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ASSEESSING THE EFFECT OF LAND USE CHANGE ON THE HYDRAULIC REGIME OF LAKE AWASSA

By

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

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Daniel Shewangizaw declares that this thesis is my own original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

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ABSTRACT

For the past years an increase in population pressure, government policy and external influences caused a consistent change in the land cover of the Lake Awassa catchment. This was mainly by deforestation as is the case in many other areas of Ethiopia as well. The effects of land cover changes have impacted the water balance of the catchment by changing magnitude and pattern of runoff, peak flow and ground water levels. This study is mainly focusing on the assessment of hydrological response due to the land cover data of 1965 and 1998 and Geographic information system (GIS) integrated with the hydrologic modeling.

The result of remote sensing assessment on the land cover of the catchment indicated that Natural Vegetation decreased by 11,768 ha or 9.06 % between years 1995-1998. This was mainly due to mainly the expansion of agriculture and urban area. Plantation expansion was 20,661 ha or 13.56 % and also urbanization increased by 1,310 ha or 0.89 %.

Based on this result, the inflow records were analysed statistically to evaluate if change in the land cover affected the hydrological response of the catchment. The result of the analysis indicated that the average inflow to Lake Awassa in 1998 is 3.15 m^3/sec or 99.34MCM, where as in scenarios year 2017 the average inflow result is 3.5m^3/s or 110.38MCM. so because of the land cover change the flow increased by 0.35 m^3/s that is 11.04MCM.

Table of Contents

ABBREVIATIONS

DEM	Digital elevation model
DEWPT	Average dew point (^{0}C)
MCM	Million Cubic Meter
PCPD	Average number of days of precipitation
PCPMM	Average precipitation (mm)
PCPSKW	Skew coefficient for daily precipitation
PCPSTD	Standard deviation for daily precipitation (mm/day)
PR_W1	Probability of wet day following dry day
PR_W2	Probability of wet day following wet day
RAINHHMX	Maximum 0.5 hr rainfall in entire period of record (mm)
SOLARAV	Average daily solar radiation (MJ/m^{2}/day)
SWAT	Soil and Water Assessment Tool
TMPSTDMN	Standard deviation of minimum air temperature (^{0}C)
TMPSTDMX	Standard deviation of maximum air temperature (^{0}C)
TPMAX	Average maximum air temperature (^{0}C)
TPMIN	Average minimum air temperature (^{0}C)
WINDAV	Average wind speed (m/s)

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1. Introduction

1.1 Back ground

Flood risk is among the most severe risks on human lives and properties, and has become more frequent and severe along with local economical development. As the watershed becomes more developed, it also becomes more hydrologically active, changing the flood volume, runoff components as well as the origin of stream flow. In turn, floods that once occurred infrequently during pre-development periods have now become more frequent and more severe due to the transformation of the watershed from rural to urban land uses. The forecast and simulation of floods is therefore essential for planning and operation of civil protection measures and for early flood warning.

Land cover changes commonly are highly pronounced in the developing countries that are characterized by agriculture based economics and rapidly increasing human population. Meyer and Turner (1994) discussed that land cover changes are caused by a number of natural and human driving forces. Whereas natural effects such as climate change are only over a long period of time, the effects of human activities are immediate and often direct. From the human factors, population growth is the most important in Ethiopia (Hurni, 1993 as cited in Tekele and Hedlund, 2000), as it is common in developing countries. Some 85% of the population of lives in rural areas and directly depend on the land for its livelihood. This means the demands of lands are increasing as population increases.

Population growth causes degradation of resources that relay on the available land and the interaction between them is very complex. Interactions can make positive or negative effects to the resources. People demand land for food production as well as for housing and it is common practice to clear the forest to make farming area and housing. The result is that land cover and land use change due to daily human intervention. Hence, understanding how the land cover change influence the lake basin hydrology will enable planners to formulate policies to minimize the undesirable effects of future land cover changes.

Land cover changes may have immediate and long-lasting impacts on terrestrial hydrology (Calder 1993) and, alter the long term balance between rainfall and evapotranspiration and the resultant runoff. In the short-term, destructive land use change may affect the hydrological cycle either through increasing the water yield or through diminishing, or even eliminating the low flow in some circumstances (Croke et al., 2004), (Saveniji 1995) suggested that in the long-term the reduction in evapotranspiration and water recycling arising from land cover changes may initiate a feedback mechanism that results in reduction rainfall.

Study of lake level fluctuation with respect to land cover dynamics enables assessment of sustainability of land use systems, because lake level reflect on the hydrological state of the entire watershed. As stated by Calder (2002), the hydrological impact of land cover changes is a referencing issue and much research is necessary.

The information can also be applied to forecast the likely effects of any potential changes in land cover on water resource systems. Generally, it is appropriate to use satellite remote sensing and Geographic information system (GIS) integrated with the hydrological modeling to analyse the hydrological response due to the land use change.

1.2 Problem statement

The Ethiopian rift is characterized by many perennial rivers, and a chain of lakes that vary in size, and hydrological and hydro geological settings. The water resources of the Rift lakes are one of the focal points for large-scale development in Ethiopia over the last few decades. Some of the lakes and their influent rivers are used for irrigation, soda abstraction, fish farming and recreation, and also support a wide variety of endemic birds and wild animals. Ethiopia's major mechanized irrigation farms and commercial fishery are confined within the Rift region. A few of the lakes have shrunk in surface area because of excessive water abstractions, while others have expanded because of increased surface run-off and groundwater inflows from percolated irrigation water.

Lake Awasa is one of the rift lakes experiencing a level raise causing damage to the environment and socio-economic activities in the surroundings. Understanding the hydrological processes and the effects of land use/cover changes on the lake will give the possibility to produce sustainable management strategies. Changes in land use practices, hence increased sediment input and modified runoff character as well as water abstraction are known to have impact on Awassa lakes.

1.3 Objectives, research questions and hypothesis

The general objective of the study is to provide an explanation for the lake level rise and its future trend by analyzing the impacts of land use/cover changes.

Specific objective

- Assess the relation of lake levels with catchment factor (land use)
- To analyse hydrologic time series related to land cover change
- To evaluate the response of a hydrologic model of the catchment to the change in land cover

To address the aforementioned objectives, the research questions for this study are:

- What trend in land cover changes can be identified in the catchment?
- How will the land cover changes affect the hydrologic model response of the catchment?

1.4 Thesis lay-out

This thesis is comprised of five chapters

Chapter 1 Introduction

Chapter 2 Study Area

Chapter 3 Literature Review

Chapter 4 Methodology

Chapter 5 Data Availability and Analysis

Chapter 6 Estimation of Total Inflow to Lake Awassa

Chapter 7 Land use change simulation

Chapter 8 Conclusion and Recommendation

Chapter 1 is the general introduction of the subject. The study area is described in chapter 2. Chapter 3 concentrates on Literature Review on the study area and effect of land use change. Chapter 4 describes the procedure how to address the objective. Chapter 5 describes hydrologic modeling using Arc GIS Soil and Water Assessment Tool (SWAT 2000), which includes the creation of hydrological data analysis, input data preparation and the calibration of the model;

chapter 6 compute Lake Awassa water level using land cover data of 1998. Chapter 7 is addressed on the implementation of the land use change scenario of 2017 from past data of 1965 and 1998 and master plan study of the area; finally chapter 8 consist the research summary, conclusion and recommendation.

CHAPTER TWO

2 Study Area

2.1 Introduction

Lake Awasa catchment has overlapping pair of calderas; namely Awasa and Corbetti containing lakes Awasa and Cheleleka respectively. The total catchment area is 1455 sq.km, of which Lakes Cheleleka (7°06'N, 38°33'E, altitude 1685 m.a.s.l) and Awasa (7°04'N, 38°26'E) account 14.5 and 100 sq.km respectively. Swamps surrounding Lake Cheleleka located right to the northeast of Awasa occupy a further 63 sq.km (Telford, 2000). Joints and faults enhance the permeability of the ignimbrite; major fault-controlled springs feed the lake.

The town of Awassa, the regional capital of the Southern Regional State is located right on the eastern shore of the lake. The existence and protection of the lake is very critical to the town and the population residing within the entire catchment. The total population of the catchment was estimated to be 360,555 growing annually by 2.9% as of 1995, (Dessie 1995). Most of the population depends on agriculture that is directly or indirectly related to the water resources of the catchment including Lake Awassa, feeder rivers and groundwater.

Lake Awassa is a Closed-catchment Lake with no surface water outflow. The lake is fed both by few ephemeral streams on the north-west and western side of the catchment and by the Tikurewuha River, which is the only perennial river, enters Lake Awassa draining the Cheleleka swamp on the north-east side. Cheleleka swamp receives surface runoff from the head waters of the eastern rift escarpment and from groundwater upstream.

Lake Awassa is the smallest and the highest of the major MER lakes (1680 m.a.s.l) between the Ziway-Shalla lakes to the north and Lakes Chamo and Abaya to the south. The lake lies within a nested caldera complex and is predominantly underlain by highly faulted ignimbrites and other silicic pyroclastic deposits (Kazmin 1979).

