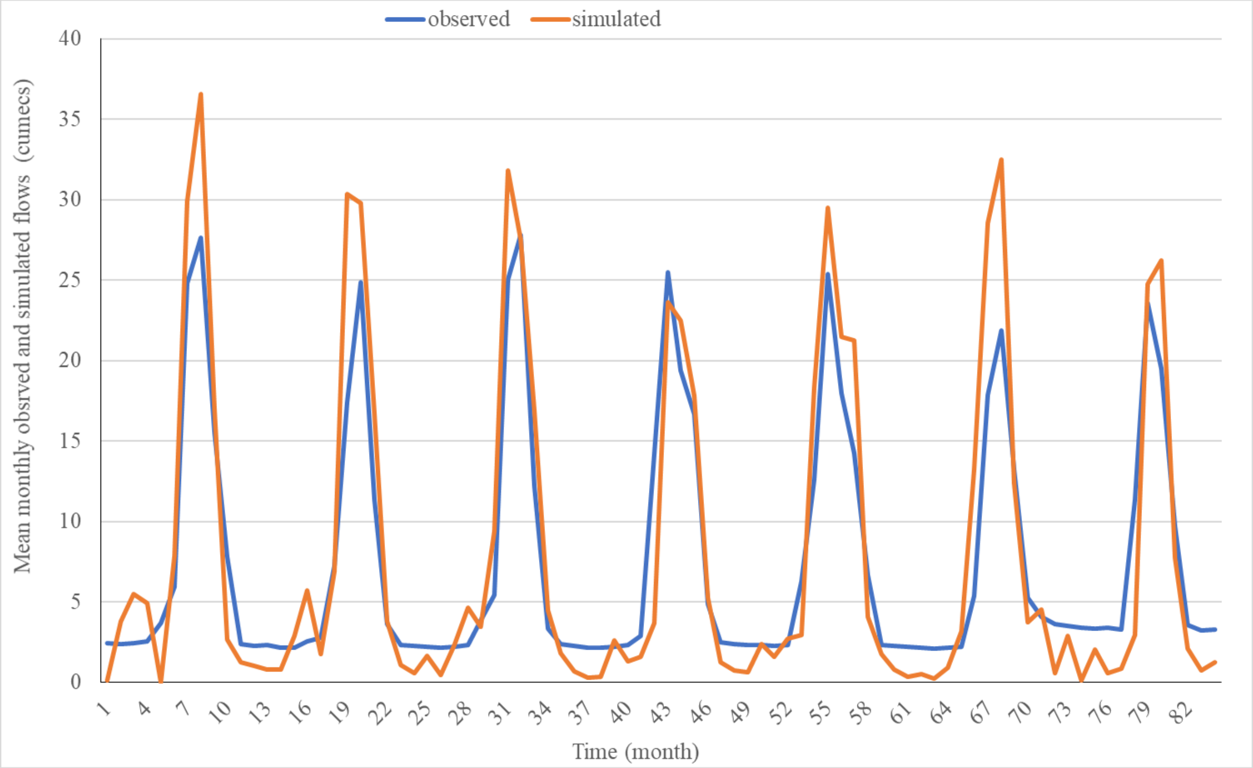


Figure 4.5: Validation average monthly observed and simulated flows Vs time

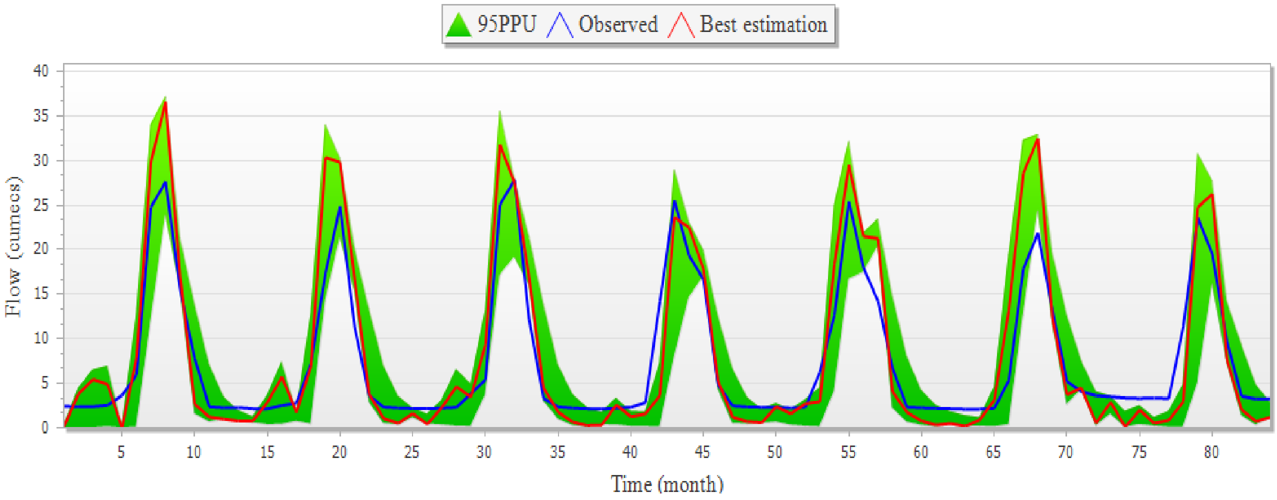


Figure 4.6: Validation 95ppu plot

The mean observed and simulated flows on validation process were found to be 7.62 and 8.08 m^3/sec respectively. The result revealed that the model slightly over predicted the stream flow of Holetta river.

Table 4.2: Summary of model performance for calibration and validation periods

Period	Monthly Model Efficiency Measures			Remark
	R^2	E_{NS}	PBIAS	
Calibration (1995-2002)	0.89	0.74	-7.3	Ok
Validation (2003-2009)	0.87	0.65	-6.4	Ok

4.4 Performance of SWAT Model

The result of SWAT model and as well its performance was evaluated after sensitive parameters were analyzed and stream flow calibration and validation were carried out using SWAT_CUP SUFI-2 algorithm respectively. These processes were performed to check and compare the simulated water balance of the watershed with the observed stream flow data.

The result of model calibration and validation, based on model efficiency measures values ($R^2 > 0.6$ and $E_{NS} > 0.5$) (Santhi C., *et al*., 2001), showed that SWAT model had a strong predictive capability in modeling the available surface water potential of Holetta river. Even though SWAT performed well, it had over predicted the stream flow of Holetta river.

4.5 Water Balance and Surface Water Potential

SWAT model simulates all hydrological components of the whole watershed based on the input data provided to the model by the user such as weather data, land use, soil and slope characteristics of the watershed. After model was calibrated and validated on monthly basis, the performance capability of the SWAT model on Holetta river catchment was evaluated and it has shown good agreement (based on R^2 and E_{NS} values) between observed and simulated flow.

Accordingly, the catchment receives a mean annual precipitation of 1213.5 mm and releases 525.2 and 16.12 mm through evapotranspiration and lateral flow respectively. The annual surface water runoff depth of the catchment was 381.71 mm. Thus, the total annual surface runoff generated by SWAT model from the whole catchment with an area of 393.25 km^2 was 149.8 Mm^3.

The mean monthly surface runoff from the catchment at the outlet in the months of January, February, March, April, May, and December were 0.582, 1.192, 2.556, 1.947, 2.080, 0.342 Mm^3 respectively.

Table 4.3: Summary of average monthly runoff from Holetta river catchment

Month	Surface Runoff (mm)	Surface Runoff Volume (m^3)	Surface Runoff Volume (Mm^3)
January	1.480	582010.000	0.582
February	3.030	1191547.500	1.192
March	6.500	2556125.000	2.556
April	4.950	1946587.500	1.947
May	5.290	2080292.500	2.080
June	24.190	9512717.500	9.513
July	143.460	56415645.000	56.416
August	135.400	53246050.000	53.246
September	46.980	18474885.000	18.475
October	5.770	2269052.500	2.269
November	3.870	1521877.500	1.522
December	0.870	342127.500	0.342

4.6 WEAP Model Result

4.6.1 Current Water Demand

WEAP21 model had performed the water allocation based on the demand site priorities and annual water use rate of each demand sites. As described under section 3.14, regardless of the differences in financial returns from each demand sites, all demand sites were given equal priority in water allocation. Holetta river catchment, which is the study area, shape file was prepared by using ArcGIS 10.1 and added to the WEAP21 model. The source of water for allocation was Holetta river in which the mean monthly stream flow was used as river head flow.

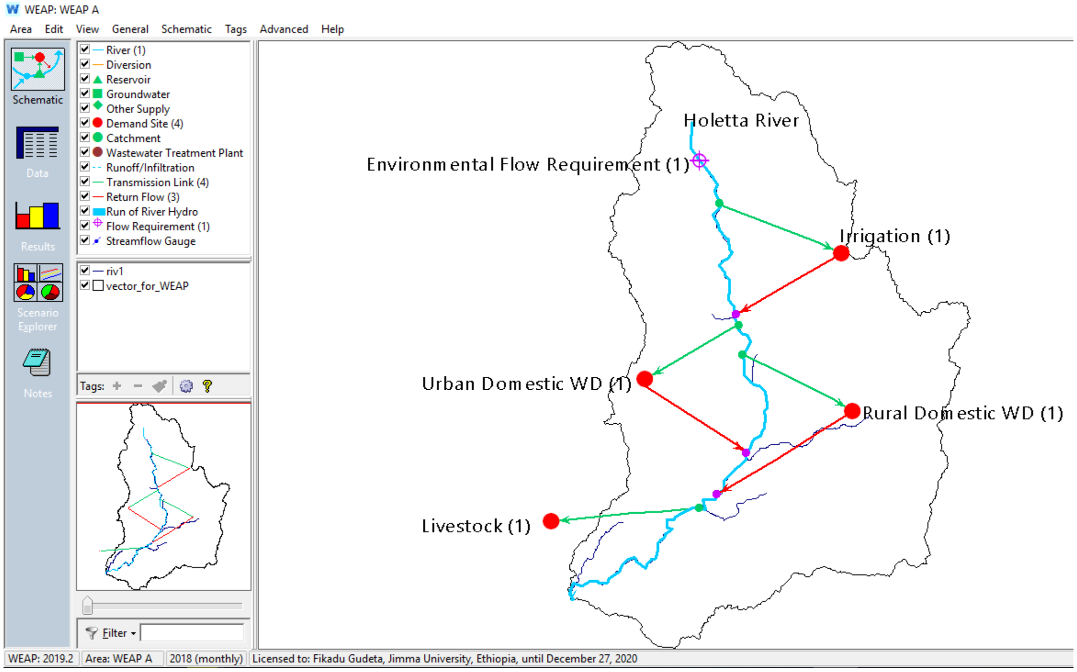


Figure 4.8: Screenshot of the schematic of Holetta river catchment for WEAP

The current water demand for both urban domestic water demand and rural domestic water demand, irrigation water demand, and livestock water demand were determined.

I. Irrigation water demand

The study area receives a mean annual rainfall of 1213.5 mm but due to spatial and temporal variation it does not satisfy the communities capacity for crop production. Modern irrigation system does not require water throughout the year due to rainy season that starts from mid-June to December in the country. Furrow irrigation type is highly experienced in the study area with unlined natural canals. As a result of this, more water is required to satisfy the crop water requirement and losses in the system.

Potato, tomato, cabbage, pepper and maize are the dominant and common crops that were cultivated by irrigation system in the study area in addition to cereal crops. Using CROPWAT 8.0 software the monthly variation of the crop was calculated and presented in table below.

Table 4.4: Crop water demand monthly variation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
Variation rate (%)	7.87	16.85	29.21	26.97	15.73	1.12	0.0	0.0	0.0	0.0	0.0	2.25

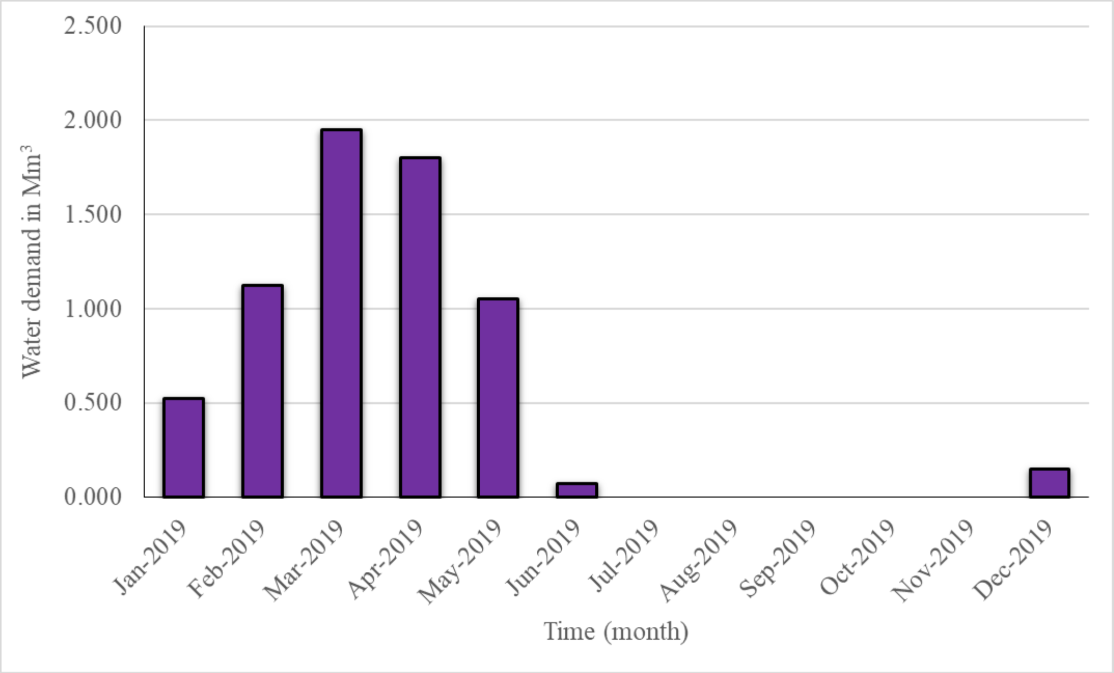


Figure 4.9: Mean monthly current irrigation water demand for the year 2019

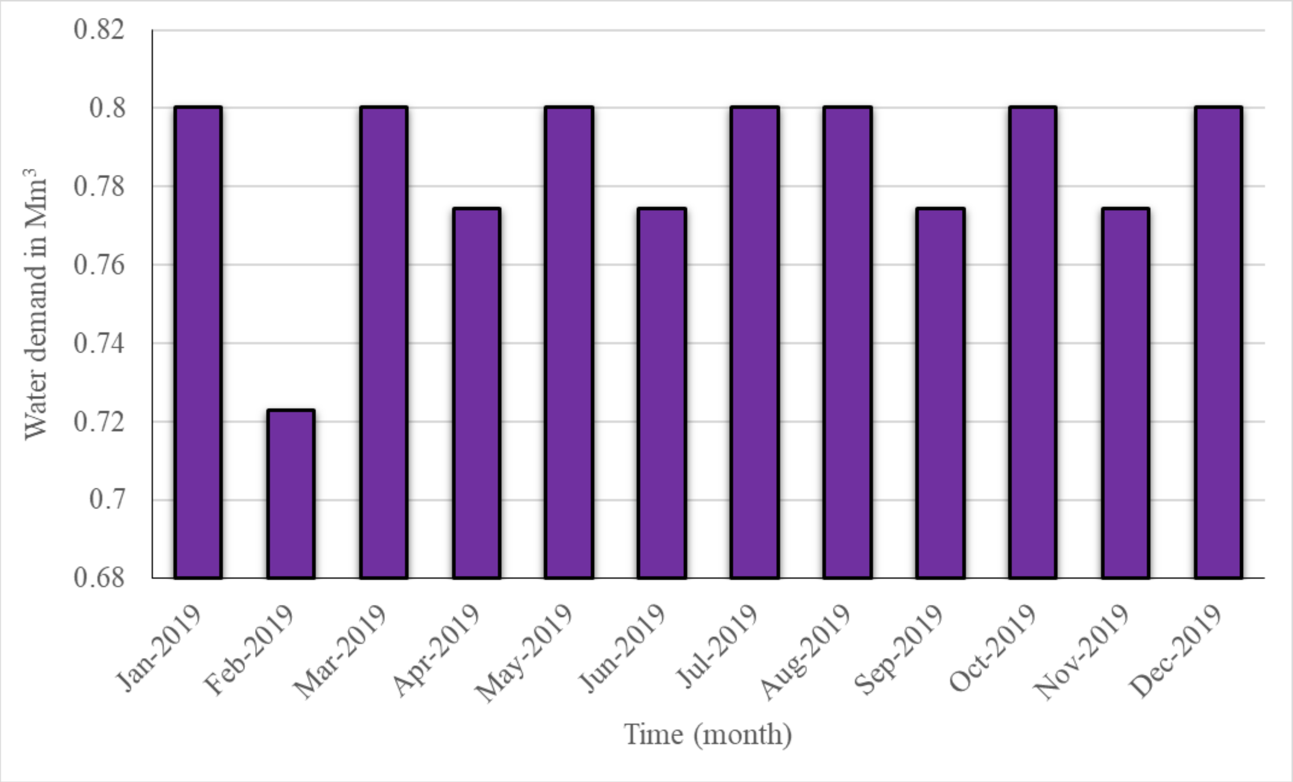
From the WEAP21 model output, the mean monthly water allocated for the cultivation of the dominant crops, in the dry season, covering a total irrigable area of 890 ha were 0.525, 1.125, 1.950, 1.800, 1.050, 0.150 Mm^3 for the months January, February, March, April, May, and December respectively.

The irrigation water requirement result showed the water requirement was high for the dry months (January to May and December) and it was zero during rainy season especially from June to September due to that the area receives heavy rain and plants do not require water.