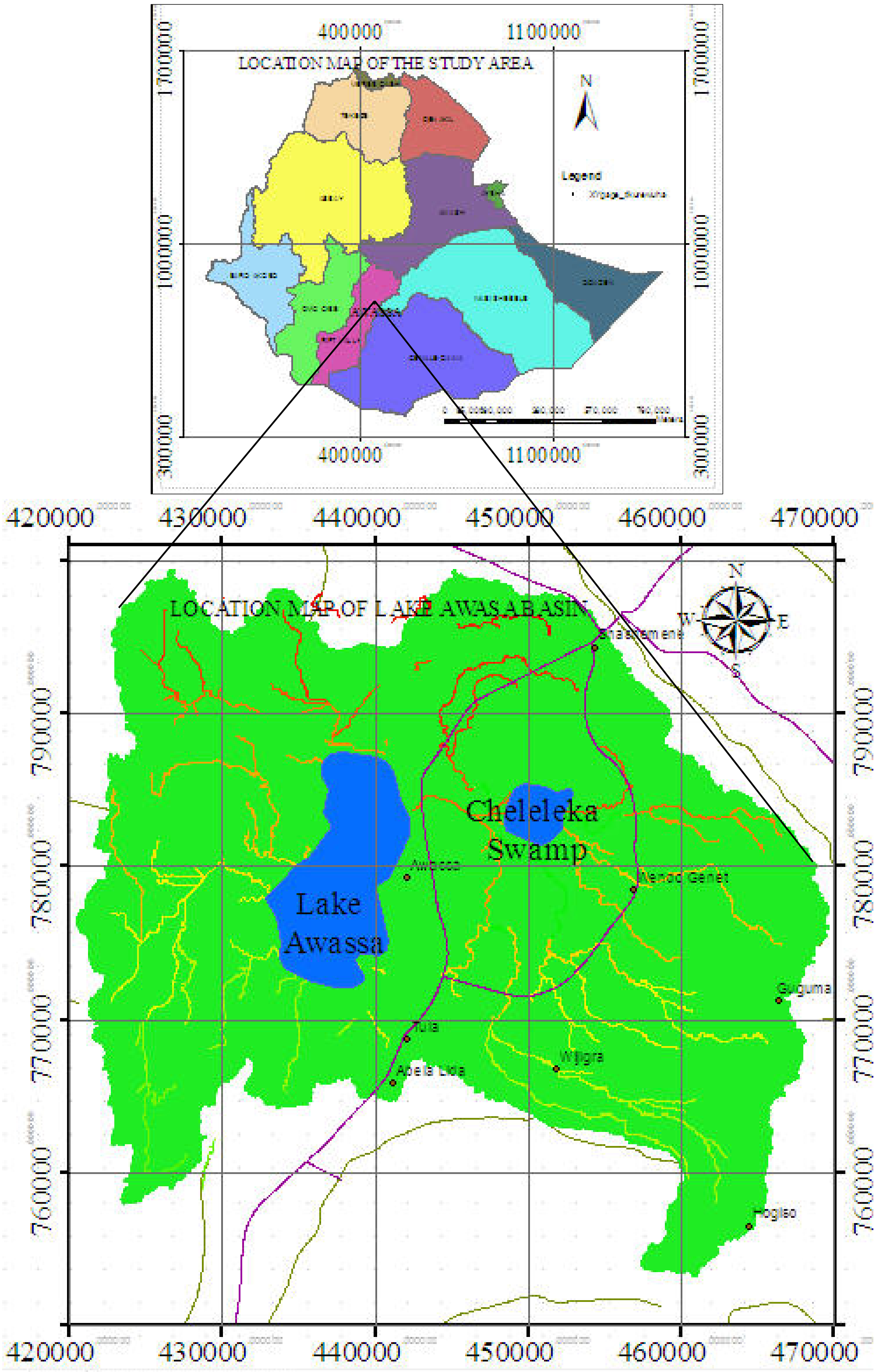

Figure 2-1: Over view of the study area

2.2 Topography

Topographically, the majority of the sub-basin is flat to gently undulating but bounded by steep escarpments with more hilly areas confined to the Wendo Koshe hills to the north west of the lake and the eastern escarpment and hills. In addition there is a steep escarpment to the west of the lake and a further one immediately north of Lake Cheleleka with a number of small volcanic plugs in the flat plain (Halcrow, 2008).

The altitude ranges from 1,680m at Lake Awasa to 2,740m on the eastern escarpment; an altitude range of 1,020. Most slopes (60%) are flat to gentle (0-8%) with a further 35% moderately sloping (8-30%) and only 6% steep to very steep (30%).

2.3 Rainfall

The mean annual rainfall in the Awasa Sub-basin ranges between 950 and 1400 mm with that for Awasa town being 959mm. the northern part of the sub-basin receives the lowest rainfall, rising to 1,200 to 1,300 mm in the eastern and western parts, and reaching 1300 to 1400 mm in the southern part of the sub-basin. There are marked inter and intra-annual variations in rainfall. There were notable periods of above average rain in 1977-79, 1981-83 and 1995-98 and periods of below average rainfall in 1980, 1984-85, 1990-94 and 2002-04. The period 1999 to 2004 is one of rainfall deficit, as indicated by the cumulative departure from the mean (Halcrow 2008).

During the year there are strong seasonal variations due to the passage of the ITCZ (Inter Tropical Convergence Zone). At Awasa the mean monthly rainfall is above 100mm between April and September inclusive, with the highest mean monthly rainfall recorded in August at 124mm. the months with the lowest rainfall are October, November, and December.

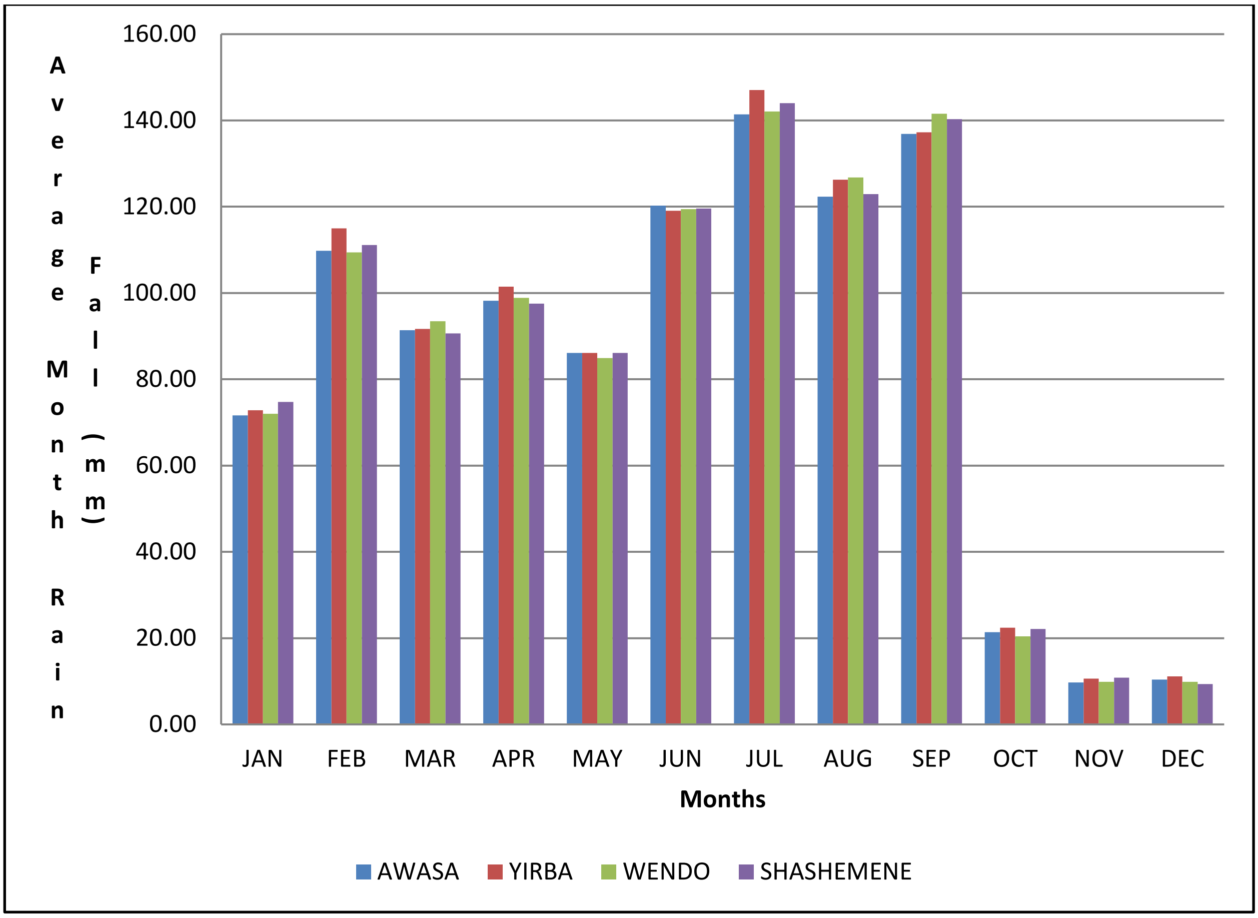

Figure 2-1: Average Monthly Rainfall distribution in the study area (1998-2007)

2.4 Temperature

The mean annual temperature in the Awasa sub-basin lies between 15-20°C. The highest temperatures are found in the lowlands and increase with altitude. The hottest months are in the spring before the rains start in March and April, with mean monthly temperatures in the lowlands around Lake Awasa lying in the range 20-25°C and falling to 15-20°C in the highlands. Temperatures are lowered during the rainy season and are coldest in July and again in December, with temperatures in the range 15-20°C in the lowlands and 10-15°C in the highest parts of the sub-basin. (Halcrow 2008)

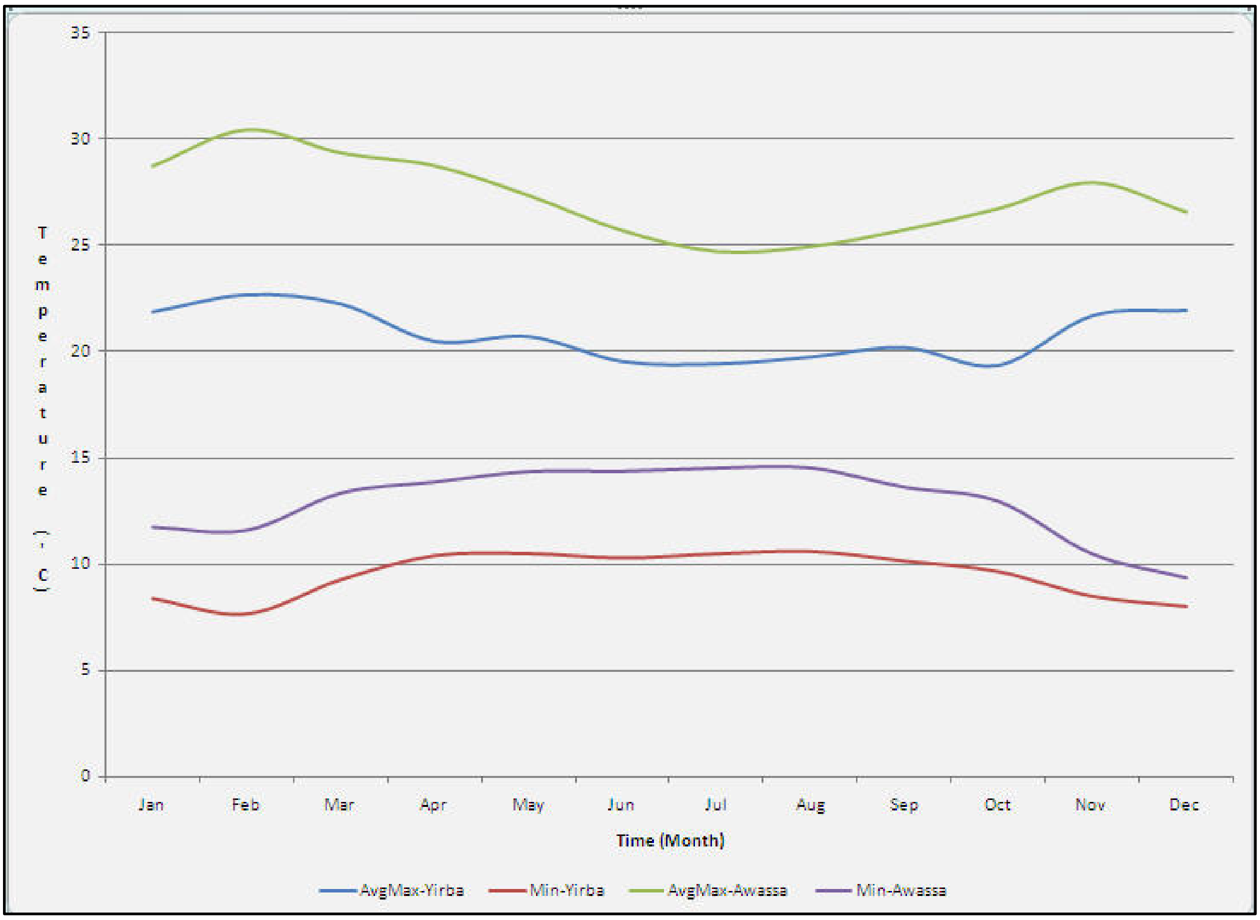

Figure 2-2: Average Monthly Minimum and Maximum Temperature for the study area Awasa (1998-2007)

2.5 Abstraction data

Lake water abstraction for human consumption is assumed to be minimal as in most cases the rural people are using groundwater source from hand dug wells, boreholes and springs. However livestock water consumption, diversion of streams and high yielding springs for small scale irrigation and towns' water supply have decreased the amount of water that has been entered in to the lake. A total of close to $2.286*10^6$ m^3/year of water which ultimately would have been reached on the lake could be assumed abstracted. This abstraction accounts for 2% of the estimated total mean annual inflow of approximately 112.1684 Mm^3 to the lake in terms of surface runoff, precipitation over the lake and through groundwater inflow from the surrounding aquifer (Gebreegziabher 2004).