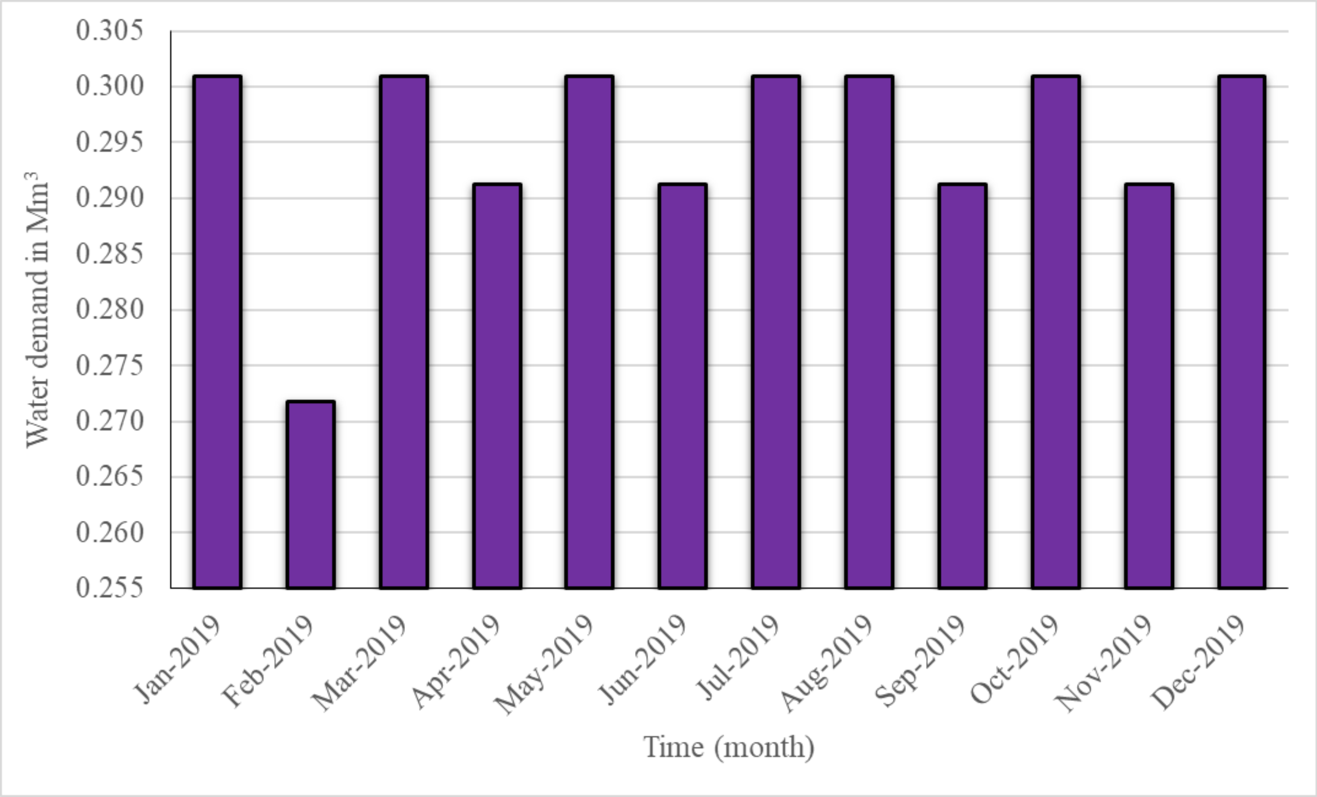
II. Domestic water demand

WEAP21 model result has revealed that rural and urban domestic water demand together consumes the more water in the study area. The average annual water use rate for both rural and urban area was taken as 87.43 cubic meter per person for a total population of 40,528 and 107,762 for urban and rural area respectively.

Generally, the WEAP model result showed that 9.42 and 3.54 Mm^3 of water were allocated for rural and urban domestic water demand sites by the end of 2019 respectively.



(a)



(b)

Figure 4.10: Mean monthly current rural (a) and urban (b) water demand

III. Livestock water requirement

One of the basic sources of income and daily diet, especially in all most Ethiopian rural areas is livestock resources. Holetta river, which flows in both rural and urban areas of the catchment, serves as a source of drinking water for variety of livestock living in the catchment. Cattle, donkeys, horses, sheep, goats and mules are the dominant and main livestock varieties in the study area.

Based on the data provided, the WEAP21 model result showed that a total water demand for the livestock in the catchment was 0.0239 million cubic meters which was more than the current water requirement for the livestock as illustrated in Table 3.5.

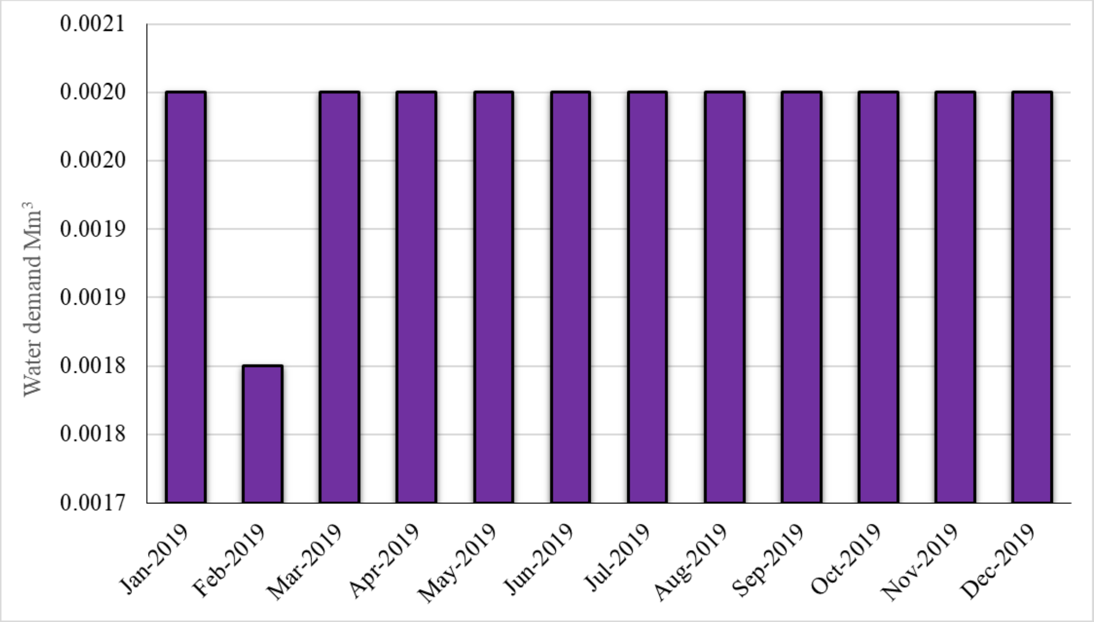


Figure 4.11: Mean monthly current livestock water demand

IV. Environmental flow requirement

Flow duration curve method was applied to determine the minimum flow of Holetta river that corresponds to 90 % of exceedance for instream flow requirement. From the graph it was found that, on monthly basis, a minimum of 2.287 m^3/sec of river flow was left for the sustainability of instream ecosystem services.

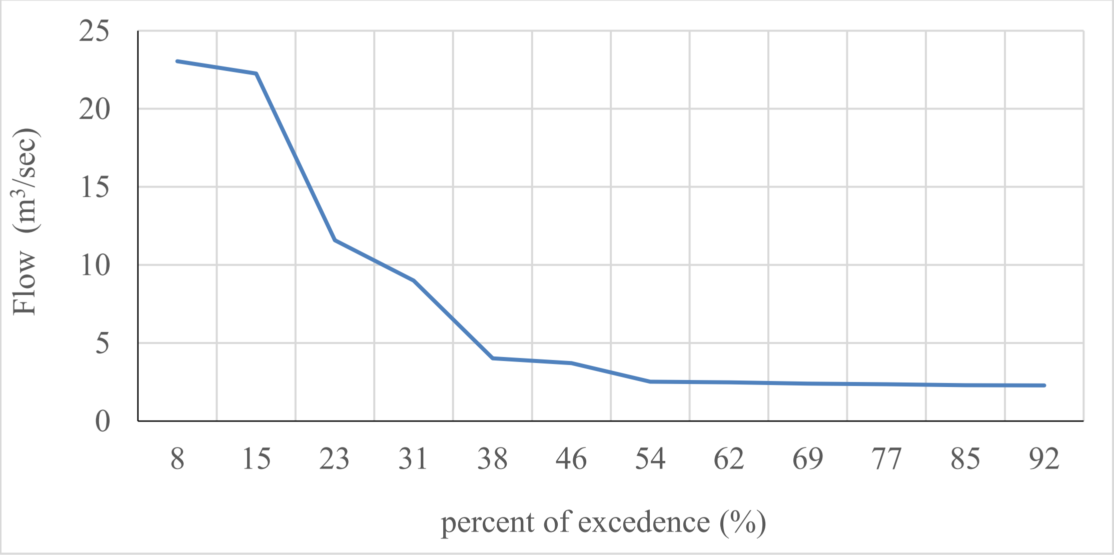
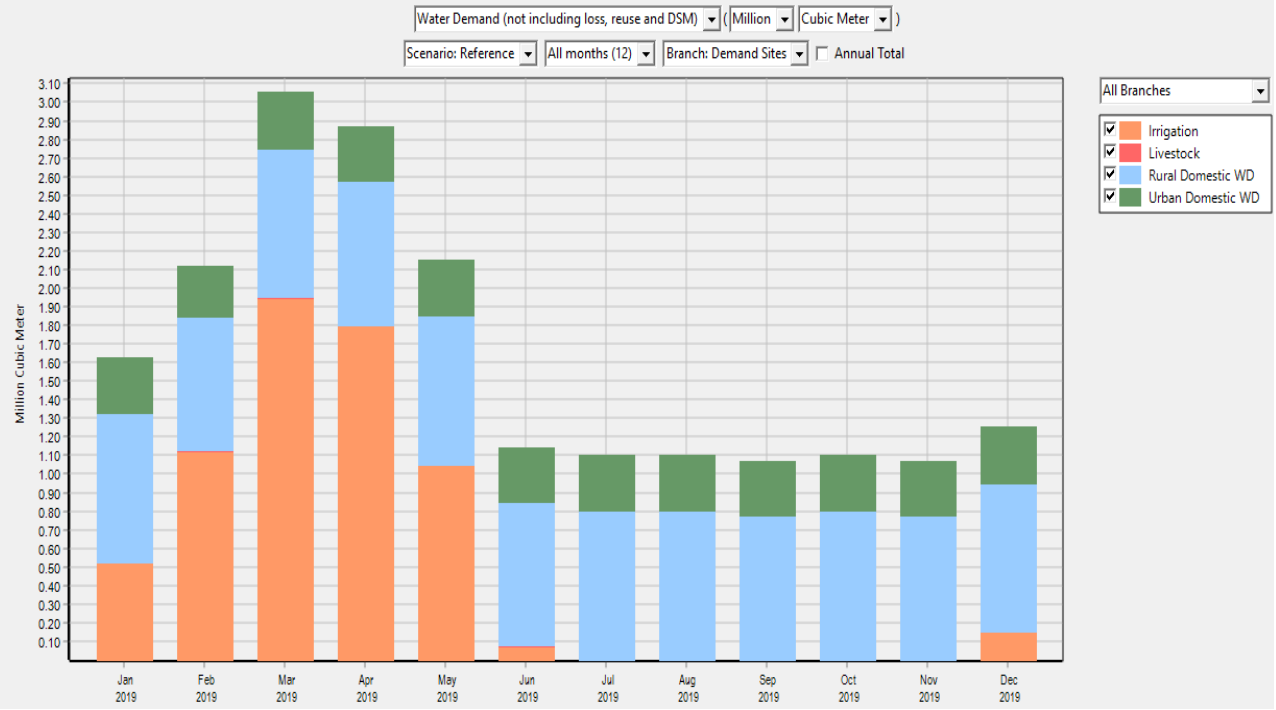


Figure 4.12: Flow duration curve

Generally, the overall current (2019) water demand of the selected demand sites in the catchment was 19.66Mm^3 excluding environmental flow requirement and system loss.