2.6 Land Use/Land Cover

The main land use of the sub-basin is rainfed agriculture of annual and perennial crops with small areas of mechanized farms at Shallo and Awasa state farms. The Cheleleka marshlands to the east of Awasa town serve as grazing land.

Land cover is dominated by cultivation with open grassland and scattered trees on plains and rolling plains, dense grass land on the seasonal and perennial marshland and wooded bush and woodlands on the mountains, and open shrubland and grassland on the elongated escarpments (Halcrow 2008).

2.7 Soil

The soils of the sub-basin are primarily deep, medium and fine textured Chromic and Haplic Luvisols in the south and east on a rolling to hilly topography with mixed perennial and annual cultivation. In the centre of the sub-basin, extending into the Wendo Koshe hills the soils are Chromic and Eutric Cambisols, moderately deep to deep and medium textured with poorly drained, fine textured Vertic Cambisols in the Cheleleka wetlands. To the north and west of the lake the soils are moderately deep to deep, well to excessively drained Vitric Andosols and small areas of very shallow Leptosols (Halcrow 2008).

2.8 Geology

The main rock units are volcano-lacustrine deposits and acidic volcanics. The recent acidic volcanics consists of obsidian, which forms the northern watershed boundary (Corbetti geothermal field) and pyroclastic products covering the foot of the highlands encroaching towards the lake from the northern recharge area. There are also scoraceous deposits of unconsolidated fragments of volcanic origin. Locally they are good unconfined aquifers covered with volcano-lacustrine deposits (Chernet, 1982; Nidaw, 1996; Dessie and Tessema, 2003). The faulting which produced the rift valley has led to extensive fracturing of the rocks. Recently reactivated very wide faults are evident in the floor of the caldera (Halcrow 2008).

2.9 River

The main surface water resources in the sub-basin are concentrated in Lake Awasa and the Chelelka wetlands which are fed by a number of streams and rivers from the eastern highlands. These wetlands act as storage and this resource then feeds Lake Awasa via the Tikurwuha river which has a flow of 6-7m^3/s throughout the year. There are very few surface water resources in the west and north of the sub-basin (Halcrow 2008).

2.10 The Lake

Beginning in the late 1980s and through the 1990s the water levels in Lake Awasa rose from a low of 0.76metres above datum in 1986 to a high of 3.79m in 1998. For the last 39 years shows that the lake rising progressively.

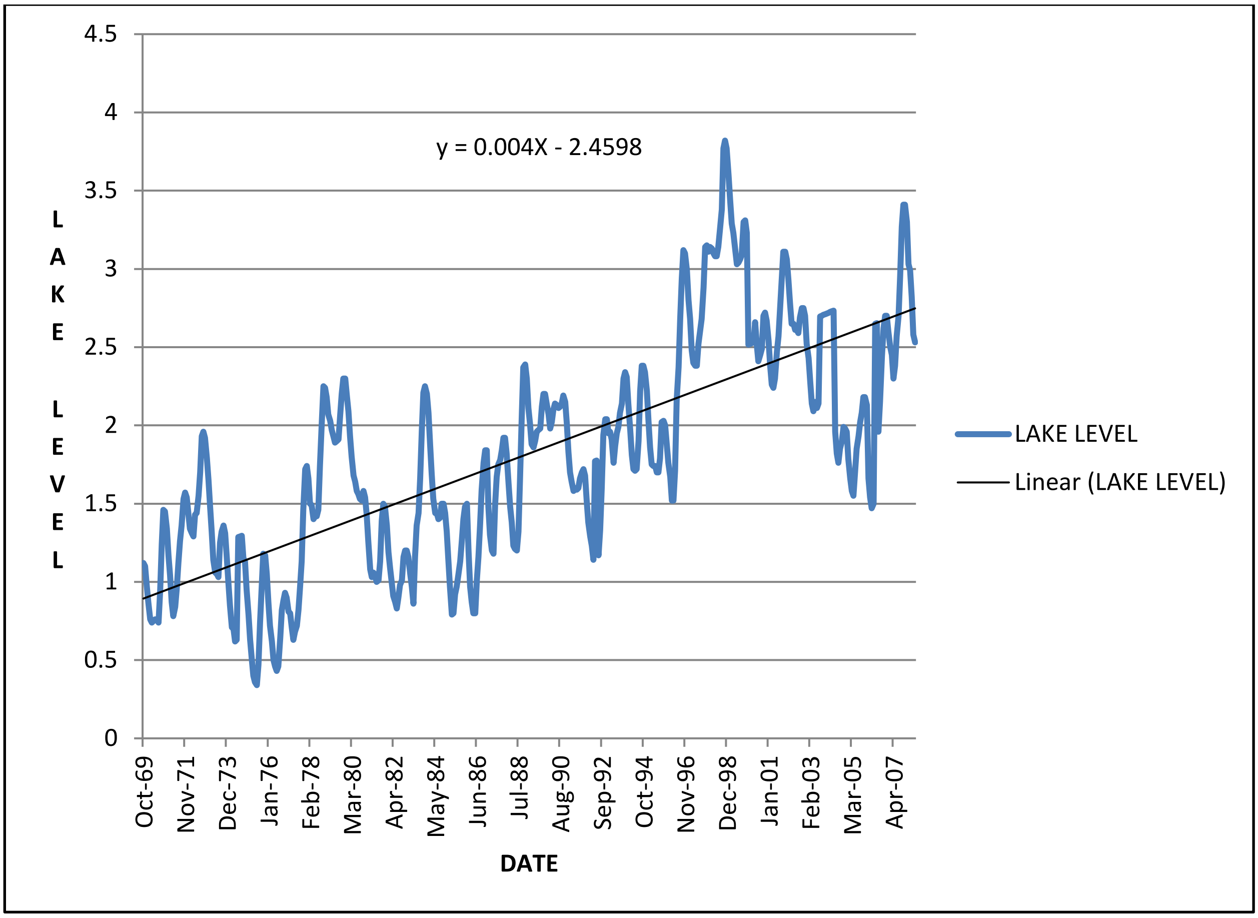

Figure 2-3: Observed average monthly lake levels (1969-2007)

2.11 Hydrology of the lake catchment

The surface area of Lake Cheleleka was about 12 km^2 in 1972 but currently it is completely disappeared as a result of siltation. The lake floor, which once was covered by water, is now filled by sediment transported from the eastern highland as a result of deforestation that has taken place over the last 30 years, prior to filling up of the basin with silt, Lake Cheleleka used to serve as a sediment trap for Tikurewuha River that flows in to Lake Awassa. As a result of losing its function as sediment trap, water and sediment load to Tikurewuha is now directly going in to Lake Awassa. Tall papyrus like grasses grow in the swampy area indicating that the deposition of transported sediment from the uplands has been in a continuous process of filling the natural reservoir of lake Cheleleka (W.W.D.S.E. 2001).

2.12 Drainage

When we compare the elevation of Lake Awassa (1680 m) with Lakes Ziway (1636 m), Langano (1585 m), Abiyata (1578 m), Shalla (1550 m) and Abaya and Chamo (1180 m) it is possible for water from the Awassa lake catchment to flow to lower laying lakes through the subsurface when hydrological conditions permits. Their relative position with respect to altitude is shown figure below (Gebreegziabher 2004).

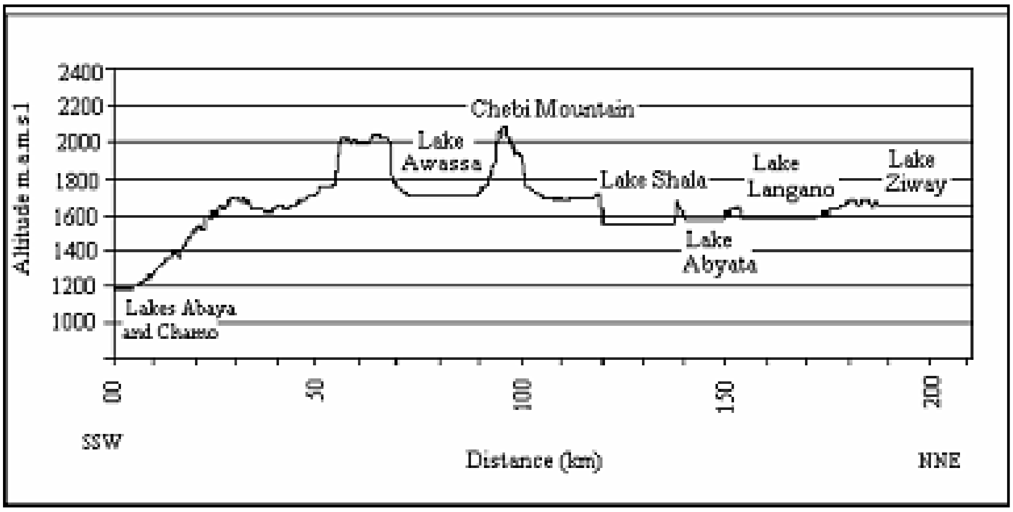

Figure 2-4: Cross-section along the Ethiopian Main Rift valley Lakes (extracted from SRTM)

2.13 Sediment Deposition

Land degradation is severe in the Lake Awassa catchment so a high sediment inflow rate of 1600 ton/km^2/year is used to estimated total annual sediment volume. This is typical for rivers of the northern Ethiopian highlands. A value of 1.7 Mm^3 is estimated for the total annual volume of sediment delivered to Lake Awassa (Halcrow, 2008).

CHAPTER THREE

3 Literature Review

3.1 The Study of Lake Awasa Level Rise Water Works Design and Supervision Enterprise (WWDSE).2001.

This study, which was concerned with studying the implications and possible causes of lake level rise, looked at land cover and land use in the Lake Awasa catchment.

The study compared land cover and land use from 1965 to that of 1998. The 1965 Data was interpreted from aerial photographs while the 1998 data was compiled from Field observation. Between 1965 and 1998 (33 years) the study found the following Land use changes, as shown in Table below:

Table 3-1: Change in land covers 1965-1998

Land cover	**Area (ha)**		**Change in land cover (%)**
	1965	**1998**	
Open Bushland	470	1,100	+1.36
Dense Bushy Woodland	18,755	8,450	-5.5
Open Bushy Woodland	12,125	3,190	-7.4
Cultivated Land	40,586	61,179	+5.1
Open Grazing Land	7,935	8,505	+7
Urban	490	1,400	+1.86
Lake	8,800	10,000	+1.4

In addition to this, the study found that Lake Cheleleka had changed from open water to grassland as the shallow lake has become in filled with sediment. By aggregating land covers to only four classes (urban, water, cultivation and natural vegetation) one can see that there has been a change from natural vegetation to cultivation between 1965 and 1998, as shown in Table below:

Table 3-2: Change in aggregated in land cover 1965-1998

Land cover	1965		1998	
	Area (ha)	%	Area(ha)	%
Urban	490	0.4	1,400	0.9
Cultivated land	40,586	34.3	81,247	54.9
Water	10,000	8.5	10,000	6.8
Natural Vegetation	67,198	56.8	55,430	37.4
Total	118,274		148,077	

1965 cultivated land made up 34.3% of the area but this had risen to 54.9% by 1998 and correspondingly the area under natural vegetation had decreased from 56.8% in 1965 to 37.4% by 1998. The report notes that between 1965 and 1998 a large part of dense woodland has been converted to cultivation, particularly in the immediate vicinity of Lake Awasa and also that the escarpment north of Lake Cheleleka has been denuded of its tree and bush cover.

The report concluded that the reason for Awasa lake level rise was the sedimentation of Lake Cheleleka resulting in a lower water storage capacity of the wetland and transfer of that water to Lake Awasa via the Tikurwuha River.

3.2 RVLB Master Plan, Phase 1 (2007).

This study mapped land use change within the whole Rift Valley Lakes basin, classifying land use changes into sixteen different categories of which some occurred within the sub-basin. These included the increase in urban areas at the expense of cultivated land, change from large-scale to smallholder cultivation, deforestation for cultivation, change from state farm to shrub land and changes in marshland.

In addition the study identified a number of themes concerning land use change from an analysis of livelihood zone information. With relevance to the sub-basin these included: that increasing population is resulting in increasing land pressure and that the subsequent fragmentation of land holdings is resulting in the situation where landholdings are increasingly unable to support the population.

Allied to this is the increasing problem of land degradation and soil erosion which is reported to be a major constraint in many areas, including the sub-basin where the increased rate of siltation has caused Lake Cheleleka to decrease in size.

Many areas, including the eastern sub-basin, also reported that rainfall was becoming increasingly erratic and that the frequency of drought years was increasing.

The common findings of both studies are that there has been an increase in cultivation at the expense of natural vegetation in the past 30 years or so years but that the rate of increase slowed dramatically in the 1998 due to the fact that most cultivable land has already been occupied. There has also been a change to sedentary cultivation from pastoralism in some places.

There is also some evidence for the degradation of land cover from woodland to bushland /shrubland although this is more difficult to discern and it is important to note that any changes are not necessarily linear in that natural vegetation can re-colonies previously cleared areas.

CHAPTER FOUR

4. Methodology

4.1 SWAT Model

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998; Arnold and Fohrer, 2005) has proven to be an effective tool for assessing water resource and non point source pollution problems for a wide range of scales and environmental conditions across the globe.

SWAT is a basin scale, continuous time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in un-gauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods.

Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management.

4.1.1 Sub watershed Discretization and Determination of HRUs.

The sub watershed discretization divides the watershed into sub basins based on topographic features of the watershed. This technique preserves the natural flow paths, boundaries, and channels required for realistic routing of water, sediment and chemicals. All of the GIS interfaces developed for SWAT use the sub watershed discretization to divide a watershed.

The number of sub basins chosen to model the watershed depends on the size of the watershed, the spatial detail of available input data and the amount of detail required to meet the goals of the project. When subdividing the watershed, keep in mind that topographic attributes (slope, slope length, channel length, channel width, etc.) are calculated or summarized at the sub basin level. The sub basin delineation should be detailed enough to capture significant topographic variability within the watershed.

Once the sub basin delineation has been completed, the user has the option of modeling a single soil land use management scheme for each sub basin or partitioning the sub basins into multiple hydrologic response units (HRUs). HRUs are used in most SWAT runs since they simplify a run by lumping all similar soil and land use areas into a single response unit. It is often not practical to simulate individual field. (Neitsch et. al, 2005), Soil and Water Assessment Tool input /output file documentation, version 2005.

4.2 Hydrologic Water Balance

Water balance is the driving force behind everything that happens in the watershed. In SWAT simulation of hydrology of the watershed can be separated in to two major divisions. The first division is the land phase of hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings in to the main channel in each sub basin. The second division is the routing phase of hydrological cycle which can be defined as the movement of water, sediments, etc through the channel network of the watershed to the outlet. As far as this research work is concerned the hydrologic cycle mainly focused on only on the movement of water, which is the runoff generation.

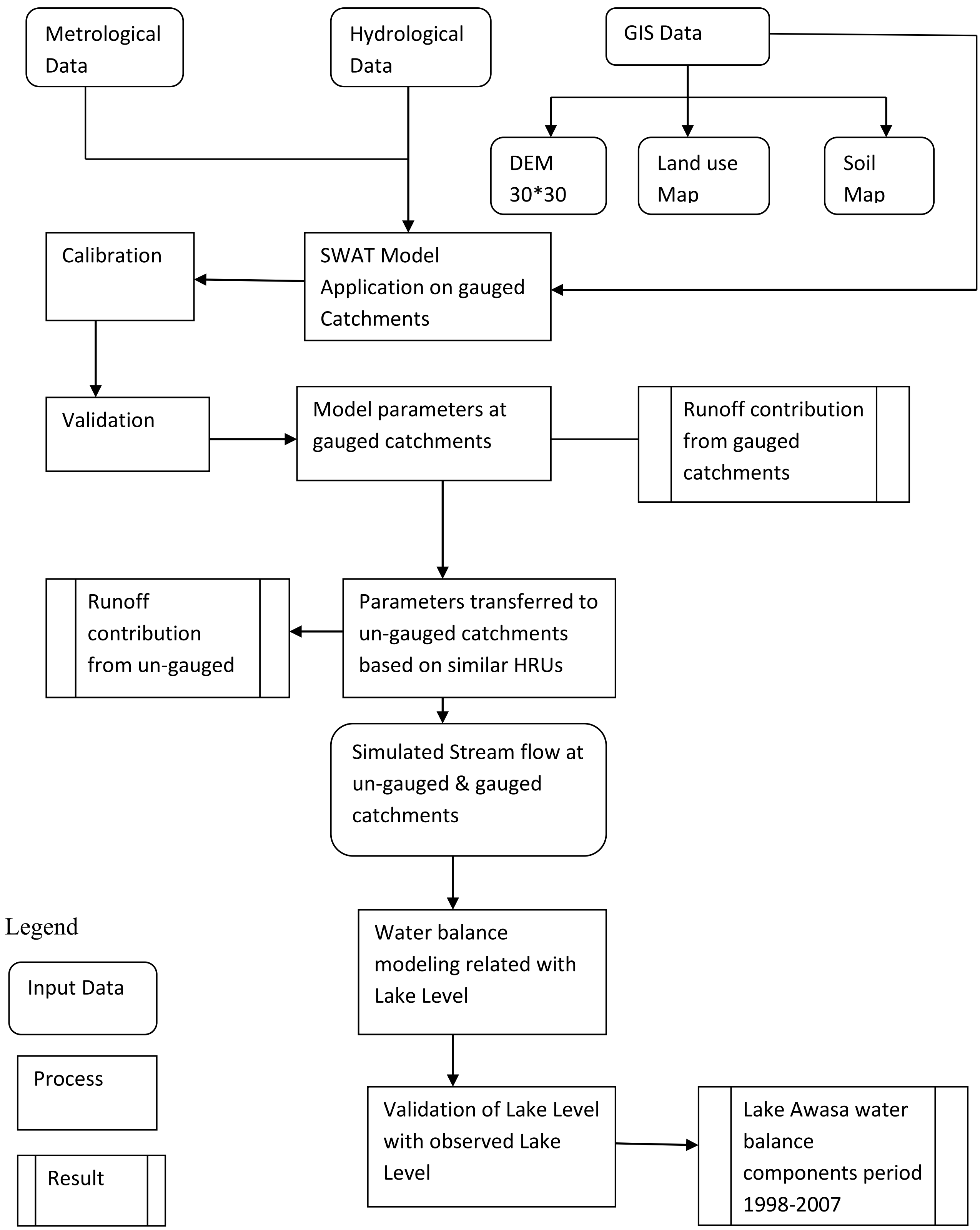

Figure 4-1: Simplified flow chart of the Methodology adopted in the research

4.2.1 Methods for Determining the Lake Level Fluctuation

The next step was to incorporate the outflow from Tikurwuha basin with the Water Balance Model of Lake Awasa. This attempt was done to model the lake water level fluctuation; since the ability of the hydrological model (SWAT) cannot directly model the lake water level.

A simple water balance base on mass conservation equation was satisfactorily implemented in the study area. After several adjustments in the discharge of the lake, the model showed a correlation factor of 0.6401 with the observed data. The water balance model is simulated for the period 1998 to 2002 and runs on monthly time steps.

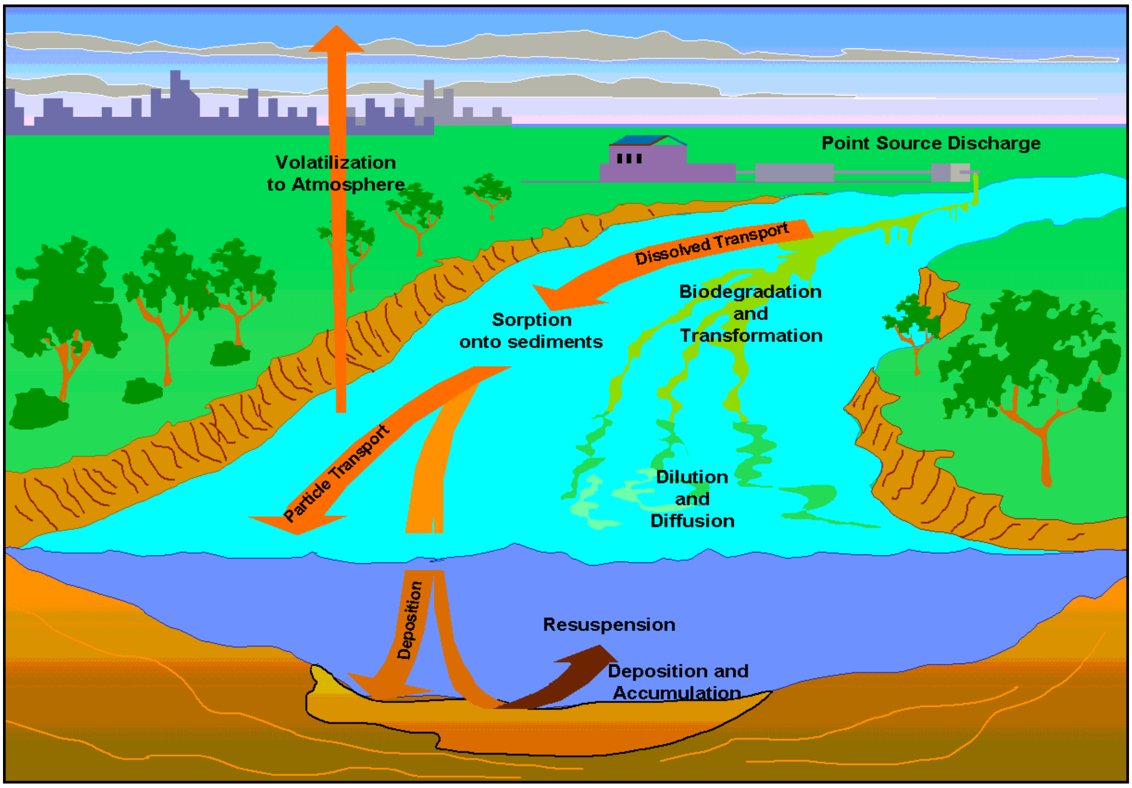

Figure 4-2: In-stream process modeled by SWAT

The model equation used is formulated below

$$dS = P - ET + R + GW_{in} - GW_{out}$$

Where;