Water Demand (not including loss, reuse and DSM) (Million Cubic Meter)

Scenario: Reference All months (12) Branch: Demand Sites ☐ Annual Total

All Branches

Figure 4.13: Current water demand of all sites (not including EFR)

4.6.2 Demand sites coverage

From the SWAT model available surface water potential result and WEAP model water allocation result for the selected demand sites, it was found that, the available surface water potential of Holetta river is less than the current water requirement during the dry months. The water shortage is seasonal and mainly due to temporal rainfall pattern. From the historical data collected, there is no rainfall during the dry season. The main recharge of the Holetta river is rainfall plus to ground water contribution as a result, the available river flow becomes less in the dry season. This indicates that, currently there is unmet demand in the study area during the dry season.

Table 4.5: Dry season water shortage volume

Months	January	February	March	April	May	December
Surface Runoff Volume (Mm^3)	0.582	1.192	2.556	1.947	2.080	0.342
Total Demand Volume (Mm^3)	1.628	2.121	3.053	2.868	2.153	1.253
Deficit Volume (Mm^3)	1.046	0.930	0.497	0.921	0.073	0.911

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Determination of the available surface water potential of a river basin or specific watershed has great importance for Integrated Water Resources Management (IWRM) and decision making. As a result, different scholars and researchers in the country as well as over the whole world have tried to model the hydrological processes of different river basins at large and at specific watershed scale using Soil and Water Assessment Tools and Water Evaluation and Planning. The SWAT model has been used over the last few decades and showed significant performance capabilities.

The result of model calibration and validation, based on model efficiency measures values ($R^2 > 0.6$ and $E_{NS} > 0.5$) (Santhi C., *et al.*, 2001), showed that SWAT model had a strong predictive capability in modeling the available surface water potential of Holetta river. Even though SWAT performed well, it had over predicted the stream flow of Holetta river.

To come up with more reliable and accurate results, it is important to analyze and follow specific procedures. Consequently, in determining the available surface water potential of Holetta river, different hydro-meteorological data have been collected and analyzed. Analysis of the collected data includes gap filling, consistency checkup and homogeneity test for more accurate and reliable model results.

The model performance efficiency measures result showed a reasonable agreement between the observed and simulated stream flow. During parameterization using SWAT-CUP SUFI-2 algorithm, selection of appropriate parameters has its own effect on model result. Both SWAT and WEAP models have showed and generated the result that is more reliable in the study area based on the input data fed to the models by the user.

Currently, based on the SWAT and WEAP model results, the surface water potential of Holetta river was found to be enough in rainy seasons but, there is unmet demand in the months of January, February, March, April, May, and December with a deficit volume of 1.046, 0.930, 0.497, 0.921, 0.073, and 0.911 Mm^3 respectively.

5.2 Recommendations

In terms of hydrology, Holetta river is one of the main sources of surface water in the study area and it has many users. Hence, the hydrology of the Holetta river catchment needs detail investigation for sustainable water resource management.

In this study only, current water requirement of selected demand sites in the study area was considered and hence, different scenarios have to be developed and future water demand of the demand sites have to be determined.

To overcome water scarcity during the dry season, it is important to store the available water in the rainy season by constructing artificial water storage. Improving the efficiency of the irrigation system is another mechanism to minimize water losses through conveyance structures due to expected rapid expansion of modern irrigation system and irrigable area.

REFERENCES

Abbaspour, K. C., 2015. SWAT-CUP: SWAT Calibration and Uncertainty Programs - A User Manual.

Adgolign, T.B., Rao GV, R.S., Abbulu, Y. 2016. WEAP modeling of surface water resources allocation in Didessa. Sustain. Water Resour. Manag. vol. 2, pp 55–70.

Agarwal Anil, Marian S. delos Angeles, Sonia Davila-Poblete, Ivan Chéret, Ramesh Bhatia, Malin Falkenmark, Fernando Gonzalez Villarreal, Torkil Jønch-Clausen, Mohammed Aït Kadi, Janusz Kindler, Judith Rees, Paul Roberts, Peter Rogers, Miguel Solanes, Albert Wright, 2000. Integrated Water Resources Management, Stockholm, Sweden: Global Water Partnership.

Arnold JG., Srinivasan R., Muttiah RS. Williams J., 2012. Large Area Hydrological Modeling and Assessment Part I: Model. Journal of the American Water Resources Association, Volume 34, No.1, pp. 73-89.

Awash Basin Authority, 2017. Awash Basin Water Allocation Strategic Plan, Addis Ababa, Ethiopia: Awash Basin Authority.

Beven, K.J. and Kirkby, M.J.,1979. A Physically Based Variable Contributing Area Model of Basin Hydrology. Hydrological Sciences Bulletin 24, pp. 43-69.

Beven K.J, Kirkby M.J, Schofield N., Tagg A.F, 1984. Testing a Physically Based Flood Forecasting Model (TOPMODEL) for Three UK Catchments. Journal of Hydrology, Volume 69, pp. 119-143.

Chow V. T., 1988. Applied Hydrology. New York: McGraw-Hill.

CunderliK, 2003. Hydrologic Model Selection for CFCAS Project: Assessment of Water Resources Risk and Vulnerability to Changing Climate Conditions, Project Report I

Dereje Adeba, M. L. Kansal, Sumit Sen, 2015. Assessment of Water Scarcity and its Impacts on Sustainable Development in Awash basin, Ethiopia. Water Resources Management pp. 71-87

Dereje Hailu (Ph.D.), Daneal F. Selassie (Ph.D.), Yenesew Mengiste (Ph.D.), Azage G/Yohannes (Ph.D.), Taddesse Shimelis, Naod Mekonnen and Tariku Ayele. 2018. The Study of Water Use and Treated Wastewater Discharge charge: Report on Charge System for Irrigation Water Abstraction and Use. Addis Ababa University, Addis Ababa, Ethiopia.

Dhami and Pandey, 2013. Comparative Review of Recently Developed Hydrologic Models

Firissa Chano, 2017. Assessment of surface water potential based on watershed modeling, a case study of Sor watershed, Ethiopia. M.Sc Thesis. Jimma University Institute of Technology School of Civil and Environmental Engineering Hydraulics and Water Resources Engineering. 74p.

Gayathri K. Devi, Ganasri B.P. & Dwarakish G.S., 2015. International Conference On Water Resources, Coastal And Ocean Engineering (ICWRCOE 2015), Elsevier B .V.

Gleik, 1996. The Changing Water Paradigm: A Look At Twenty-First Century Water Resources.

Global Water Partnership, (2000), Global Water Partnership Technical Advisory Committee, Background Paper no.4.

GTP-2 (2015). Growth and Transformation Plan-2 for Water Sector, Addis Ababa, Ethiopia.

Henock B., 2015. Challenges and Possible Cooperation: Integrated Water Resource Management.

H. Assata, E. Van Beek, C. Borden, P. Gijsbers, A. Jolma, S. Kaden, M. Kaltofen, J.W. Labadie, D.P. Loucks, N.W.T. Quinn, Sieber, A. Sulis, W.J Werick, D.M. Wood., 2008. Generic Simulation Mdels For Facilitating Stakeholder Involvement in Water Resources Planning and

Management: A Comparision, Evaluation, and Indentification of Future Needs., U.S. Department of Energy at DigitalCommons@University of Nebraska - Lincoln.

J. Pittock & B. A. Lankford, 2010. Environmental Water Requirements: Demand Management in an Era of Water Scarcity. Journal of Integrative Environmental Sciences, Vol. 7(1), pp. 75–93.

Jack Sieber & David Purkey., 2015. WEAP USER GUIDE. Stockholm: Stockholm Environment Institute.

Karim C. Abbaspour, Saeid Ashraf Vaghefi & Raghvan Srinivasan., 2017. A Guideline for Successful Calibration and Uncertainty Analysis for Soil and Water Assessment: A Review of Papers from the 2016 International SWAT Conference.

Kramer K., 2000. Design of a Community Based DAM in Holetta, Ethiopia. Technical University of Darmstadt, Darmstadt.

Kumela T., 2011. Performance Comparison of Conceptual Rainfall Runoff Models on Muger sub catchment Abbay River Basin, M.Sc. Thesis. Addis Ababa University, Ethiopia. p111.

Loughlin G., 1999. Rainfall-Runoff Processes and Modelling. Journal Of Hydraulic, pp. 34(6): 733-751.

Mahtsente, T., Assefa M. & Dereje, H., 2017. Rainfall-runoff relation and runoff estimation for Holetta River, Awash subbasin, Ethiopia using SWAT model. International Journal of Water Resources and Environmental Engineering, Volume Vol. 9(5), pp. 102-112.

Merritt, W.S., A. Letcher, A.J. Jakeman. 2003. A Review of Erosion and Sediment Transport Models. Environmental Modeling and Software 18(1): pp. 761-799.

Molle, 2006. Planning and Managing Water Resources at the River Basin Level: Emergence and Evolution of Concepts.Comrehensive Assessment of Water Management in Agriculture. Research Report 16. IWMI and IRD.

MoWR, 2002. Water Sector Development Program (WSDP), Addis Ababa: Ethiopia.

Munyaneza O., Mukubwa A., Maskey S., Uhlenbrook S., and Wenninger J., 2014. Assessment of surface water resources availability using catchment modelling and the results of tracer studies in the mesoscale Migina Catchment, Rwanda. Hydrol. Earth Syst. Sci., 18, 5289–5301, 2014, www.hydrol-earth-syst-sci.net/18/5289/2014/ doi:10.5194/hess-18-5289-2014

Nash & Sutcliff, 1970. River Flow Forecasting Through Conceptual Models, part I – a discussion of principles. Journal of Hydrology, p. 282–290.

Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R., King K.W. 2005. Soil and Water Assessment Tool Theoretical Documentation. USDA Agricultural Research Service and Texas A and M Black land Research Center. 476 p.