P = direct precipitation into the lake

ET = evapotranspiration

R = Surface Runoff into the lake

GW_{in} = ground water inflow into the lake

GW_{out} = ground water outflow from the lake

dS = change in lake storage

In this research, the water balance model used the same concept for modeling the lake or a reservoir. Neitsch (2002) expressed the water balance of a reservoir as:

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep}$$

Where;

V = volume of water in the impoundment at the end of a day

V_{stored} = volume of water stored in the water body beginning of the day

V_{flowin} =volume of water entering the water body per day

$V_{flowout}$ = volume of water flowing out of water body per day

V_{pcp} = volume of precipitation falling on the water body per day

V_{evap} = volumes of water removes by evaporation per day

V_{seep} = volume of water lost from water body by seepage

As mentioned above, the Lake Awassa gets the inflow from one perennial Tikurwuha River without surface outlet. The eastern escarpment contributes most of the inflow through the lake.

4.3 Weather Generator

SWAT includes the WXGEN weather generator model (Sharpley and Williams, 1990) to generate climatic data or to fill in gaps in measured records. The occurrence of rain on a given day has a major impact 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 rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green & Ampt method is used for infiltration, maximum temperature, 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. To Generate the data, weather parameters were developed by using the weather parameter calculator WXPARM (Williams, 1995) and dew point temperature calculator DEW02

(Liersch, 2003), which were downloaded from SWAT website (http://www.brc.tamus.edu/swat/soft_links.html).

The daily precipitation generator is a Markov chain-skewed (Nicks, 1974) or Markov chain-exponential model (Williams, 1995). A first-order Markov chain is used to define the day as wet or dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount. In this research work a skewed distribution has been used. See appendix-B

4.3.1 Occurrence of Wet or Dry Day

With the first-order Markov-chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.1 mm of rain or more.

Wet-Dry probabilities and monthly statistics value of rainfall, Maximum, Minimum Temperature, solar radiation, wind speed and relative humidity for principal stations in the study area have been computed based on the formula presented in Appendix-B

The weather generator stochastically determines the occurrence of rainfall in a particular day. The probability of a wet day on day i given a wet day on day i – 1, Pi (W/W), and the probability of a wet day on day i given a dry day on day i – 1, Pi (W/D), for each month of the year. From these inputs the remaining transition probabilities can be derived:

$P_i(D/W) = 1\text{-}P_i(W/W)$

$P_i(D/D) = 1\text{-}P_i(W/D)$

Where: Pi (D/W) is the probability of a dry day on day i given a wet day on day i – 1 and

Pi (D/D) is the probability of a dry day on day i given a dry day on day i – 1.

To define a day as wet or dry, SWAT generates a random number between 0.0 and 1.0. This random number is compared to the appropriate wet-dry probability, Pi (W/W) or Pi (W/D). If the random number is equal to or less than the wet-dry probability, the day is defined as wet. If the random number is greater than the wet-dry probability, the day is defined as dry.

Skewed probability distribution function has been used for the study area to describe the distribution of rainfall amount.

4.4 Surface Runoff

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green & Ampt infiltration method (1911). For these research work SCS curve number method has been used.

The SCS curve number used (SCS, 1972)

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

Where:

Q_{surf} = accumulation runoff or precipitation excess (mm)

R_{day} = precipitation depth for the day (mm)

I_a = initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm)

S = retention parameter (mm)

The retention parameter varies spatially due to change in soil, land use, management and slope, and temporally due to change in soil water content. The retention parameter (S) is defined as:

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

CN is runoff curve number for the day. The initial abstraction (I_a) is commonly approximate as 0.2S and the equation becomes:

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

Runoff will only occur when $R_{day} > I_a$ Curve number is based on the soils and land uses in the watershed.

SWAT consist two methods for calculating runoff: SCS Curve Number and Green Ampt. In this research, SCS Curve Number was used since Green and Ampt methods require hourly precipitation data (Neitsch 2002) which was not available.

4.4.1 Peak Runoff Rate

The peak discharge or the peak surface runoff rate is the maximum volume flow rate passing a particular location during a storm event. SWAT calculates the peak runoff rate with a modified rational method. In rational method it assumed that a rainfall of intensity i begins at time t = 0 and continues indefinitely, the rate of runoff will increase until the time of concentration, t = t_{conc}. The modified rational method is mathematically expressed as:

$$q_{peak} = \frac{\alpha_{tc} * Q_{surf} * Area}{3.6 * t_{conc}}$$

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

α_{tc} is the fraction of daily rainfall that occurs during the time of concentration,

Q_{surf} the surface runoff (mm),

Area is the sub-basin area (km^2)

t_{conc} is the time of concentration (hr), 3.6 is a conversion factor.

SWAT estimates the value of α using the following equation:

$$\alpha_{tc} = 1 - exp[2 * t_{conc} * \ln(1 - \alpha_{0.5})]$$

Where: t_{conc} is the time of concentration (hr), and

$\alpha_{o.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall

4.4.2 Time of Concentration

The time of concentration, t_{conc}, is a time within which the entire sub basin area is discharging at the outlet point. It is calculated by summing up both the overland flow time of the furthest point in the sub basin to reach a stream channel (t_{ov}) and the upstream channel flow time needed to reach the outlet point (t_{ch}):

$t_{conc} = t_{ov} + t_{ch}$

The overland flow time (t_{ov}) is computed as:

$$t_{ov} = \frac{L_{sip}}{3600 * V_{ov}}$$

Where: L_{sip} is the average sub basin slope length (m),

V_{ov} is the overland flow velocity (m/s), and 3600 is a unit conversion factor.

The overland flow velocity for a unit width along the slope is calculated by using the Manning's equation:

$$V_{ov} = \frac{{q_{ov}}^{0.4} * Slp^{0.3}}{n^{0.6}}$$

Where: q_{ov} is the average overland flow rate (m3/s),

Slp is the average slope of the sub basin (m/m),

n is Manning's roughness coefficient of the sub basin.

Assuming an average flow rate of 6.35 mm/hr and substituting the equation of V_{ov} into t_{ov}, the simplified equation of the overland flow becomes:

$$t_{ov} = \frac{{t_{slp}}^{0.6} * n^{0.5}}{16 * slp^{0.3}}$$

Channel flow time is computed as:

$$t_c = \frac{L_c}{3.6 * V_c}$$

Where: L_c is the average flow channel length (km),

V_c is the average flow channel length is calculated as:

$$L_c = \sqrt{L * L_{con}}$$

Where: L is the channel length from the furthest point to the sub basin outlet (km),

L_{con} is the distance along the channel to the sub basin centroid (km)

Assuming L_{con} = 0.51, and using the Manning's equation for V_c for a trapezoidal channel with side slope of 2:1 and bottom width to depth ratio of 10:1, channel flow time becomes:

$$t_{ch} = \frac{0.62 * L * n^{0.75}}{Area^{0.125} * {Slp_{ch}}^{0.375}}$$

Where: t_{ch} is the time of concentration for channel flow (hr), L is channel length from the most distant point to the sub basin outlet (km),

n is Manning's roughness coefficient for the channel,

Area is the sub basin area (km^2), and

Slp_{ch} is the channel slope (m/m).

4.4.3 Surface Runoff Lag

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated. SWAT incorporates a surface runoff storage feature to lag a part of the surface runoff release to the main channel.

Once surface runoff is calculated, the amount of surface runoff released to the main channel is calculated as:

$$Q_{surf} = \left(Q'_{surf} + Q_{stor,i-1}\right) * \left(1 - Exp\left[\frac{-surlag}{t_{conc}}\right]\right)$$

Where: Q_{surf} is amount of surface runoff discharged to main channel in a day (mm),

Q'_{surf} is amount of surface runoff generated in a sub basin in a day (mm),

$Q_{stor,i-1}$ is the surface runoff stored or lagged from the previous day (mm),

Surlag is the surface runoff lag coefficient, and

t_{conc} is the time of concentration for the sub basin (hrs)

4.4.4 Routing Method

The routing phase is the second division of hydrological cycle which can be defined as the movement of water, sediments, etc through the channel network of the watershed to the outlet. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method.

The variable storage routing method was developed by Williams (1969) and used in the HYMO (Williams and Hann, 1973) and ROTO (Arnold et al., 1995) model has been used in this research work.

For a given reach segment, storage routing is based on the continuity equation:

$\Delta V_{storage} = V_{in} - V_{out}$

Where: V_{in} is the volume of inflow during the time step (m^3 water),

V_{out} is the volume of outflow during the time step (m^3 water), and

$\Delta V_{storage}$ is the change in volume of storage during the time step (m^3 water)

4.5 Potential Evapotranspiration

The concept defined PET as the rate at which evapotranspiration would occur from a large area uniformly covered with growing vegetation that has access to an unlimited supply of soil water content and that was not exposed to advection or heat storage effect.

As the evapotranspiration rate is strongly influenced by a number of vegetative surface characteristics, Penman (1956) redefined PET as "The amount of water transpired by short green crop, completely shading the ground, of uniform height and never short of water". Grass type of vegetation has been used as reference crop by Penman, but later researchers have suggested that alfalfa at a height of 30 to 50 cm may be a more appropriate choice.

The SWAT model requires monthly data of long-term mean potential evapotranspiration (PET). There are number of methods to estimate evapotranspiration and they are based on specific climate variable required for calculation. In this study daily potential evaporation is calculated by using Penman-Monteith formula. The Penman approach of estimating evapotranspiration combines the mass transfer and energy balance approach because of which it gained strong physical base (Dingman, 2002). The Penman Monteith requires radiation, air temperature, air humidity, and wind speed data.

Penman-Monteith is considered as the de-facto standard. However, also the method is most data demanding. The equation:

$$\lambda E_0 = \frac{\Delta * (H_{net} - G) + \rho_{air} * C_p \left[{(e_z{}^0 - e_z)}/{r_a} \right]}{\Delta + \gamma * \left[1 + {r_c}/{r_a} \right]}$$

Where:

λ = latent heat flux density (MJ m^{-2} d^{-1})

E = depth rate evaporation (mm d^{-1})

Δ = slope of saturation vapor pressure – temperature curve (kpa $^0C^{-1}$)

H_{net} = net radiation (MJ m^{-2} d^{-1})

G =heat flux density to the ground (MJ m^{-2} d^{-1})

ρ_{air} = air density (kg m^{-3})

C_p = specific heat at constant pressure (MJ m^{-2} d^{-1})

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

γ = psychometric constant (kpa $^0C^{-1}$)

r_c = pant canopy resistant (sm^{-1})

r_{at} = diffusion resistance of the air layer (aerodynamic resistance) (sm^{-1})

4.6 Sensitivity Analysis

Sensitivity analysis is a simple technique for assessing the effect of uncertainty on the system performance. It is also a measure of the effect of change of one parameter on another. The sensitivity analysis was undertaken by using a built-in tool in SWAT2005 that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) design method of Morris (1991). The OAT design appeared to be a very useful method for SWAT modeling as it is able to analyze sensitivity on high number of parameters. The LH-OAT sensitivity analysis method combines thus the robustness of the Latin Hypercube sampling that ensures that the full range of all parameters has been sampled with the precision of an OAT designs assuring that the changes in the output in each model run can be unambiguously attributed to the input changed in such a simulation leading to a robust and efficient sensitivity analysis method.

Therefore sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Lenhart et al. 2002)

Table 4-1: Sensitivity classes as per Lenhart et al. (2002)

Class	Index	Sensitivity
I	0.00<=/I/<0.05	Small to negligible
II	0.05<=/I/<0.2	Medium
III	0.2<=/I/<1	High
IV	/I/>=1	Very high

Using the built in tool in SWAT model sensitivity analysis has been performed for all major gauged stream flow in the basin and the result is found in modeling section of this report.

4.7 Calibration and Validation of Model.

4.7.1 Calibration.

Physically based semi distributed model SWAT generally have a large number of parameters which are not directly measurable and must therefore be estimated through model calibration, i.e. by fitting the simulated outputs of the model to the observed outputs of the watershed by adjusting the model parameters. A measure of the fit between the simulated and observed outputs is called calibration. The goal of calibration is to find those values for the model parameters that minimize (Maximize) the specified calibration criterion.

As per (Refsgaard and Storm, 1996) three types of calibration procedures can be differentiated:

a. Trial-and-error, manual parameter adjustment;
b. Automatic, numerical parameter optimization;
c. A combination of (1) and (2).

For this research work the measured stream flow data of Tikurewuha were manually calibrated from a period of 1998-2002 and the result is presented in chapter six of this report.

Table 4-2: Most common parameters used in SWAT model for runoff generation

S.No.	Parameters
1	Base flow alpha factor [days]; ALPHA_BF
2	Threshold water depth in the shallow aquifer for flow [mm]; GWQMN
3	Groundwater "revap" coefficient ;GW_REVAP
4	Threshold water depth in the shallow aquifer for "revap" [mm]; REVAPMN
5	Soil evaporation compensation factor ; ESCO
6	Average slope steepness [m/m]SLOPE
7	Average slope length [m];SLSUBBSN
8	Temperature lapse rate [°C/km];TLAPS
9	Channel effective hydraulic conductivity [mm/hr]; CH_K2
10	Initial SCS CN II value;CN2
11	Available water capacity [mm WATER/mm soil]; SOL_AWC
12	Surface runoff lag time [days]; surlag

13	Groundwater delay [days];GW_DELAY
14	Deep aquifer percolation fraction ; rchrg_dp
15	Maximum canopy storage [mm]; canmx
16	Saturated hydraulic conductivity [mm/hr]; sol_k
17	Soil depth [mm]; sol_z
18	Moist soil albedo ; sol_alb
19	Plant uptake compensation factor ;epco
20	Manning's n value for main channel ;ch_n
21	Maximum potential leaf area index ;blai
22	Biological mixing efficiency ;BIOMIX

4.7.2 Validation

Validation is the process of testing model performance of the calibrated model parameter set against an independent set of measured data. For this research work validation period was taken as 3 years beginning Jan. 1, 2004 – Dec. 31, 2006.

4.8 Model Performance

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability (Goswami et al., 2005)

A forecast efficiency criterion is therefore necessary to judge the performance of the model. Assessing performance of a hydrologic model (Krause et al., 2005) requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations.

The model simulation has been evaluated using efficiency criteria such as coefficient of determination, R^2 [Nash and Sutcliff (E_{NS}), 1970], percent difference D, & root mean square error standard deviation ratio (RSR)

The R^2 coefficient and E_{NS} simulation efficiency measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. The range of values for R^2 is 1.0 (best) to 0.

The r^2 coefficient for n time steps is calculated as:

$$r^2 = \frac{[\sum_{i=1}^{n}(q_{si} - q_s)(q_{oi} - q_o)]^2}{\sum_{i=1}^{n}(q_{st} - q_s)^2 \sum_{i=1}^{n}(q_{oi} - q_o)^2}$$

Where: q_{si} is the simulated value

q_{oi} is the measured values

q_s is the average simulated value

q_o is the average measured value

The E_{NS} simulation efficiency for n time steps is calculated as:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})^2}{\sum_{i=1}^{n}(q_{oi} - q_o)^2}$$

Where: q_{si} is the simulated value

q_{oi} is the measured value

The statistical index of modeling efficiency (E_{NS}) values range from 1.0(best) to negative infinity.

The percent difference for a quantity (D) over a specified period with total days is calculated from measured and simulated values of the quantity in each model time step as:

$$D = 100 * \left[\frac{(\sum_{i=1}^{n} q_{oi} - \sum_{i=1}^{n} q_{si})}{\sum_{i=1}^{n} q_{oi}}\right]$$

Where: q_{st} is the simulated value

q_{oi} is the measured value

A value close to 0% is best for D. A negative value indicates model over estimation and a positive value indicate model under estimation.

RMSE Observation standard deviation ratio (RSR) also another performance rating can be described as follows:

RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information recommended by Legates and (McCabe 1999, Cited in D.N Moriasi, 2007). RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation

$$RSR = \frac{[\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2]^{1/2}}{\left[\sum_{i=1}^{n}\left(Q_{obs} - Q'_{obs}\right)^2\right]^{1/2}}$$

Where: Q_{obs} is the observed flow.

Q_{sim} is the simulated flow.

Q'_{obs} is mean observed flow.

RSR incorporates the benefits of error index statistics and includes a scaling / normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR, the lower the RMSE, and the better the model simulation performance.

Note: $NSE= 1- (RSR)^2$

Table 4-3: General Performance ratings for recommended statistics for a monthly time step. (D. N Moriasi, et al. 2007)

Performance Rating	**For Stream Flow**		
	RSR	NSE	%D
Very good	0.0<=RSR<=0.5	0.75<NSE<=1	D <=±10
Good	0.5<RSR<=0.6	0.65<NSE<=0.75	±10 <=D < ±15
Satisfactory	0.6<RSR<=0.7	0.5<NSE<=0.65	±15<=D<± 25
Unsatisfactory	RSR>=0.7	NSE<=0.5	D >= ± 25

CHAPTER FIVE

5 Data Availability and Analysis

5.1 ARCWAT Model input

5.1.1 Hydro meteorological data.

Hydrological model SWAT largely depends on hydro meteorological data such as precipitation, temperature, relative humidity, wind speed and solar radiation and hydrological data such as river discharge.

The model allows values for daily precipitation, maximum/ minimum air temperatures, solar radiation, wind speed and relative humidity to be input from records of observed data or generated during the simulation.

Hydrometeoological datas' were collected from National Meteorological Agency (NMA). Datas like daily precipitation, daily maximum and minimum temperature were collected in a soft copy format and other weather information like wind speed, sunshine hours and relative humidity were collected in a hard copy format which later encoded to soft copy format.

5.1.2 Filling in missing weather data

The ability of SWAT to reproduce observed stream hydrographs is greatly improved by the use of measured precipitation data. For this research work the weather information used was considered for a period of 1998-2007. Missing weather data are left as it was in name.dbf format and a negative (-99.0) inserted for missing data. This value tells SWAT to generate weather data for that day. Daily values for weather are generated from average monthly values. The model generates a set of weather data for each sub basin. The method used for weather generator has been mentioned in methodology section.

The same weather generator technique has been applied for filling in maximum, minimum temperature, wind speed, relative humidity and solar radiation.

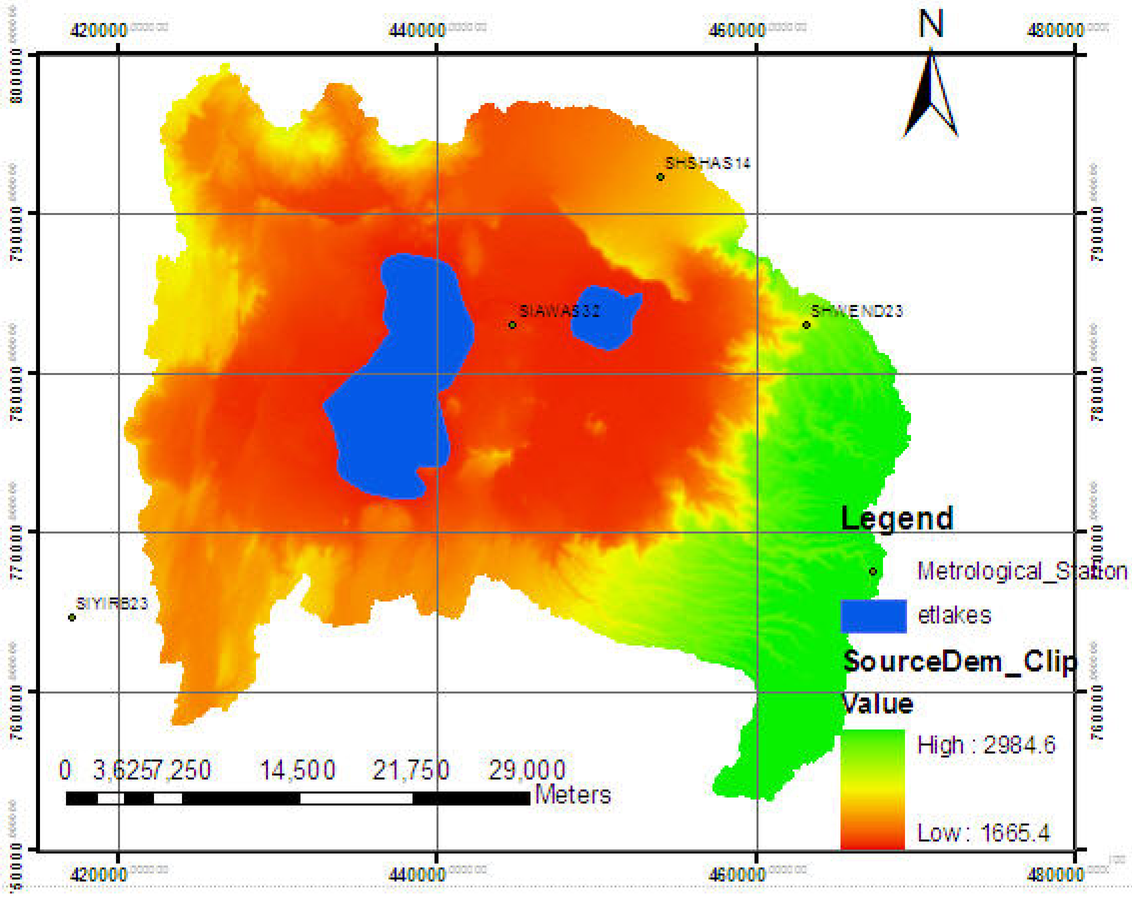

Figure 5-1: Spatial Distribution of Metrological Station of Lake Awassa Basin

5.2 Hydrological Data

Daily stream flow data with in Lake Awassa Basin were collected from Ministry of Water Resources (MoWR). Even though, long record of time series data are available, concurrent data set for all the stations from a period of 1998-2002 and has been used for model calibration and from 2004-2006 used for model validation.