Peter Ashton , 2003. Handbook for the Assessment of Catchment Water Demand and Use.

Pieter van der Zaag, 2003. Basics of Water Resources. UNESCO-IHE Delft & University of Zimbabwe.

Santhi C., Arnold J. G., Williams J. R., Dugas W. A., Srinivasan R., and Hauck L. M., 2001. Validation of the SWAT Model on a Large River Basin With Point and Nonpoint Sources. Journal of American Water Resources Association, Volume 37, p. 1169–1188.

SEI, 2005. WEAP Application Report, Stockholm, Sweden: Stockholm Environmental Institute .

SEI, 2005. WEAP Tutorial: A Collection of Standalone Modules to Aid in Learning the WEAP Software, Stockholm, Sweden.

Seleshi Bekele Awulachew, Aster Denekew Yilma, Makonnen Loulseged, Willibald Loiskandl, Mekonnen Ayana, Tena Alamirew, 2010. Water Resources and Irrigation Development in Ethiopia.

Seleshi Bekele Awulachew, Aster Denekew Yilma, Makonnen Loulseged, Willibald Loiskandl, Mekonnen Ayana, Tena Alamirew., 2007. Water Resources and Irrigation Development in Ethiopia, Colombo, Sri Lanka: International Water Management Institute.

Setegn, S.G., R. Srinivasan, and B. Dargahi. 2008. Hydrological modeling in the Lake Tana Basin, Ethiopia using SWAT model. The Open Hydrology Journal 2(1).

Sharma K. D., Sorooshian S. and Wheater H., 2008. Hydrological Modelling in Arid and Semi-Arid Areas. New York: Cambridge University Press. 223 p ISBN-13 978-0-511-37710-5.

Sieber, 2012. Water Evaluation and Planning system user guide for WEAP.

Subramanya, K., 2008. Engineering Hydroogy. 3rd ed. New York: McGraw-HIll.

Tadesse, 2006. “Surface Waters Potential of the Hantebet Basin, Tigray, Northern Ethiopia”. CIGR Ejournal. Manuscript LW 05 010., Volume VIII, pp. 1-31.

Tessema, S.M., 2011. Hydrological modeling as a tool for sustainable water resources management: a case study of the Awash River basin. TRITA LWR.LIC 2056, Sweden.

Tilahun, A., 2015. Assessing Surface Water Potential and Water Demand in Genale Dawa River Basin: Addis Ababa University

USACE-HEC, 2010. Hydrologic Modeling System,HEC-HMS v3.5. User’s Manual, US Army Corps of Engineers, Hydrologic Engineering Center.

USDA Soil Conservation Service (SCS), 1972. National Engineering Handbook Section4 hydrology. United States Department of Agriculture (USDA). Washington, DC. 10 (1):10-24.

UNEP, 2010. Africa Water Atlas, Division of Early Warning and Assessment (DEWA), Nairobi, Kenya: United Nations Environment Program (UNEP).

UNESCO, 1975. World Water Balance and Water Resources of the Earth.

Ven Te Chow, David R. Maidment, Larry W. Mays, 1988. Applied Hydrology. New York: McGraw Hill.

WHO (World Health Organization). 2003. Right to Water Retrieved from Office of United Nation Commissioner for Human Rights: http/: www2.ohchr.org /English /issues/ water/ does/Right-to-water.pdf.

Worthington, A. C., 2010. Commercial and Industrial Water Demand Estimation: Theoretical and Methodological Guidelines for Applied Economics Research, Australia: Griffith University.

Yates D., Sieber J., Purkey D., Huber-Lee A., 2005. WEAP21 a Demand, Priority, and Preference Driven Water Planning Model. Part 1. Model Characteristics. Water International 30 (4), 487-500.

Zinash Sileshi, Azage Tegegne, and Getnet TekleTsadik. 2003. Water Resources for Livestock in Ethiopia: Implications for Research and Development. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia: 66-79.

APPENDICES

Appendix A: Average Monthly Precipitation Data of Meteorological station

month	Holetta station	Adis Alem station	Kimoye station	Wolenkomi station
1	0.210317492	0.43904	0.594758	0.6175396
2	0.300972864	0.78065	0.825354	0.53668532
3	1.378792309	1.61501	1.929704	1.67399833
4	1.979772347	1.76589	2.311667	2.57014356
5	2.06569715	2.35906	2.702554	2.2324607
6	6.481583468	4.76132	4.140456	6.82072726
7	12.69927313	7.89188	7.203837	9.97401571
8	11.23804907	6.8317	6.320548	7.44048906
9	5.557871337	3.95593	3.5625	3.63901268
10	1.244514547	0.7724	0.826671	0.82942835
11	0.264267921	0.70036	0.240273	0.41147958
12	0.142797363	0.25312	1.297907	0.180397

Appendix B: Weather Generator Input Parameters

Month	1	2	3	4	5	6	7	8	9	10	11	12
TMPMX	23.95	25.13	26.10	25.92	25.83	23.45	21.13	21.73	22.07	22.41	21.67	22.86
TMPMN	9.64	11.47	14.70	14.79	15.15	14.73	13.54	13.70	13.75	12.50	11.50	9.81
TMPSTDMX	1.00	1.40	1.50	1.77	1.67	2.93	2.25	2.02	1.85	1.88	1.81	1.23
TMPSTDMN	2.78	2.73	2.24	2.20	2.44	1.76	0.84	1.17	1.93	2.29	2.48	2.81
PCPMM	6.51	8.50	42.74	59.39	64.04	194.44	393.68	348.38	166.74	38.58	7.93	4.43
RAINHHMX	0.27	0.35	1.78	2.47	2.67	8.10	16.40	14.52	6.95	1.61	0.33	0.18
PCPSTD	1.2164	1.2088	3.3542	3.8267	4.3327	7.0293	10.4456	9.8712	6.1283	2.9103	1.324	0.7966
PCPSKW	11.0372	5.9875	4.2701	2.9065	3.6033	1.9467	1.7825	1.6271	1.6971	3.1796	8.9175	8.8539
PR_W1	0.0474	0.0686	0.1754	0.216	0.1976	0.4216	0.4667	0.3889	0.2444	0.0668	0.0466	0.0435
PR_W2	0.6937	0.6835	0.7739	0.7929	0.8	0.9094	0.9575	0.9463	0.9026	0.8043	0.7311	0.6931
PCPD	4.63	5.79	14.38	16.5	16.88	25.75	30.38	29.5	24.38	9.79	4.96	4.21
SOLARAV	21.58	24.27	23.04	23.31	22.07	18.35	12.13	13.38	19.52	22.59	23.06	22.56
DEWPT	7.12	6.20	9.94	12.14	11.26	14.08	15.61	16.09	14.63	10.64	7.35	5.55
WINDAV	0.46	0.45	0.50	0.48	0.45	0.32	0.27	0.23	0.29	0.34	0.38	0.41

Appendix C: Holetta Statistical Analysis of Daily Precipitation Data (1993 - 2016)

Statistical Analysis of Daily Precipitation Data (1993 - 2016)

Input Filename = HoletapcpSTAT.txt

Number of Years = 24

Number of Leap Years = 6

Number of Records = 8766

Number of No Data values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	6.51	1.2164	11.0372	0.0474	0.6937	4.63
Feb.	8.5	1.2088	5.9875	0.0686	0.6835	5.79
Mar.	42.74	3.3542	4.2701	0.1754	0.7739	14.38
Apr.	59.39	3.8267	2.9065	0.216	0.7929	16.5
May.	64.04	4.3327	3.6033	0.1976	0.8	16.88
Jun.	194.44	7.0293	1.9467	0.4216	0.9094	25.75
Jul.	393.68	10.4456	1.7825	0.4667	0.9575	30.38
Aug.	348.38	9.8712	1.6271	0.3889	0.9463	29.5
Sep.	166.74	6.1283	1.6971	0.2444	0.9026	24.38
Oct.	38.58	2.9103	3.1796	0.0668	0.8043	9.79
Nov.	7.93	1.324	8.9175	0.0466	0.7311	4.96
Dec.	4.43	0.7966	8.8539	0.0435	0.6931	4.21

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

(written by Stefan Liersch, Berlin, August 2003)

Appendix D: Average Daily Dew Point Temperature for Period (1993 - 2016)

This file has been generated by the program 'dew02.exe'

Input Filename = MaxMinRH.txt

Number of Years = 24

Number of Records = 8766

Number of No Data Values

tmp_max = 0

tmp_min = 0

hmd = 0

Average Daily Dew Point Temperature for Period (1993 - 2016)

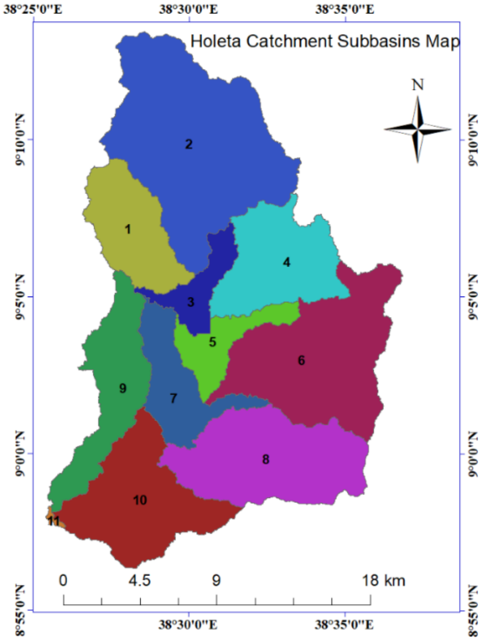
Month	tmp_max	tmp_min	hmd	dewpt
Jan	23.95	9.64	50.86	7.12
Feb	25.13	11.47	44.92	6.2
Mar	26.1	14.7	52	9.94
Apr	25.92	14.79	58.58	12.14
May	25.83	15.15	55.32	11.26
Jun	23.45	14.73	72.28	14.08
Jul	21.13	13.54	88.64	15.61
Aug	21.73	13.7	89.56	16.09
Sep	22.07	13.75	80.05	14.63
Oct	22.41	12.5	63.47	10.64
Nov	21.67	11.5	53.59	7.35
Dec	22.86	9.81	46.93	5.55

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]
dewpt = average daily dew point temperature in month [°C]
(written by Stefan Liersch, August, 2003)

Appendix E: Map of Holeta river catchment Sub-basins



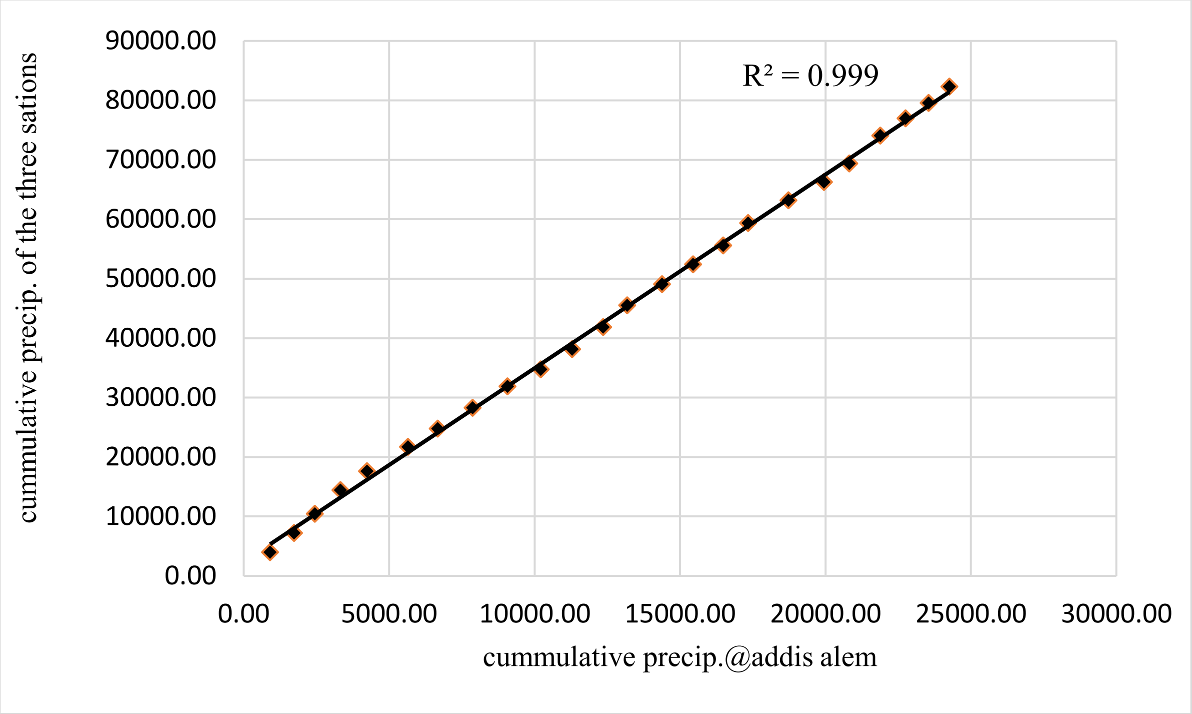
Appendix F: Mean Annual Flow at Holetta Gauging Station

Year	Flow (cumecs)	Year	Flow (cumecs)
1993	5.452865252	2002	7.521560106
1994	7.0687383	2003	7.488551286
1995	7.20198462	2004	6.758516321
1996	8.504309368	2005	6.576102106
1997	7.19964719	2006	6.274615975
1998	10.14138383	2007	6.877723688
1999	8.002736508	2008	6.590036914
2000	8.318210107	2009	6.320676094
2001	8.323257565		

Appendix G: Double Mass Curve Data and Graph

Year	Annual Sum of Precipitation @Holetta	Annual Sum of Precipitation @Adis Alem	Annual Sum of Precipitation @Kimoye	Annual Sum of Precipitation @Wolenkomi
1993	1337.83	908.10	1150.14	1515.00
1994	1233.07	819.99	836.50	1151.30
1995	1199.17	717.76	1049.60	974.10
1996	1605.08	883.51	1122.30	1283.70
1997	1431.85	911.06	742.20	1006.90
1998	1685.64	1402.10	1242.20	1159.00
1999	1482.36	1032.60	769.60	793.30
2000	1584.31	1190.90	946.90	981.73
2001	1450.51	1199.20	1014.20	1125.56
2002	1041.67	1148.30	861.70	979.72
2003	1435.00	1077.60	915.00	1015.90
2004	1389.64	1072.50	1083.40	1264.67
2005	1514.00	818.55	990.40	1135.15
2006	1101.60	1198.39	988.90	1510.08
2007	1397.27	1065.60	1098.90	832.60
2008	1345.24	1040.48	899.10	921.85

2009	1118.52	850.16	999.71	1649.38
2010	1714.27	1388.70	1150.70	955.17
2011	929.74	1225.93	631.13	1518.51
2012	1113.93	869.09	780.88	1235.91
2013	1406.81	1064.60	1802.99	1477.79
2014	1142.12	871.39	916.70	855.60
2015	1110.97	785.86	685.30	795.88
2016	964.23	716.52	796.40	976.40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80000.00
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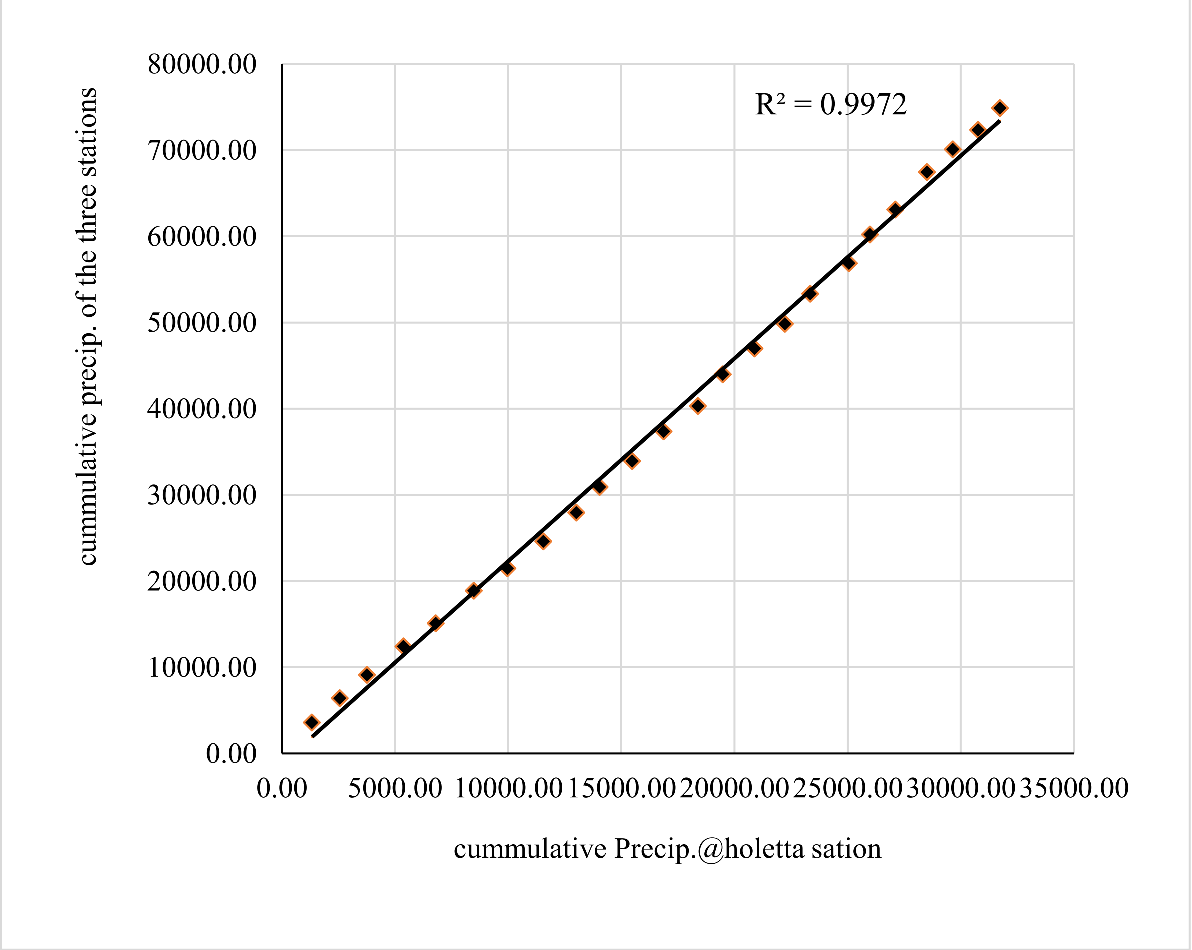
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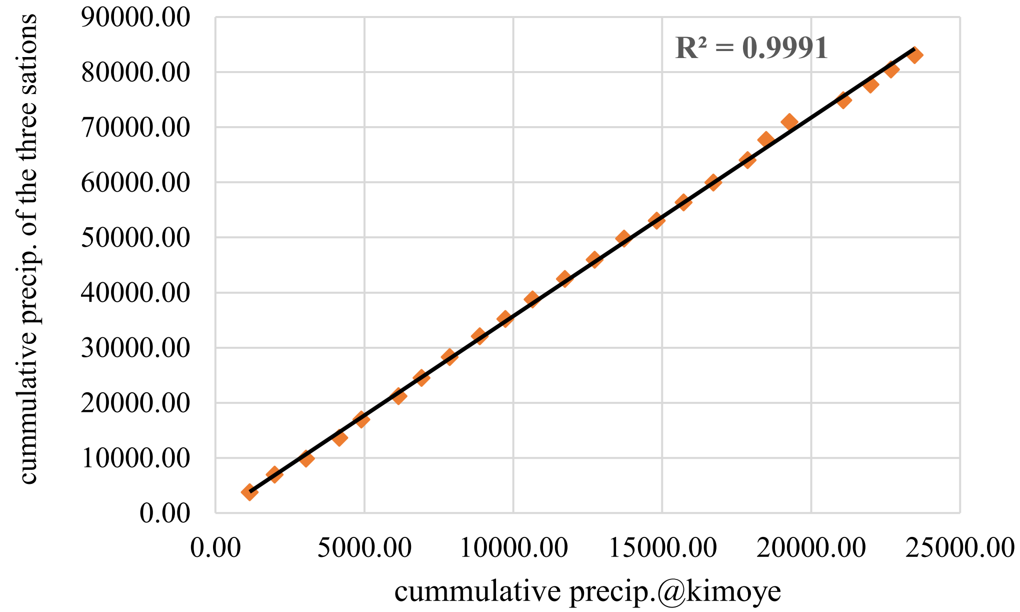
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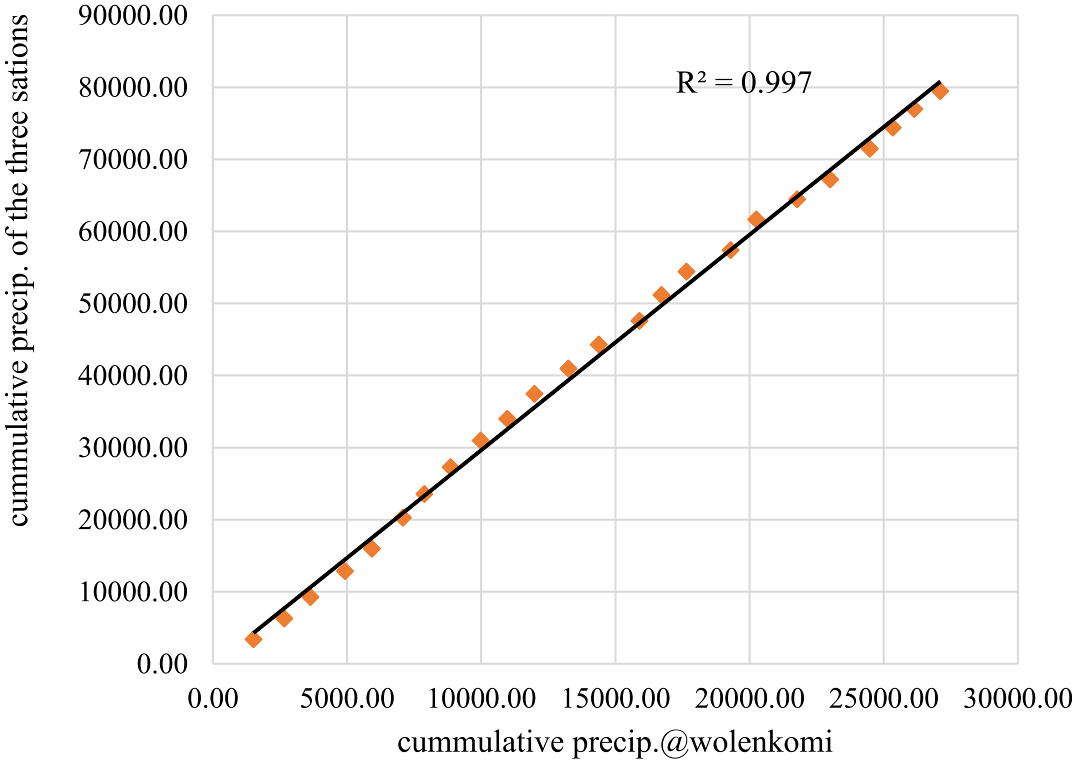
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cummulative precip. of the three sations
cummulative precip.@wolenkomi