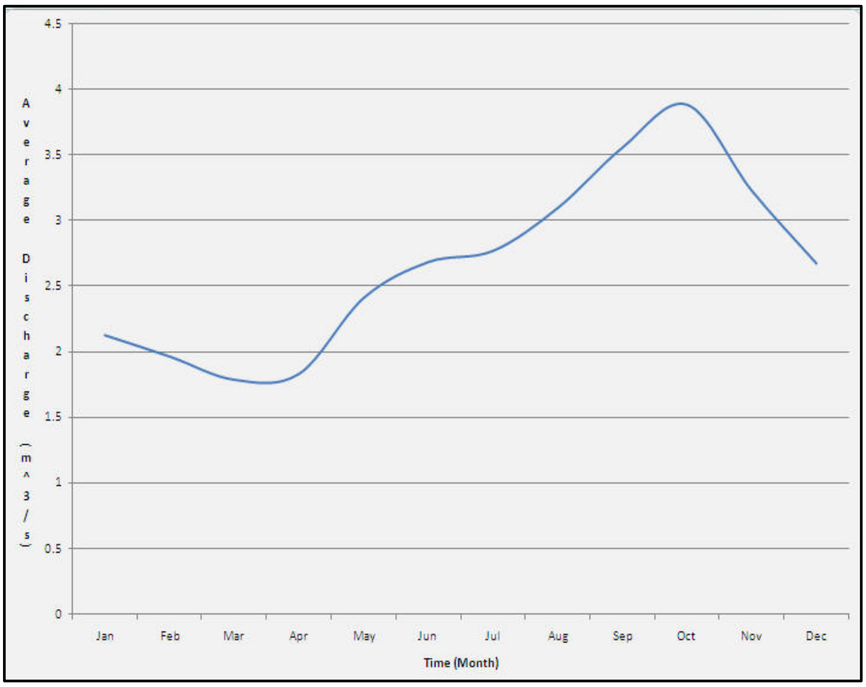

Figure 5-2: Long term Monthly average discharge of Tikurewuha River at Dato village from a period of 1980 – 2002 and 2004-2006

5.3 Spatial input Data

5.3.1 Digital Elevation Model (DEM)

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. Digital elevation model is one of the essential inputs required by SWAT to delineate the watershed in to a number of sub watershed or sub basins. DEM is used to analyze the drainage pattern of the watershed, slope, stream length, width of channel within the watershed. The digital elevation model used in this study was obtained from the NASA Shuttle Radar Topographic Mission (SRTM) with a resolution of 30m*30m. The raw DEM was processed & projected using ARCGIS 9.3 & Arc Map 9.3 version software package.

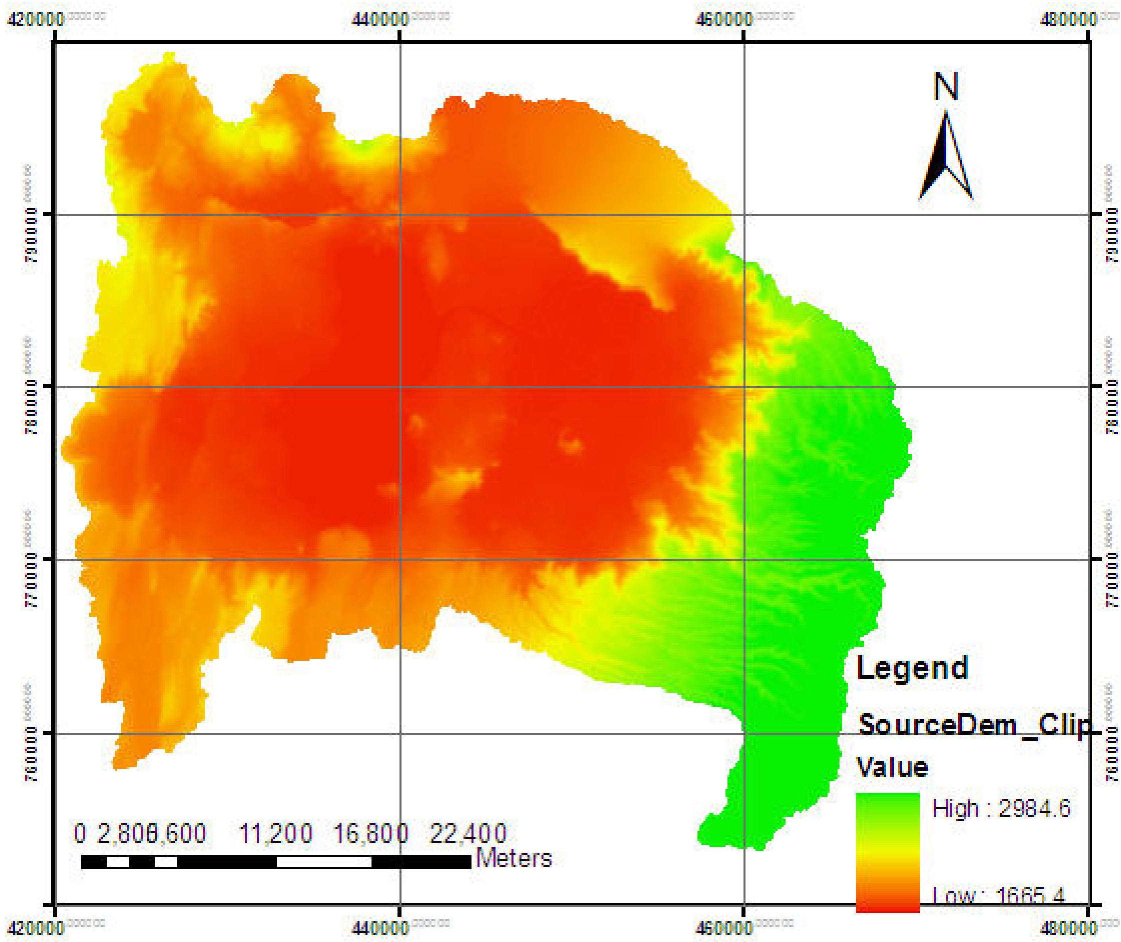

Figure 5-3: Digital Elevation Model for Lake Awassa Basin

5.4 Land use / Land cover Data

Reclassification of land use was done using land cover classes from USDA data set. In order to simplify the model, six land cover types were implemented for the area: Urban, Cultivated land, Water, Natural vegetation, Grassland, and Marshland.

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. The infiltration rate will decrease as the soil becomes saturated. When the application rate is higher than the infiltration rate, surface depression start to be infilling. If the application rate continues to become higher than the infiltration rate and all the surface depressions have been filled, surface runoff will initiate (Neitsch 2002).

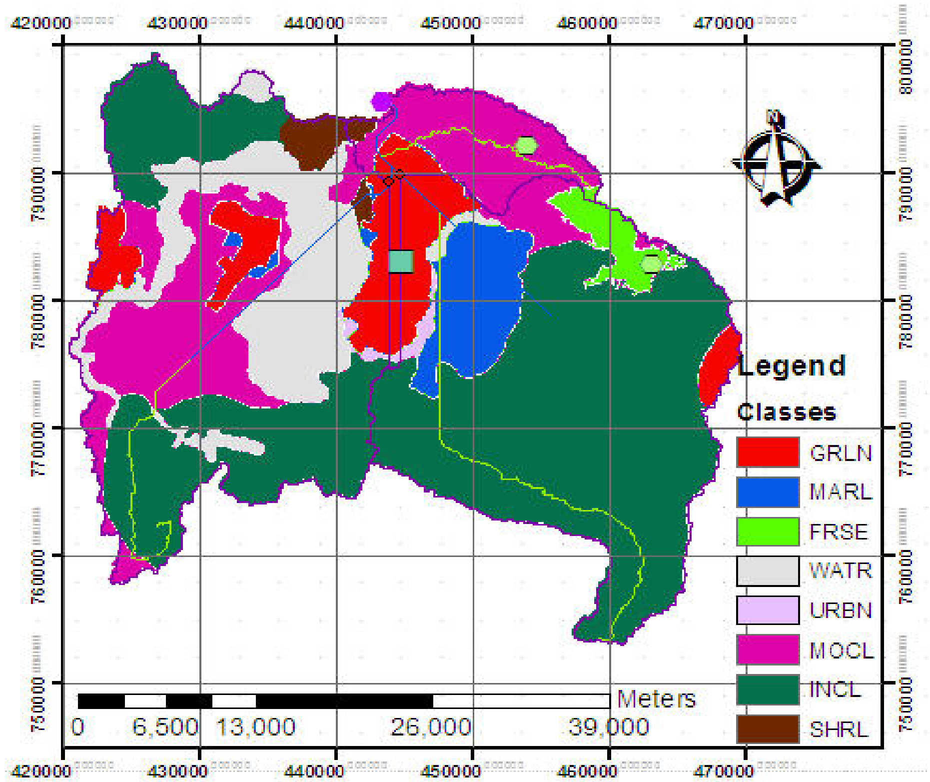

Figure 5-4: Land use map of 1998

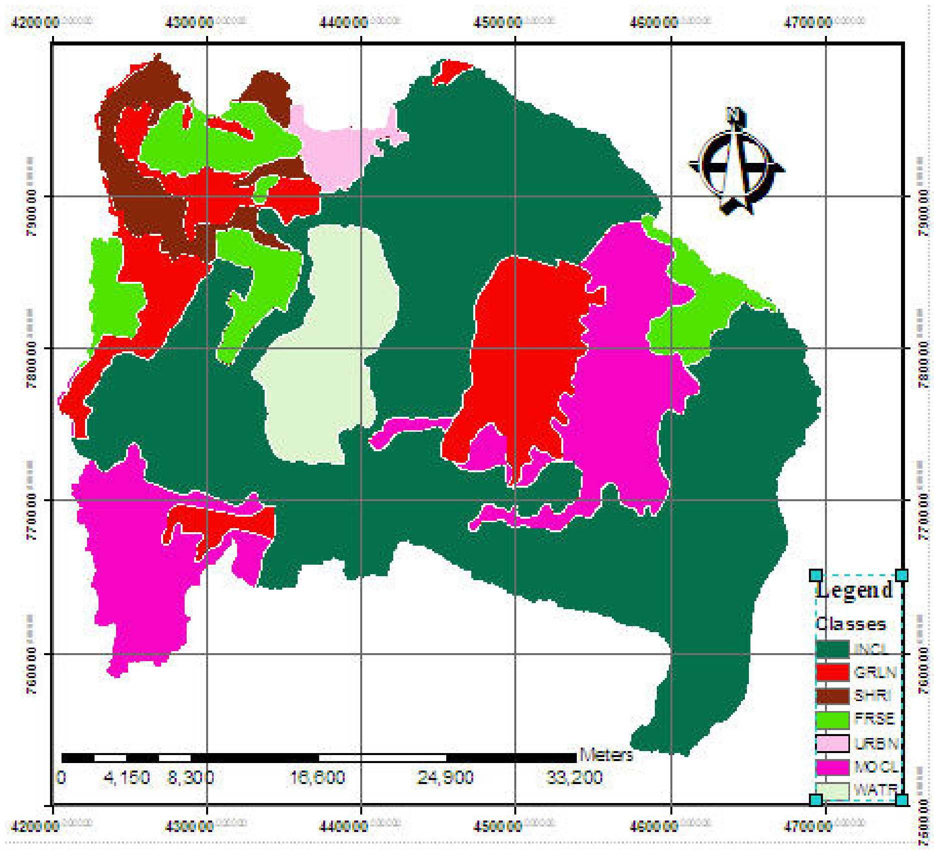

Figure 5-5: Land use map of 1965

Table 5-1: Land covers in Lake Awasa catchment at 1965 and 1998 (Halcrow 2008)