Appendix H: Average Monthly Observed Flow for Calibration and Simulated Flows

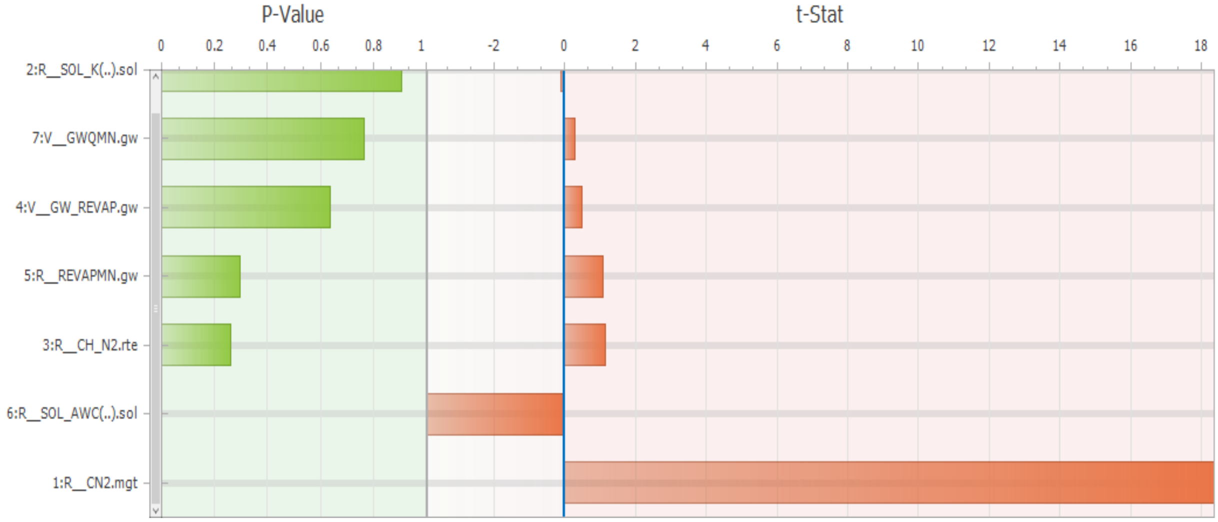
Date	Observed Flow (cumecs)	Best Simulated Flow (cumecs)	Date	Observed Flow (cumecs)	Best Simulated Flow (cumecs)
Jan-1995	2.14	0	Mar-1998	2.15	1.396
Feb-1995	2.19	0	Apr-1998	2.16	0.6229
Mar-1995	2.11	0.8071	May-1998	4.28	4.582
Apr-1995	2.17	0.2046	Jun-1998	16.36	13.61
May-1995	3.14	0.2299	Jul-1998	29.67	32.72
Jun-1995	9.14	3.468	Aug-1998	31.45	33.31
Jul-1995	26.36	24.3	Sep-1998	19.62	17.72
Aug-1995	19.25	24.31	Oct-1998	6.35	2.753
Sep-1995	11.32	15.24	Nov-1998	2.76	0.8199
Oct-1995	3.13	7.694	Dec-1998	2.4	0.1077
Nov-1995	2.76	0.6237	Jan-1999	2.33	0.113
Dec-1995	2.72	0.3677	Feb-1999	2.23	0.0036
Jan-1996	2.82	0.0259	Mar-1999	2.32	2.779
Feb-1996	2.59	0.0049	Apr-1999	3.18	3.563
Mar-1996	2.49	0.1394	May-1999	4.65	0.0767
Apr-1996	2.38	1.155	Jun-1999	9	7.068

May-1996	5.96	0	Jul-1999	28.73	35.32
Jun-1996	12.23	7.28	Aug-1999	29.63	39.35
Jul-1996	27.52	15.23	Sep-1999	11.49	12.32
Aug-1996	22.23	26.81	Oct-1999	3.85	4.637
Sep-1996	14.46	18.28	Nov-1999	2.39	3.563
Oct-1996	4.56	0.8767	Dec-1999	2.28	0.0507
Nov-1996	2.46	0.3989	Jan-2000	2.2	1.749
Dec-1996	2.35	0.0948	Feb-2000	2.17	3.744
Jan-1997	2.22	0.0224	Mar-2000	2.13	4.327
Feb-1997	2.15	0.0144	Apr-2000	2.26	1.197
Mar-1997	2.15	0.1282	May-2000	2.42	3.878
Apr-1997	2.17	1.474	Jun-2000	11.22	15.04
May-1997	4.2	0.2841	Jul-2000	25.63	39.75
Jun-1997	11.25	3.783	Aug-2000	33.34	43.21
Jul-1997	19.21	21.94	Sep-2000	16.64	22.74
Aug-1997	27.89	32.35	Oct-2000	4.56	9.837
Sep-1997	14.37	20.02	Nov-2000	2.38	1.732
Oct-1997	2.31	1.154	Dec-2000	2.21	0.2477
Nov-1997	2.17	0.166	Jan-2001	2.16	1.15

Dec-1997	2.1	0.0476	Feb-2001	2.12	0.1449
Jan-1998	2.3	0.0918	Mar-2001	2.17	2.225
Feb-1998	2.2	0.0017	Apr-2001	2.15	0.2295
May-2001	3.18	4.969	Sep-2003	15.54	11.09
Jun-2001	9.41	14.89	Oct-2003	7.8	1.39
Jul-2001	26.36	35.32	Nov-2003	2.39	0.2439
Aug-2001	32.56	29.12	Dec-2003	2.28	0.0803
Sep-2001	14.23	14.66	Jan-2004	2.3	1.935
Oct-2001	2.35	13.33	Feb-2004	2.17	3.606
Nov-2001	2.13	0.931	Mar-2004	2.16	3.651
Dec-2001	2.06	0.2516	Apr-2004	2.53	1.999
Jan-2002	2.07	0.0703	May-2004	2.8	0.8655
Feb-2002	2.02	0.0215	Jun-2004	7.25	10.3
Mar-2002	2.04	0.079	Jul-2004	17.4	19.4
Apr-2002	2.02	5.202	Aug-2004	24.89	33.82
May-2002	2.01	8.819	Sep-2004	11.36	6.203
Jun-2002	7.42	15.69	Oct-2004	3.65	0.3731
Jul-2002	23.96	30.92	Nov-2004	2.35	0.0996
Aug-2002	29.15	40.99	Dec-2004	2.25	2.311

Sep-2002	16.63	22.23	Jan-2005	2.2	0.1787
Oct-2002	4.77	6.196	Feb-2005	2.18	3.793
Nov-2002	2	1.212	Mar-2005	2.23	5.263
Dec-2002	3.16	1.193	Apr-2005	2.32	4.78
Jan-2003	2.46	0.0533	May-2005	3.85	0.0265
Feb-2003	2.38	0.2352	Jun-2005	5.44	9.425
Mar-2003	2.41	9.208	Jul-2005	25.06	32
Apr-2003	2.56	0.624	Aug-2005	27.83	37.97
May-2003	3.66	3.034	Sep-2005	12.21	16.97
Jun-2003	9.65	17.89	Oct-2005	3.33	1.259
Jul-2003	24.79	34.93	Nov-2005	2.38	0.3059
Aug-2003	27.64	45.99	Dec-2005	2.24	0.7042

Appendix I: Flow sensitive parameters



Appendix J: Average Monthly Observed Flow for Validation and Best Simulated Flow

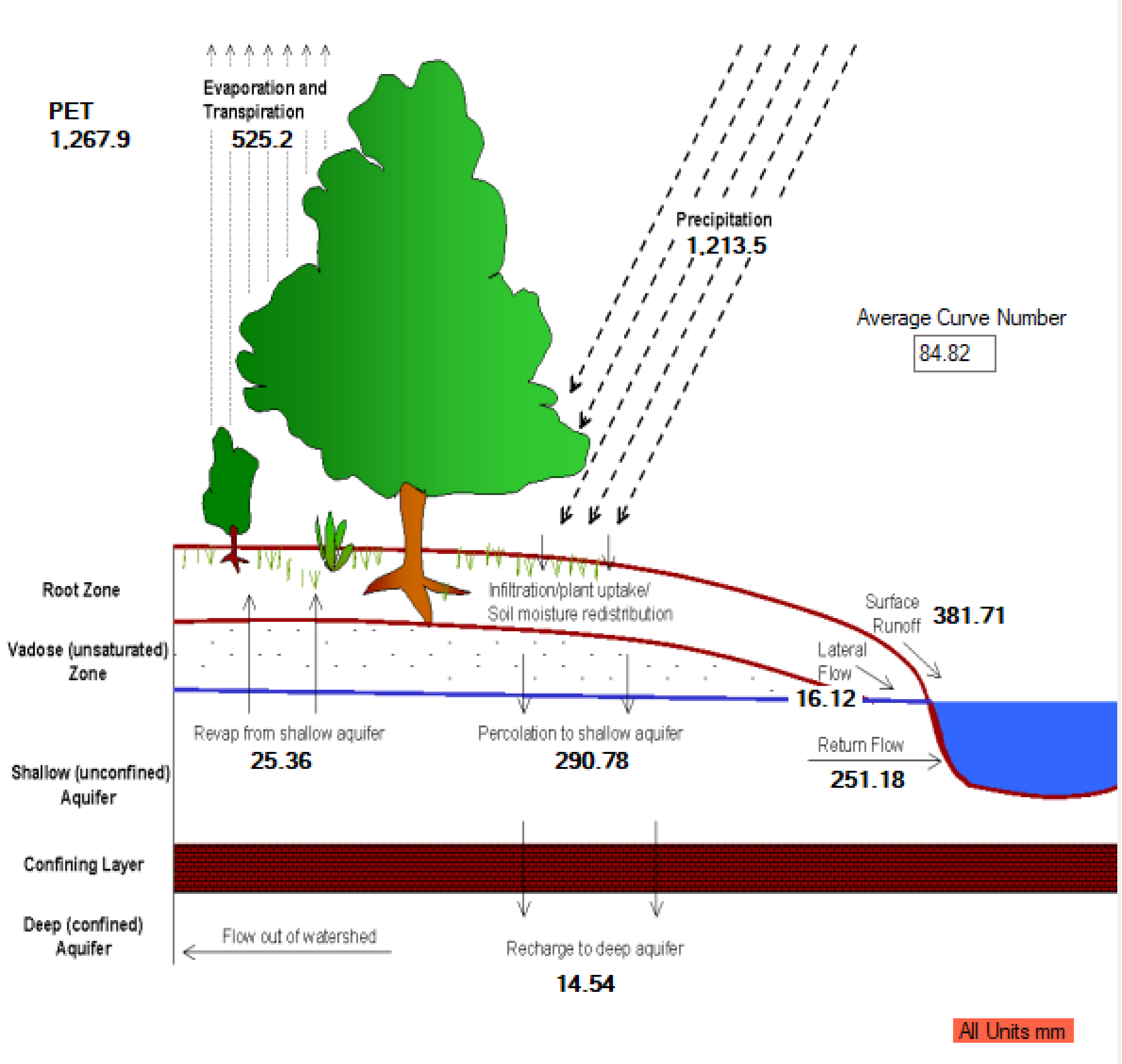
Date	Observed Flow (cumecs)	Best Simulated Flow (cumecs)	Date	Observed Flow (cumecs)	Best Simulated Flow (cumecs)
Jan-2006	2.17	1.656	Jan-2008	2.21	0.5584
Feb-2006	2.14	0.459	Feb-2008	2.17	2.559
Mar-2006	2.22	2.935	Mar-2008	2.11	1.717
Apr-2006	2.34	6.016	Apr-2008	2.13	3.066
May-2006	2.86	4.582	May-2008	3.38	3.391
Jun-2006	14.2	9.835	Jun-2008	9.53	20
Jul-2006	25.5	32.22	Jul-2008	17.85	29.89
Aug-2006	19.36	27.2	Aug-2008	21.87	21.29
Sep-2006	15.65	15.86	Sep-2008	13.22	20.43
Oct-2006	4.86	3.454	Oct-2008	5.24	2.961
Nov-2006	2.49	1.237	Nov-2008	4.08	1.154
Jan-2007	2.33	0.1907	Jan-2009	3.51	0.247
Feb-2007	2.32	0.3184	Feb-2009	3.38	0.4843
Mar-2007	2.25	2.889	Mar-2009	3.33	0.2177
Apr-2007	2.32	1.541	Apr-2009	3.38	1.143

May-2007	6.27	1.67	May-2009	4.25	3.643
Jun-2007	12.63	4.644	Jun-2009	11.39	14.93
Jul-2007	25.4	25.02	Jul-2009	23.58	29.42
Aug-2007	17.99	22.3	Aug-2009	19.49	32.26
Sep-2007	14.25	17.11	Sep-2009	9.74	11.69
Oct-2007	6.7	4.48	Oct-2009	3.58	3.009
Nov-2007	2.34	0.7606	Nov-2009	3.25	4.294
Dec-2007	2.27	0.5462	Dec-2009	3.27	0.375

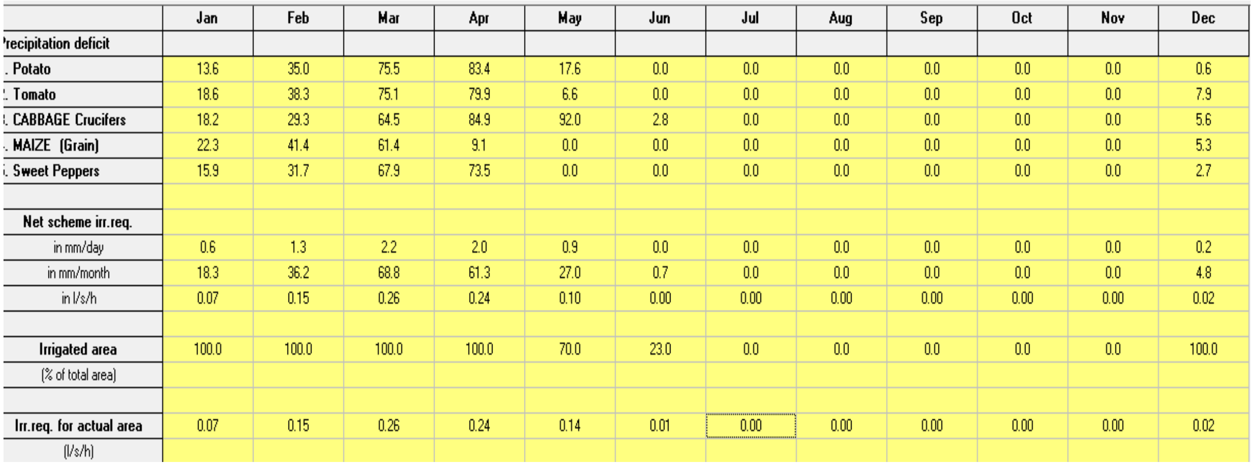
Appendix K: Average monthly observed flow for flow duration curve

month	Flow in cumecs	% of exceedance
Jan	23.046	8
Feb	22.269	15
Mar	11.59	23
Apr	9	31
May	4.014	38
Jun	3.718	46
Jul	2.527	54
Aug	2.475	62
Sep	2.394	69
Oct	2.355	77
Nov	2.296	85
Dec	2.284	92

Appendix L: Water balance components of Holetta river catchment



Appendix M: Crop water requirement



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
recipitation deficit												
. Potato	13.6	35.0	75.5	83.4	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6
. Tomato	18.6	38.3	75.1	79.9	6.6	0.0	0.0	0.0	0.0	0.0	0.0	7.9
. CABBAGE Crucifers	18.2	29.3	64.5	84.9	92.0	2.8	0.0	0.0	0.0	0.0	0.0	5.6
. MAIZE (Grain)	22.3	41.4	61.4	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3
. Sweet Peppers	15.9	31.7	67.9	73.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
Net scheme irr.req.												
in mm/day	0.6	1.3	2.2	2.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2
in mm/month	18.3	36.2	68.8	61.3	27.0	0.7	0.0	0.0	0.0	0.0	0.0	4.8
in l/s/h	0.07	0.15	0.26	0.24	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Irrigated area	100.0	100.0	100.0	100.0	70.0	23.0	0.0	0.0	0.0	0.0	0.0	100.0
(% of total area)												
Irr.req. for actual area	0.07	0.15	0.26	0.24	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.02
(l/s/h)												