S. No.	Land use Type	1965		1998	
		Area (ha)	**%**	**Area (ha)**	**%**
1	Urban	490	0.34	1800	1.23
2	Cultivated land	40586	28.41	61247	41.96
3	Water	10000	7.00	10000	6.85
4	Natural vegetation	67198	47.03	55430	37.98
5	Grassland	13723	9.61	10171	6.97
6	Marshland	7592	5.31	7306	5.01
	Total	**142,873**		**145954**	

Table 5-2: Summary of land cover changes for the period 1965-1998

S.No.	Land use Type	1965 - 1998	
		Ha	%
1	Urban	-1310	-0.89
2	Cultivated land	-20661	-13.56
3	Water	0	0.15
4	Natural vegetation	11768	9.06
5	Grassland	3552	2.64
6	Marshland	286	0.31

5.5 Soil

The soils of the sub-basin are primarily deep, medium and fine textured Chromic and Haplic Luvisols in the south and east on a rolling to hilly topography with mixed perennial and annual cultivation. In the centre of the sub-basin, extending into the Wendo Koshe hills the soils are Chromic and Eutric Cambisols, moderately deep to deep and medium textured with poorly drained, fine textured Vertic Cambisols in the Cheleleka wetlands. To the north and west of the lake the soils are moderately deep to deep, well to excessively drained Vitric Andosols and small areas of very shallow Leptosols.

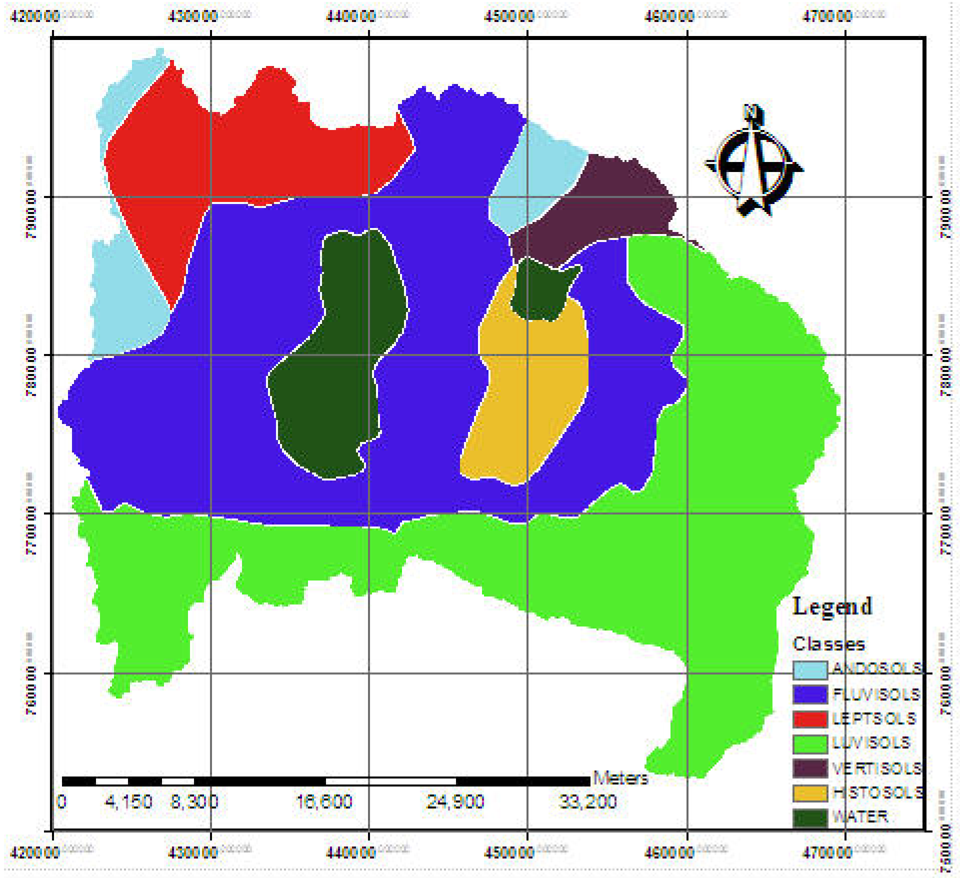

Figure 5-6: Soil Map of Lake Awassa Basin

CHAPTER SIX

6 Estimation of Total Inflow to Lake Awassa

6.1 Calibration and verification of gauged catchments

Hydrological modeling plays an important role in planning and management of water resources. In Lake Awassa basin, the river which is flowing in to the lake is not gauged and the water yield from un-gauged part of the basin has not quantified properly. In order to quantify the runoff contribution from each un-gauged catchments, and to study hydrological processes in LAB, SWAT hydrological model has been applied. The only river gauged in Lake Awassa Sub-basin is the Tikurewuha River. Its catchment area based on SWAT delineation is 74176 ha. The un-gauged part of this watershed has a catchment area of 67301 ha. As it was indicated in the description of study area only 52.43 % of the total area is gauged and 47.57 % is not gauged and hence, the estimation of runoff from this huge percentage area of un-gauged part is very crucial for current and future Water resources development projects.

6.2 Modeling Tikurewuha Watershed

Tikurewuha River is the only perennial river in the basin which empties the flow in to Lake Awassa. It has a catchment area of 74176 ha and its elevation ranging from 1681-2984m +MSL. In order to model this gauged river using SWAT, the spatial input which is shown in fig 6.1 have been used. For modeling purpose a watershed is partitioned in to a number of sub watersheds.

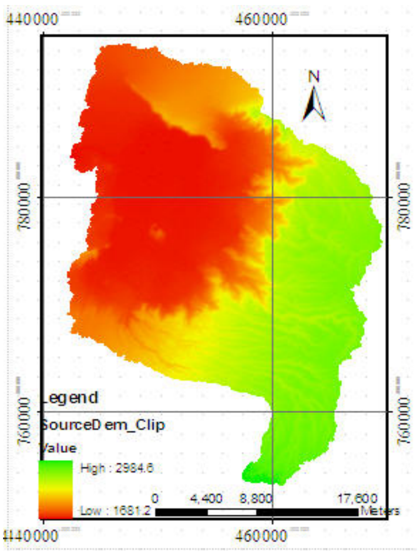

Figure 6-1: Tikure Wuha watershed DEM

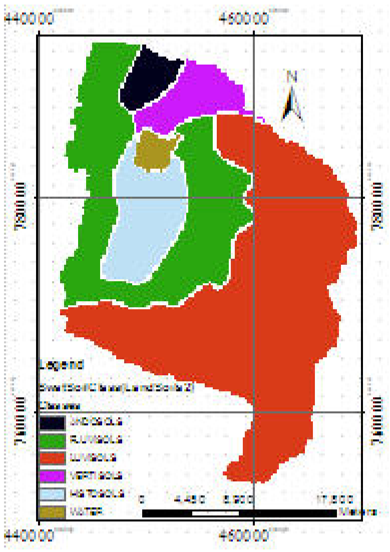

Figure 6-2: Soil reclacified map of Tikure Wuha Watershed

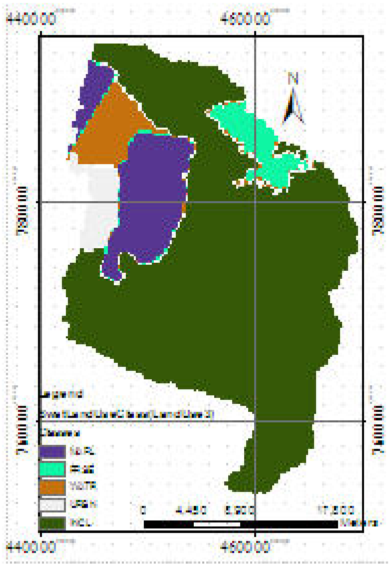

Figure 6-3: Land use map of 1998 Tikurewuha watershed

Table 6-1: Land use classification of Tikurewuha catchment used in SWAT

No	Land use	SWAT Land use Class	Area (ha)	% of Total Area
1	Intensive Cultivated	INCL	43,264.57	61.29
2	Residential	URBN	2,14.35	0.29
3	Forest-Evergreen	FRSE	2,920.05	3.89
4	Moderately Cultivated	MOCL	12,546.33	16.71
5	Water	WATR	11.86	0.01
6	Grassland	GRLN	16,565.18	11.62
Total			**75,522.37**	**100**

Table 6-2: Soil type of upper Tikurewuha catchment

No	Soil Type	Area (ha)	% of Total Area
1	ANDOSOLS	2,483.6225	3.31
2	FLUVISOLS	21,913.9060	29.19
3	HISTOSOLS	6,705.3664	8.93
4	LEPTSOLS	451.7817	0.60
5	LUVISOLS	35,797.1315	47.68
6	VERTISOLS	4,129.4860	5.50
7	WATER	195.9647	1.59
Total		**73,677.2588**	**100**

Table 6-3: Slope classification of Tikurewuha Catchment

No	Slope Classification	Area (ha)	% of Total Area
1	0-10	39,677.2385	52.85
2	10-20	13,043.4896	17.37
3	20-9999	19,956.5306	26.58
Total		**73,677.2587**	**100**

6.2.1 Sensitivity Analysis

Sensitivity analysis has been done on the built in extension program embedded in SWAT. Sensitivity analysis has been carried out for 27 parameters. Only few sensitive parameters were considered and the parameters with their mean relative sensitivity value at the outlet for the runoff are presented in table 6.4 below.

Table 6-4: Result of the sensitivity analysis of flow in Tikurewuha watershed

Rank	Parameters	Lower Bound	Upper Bound	Relative Sensitive Value
1	Alpha_Bf	0	1	0.262E+00
2	Esco	0	1	0.120E+00
3	Sol_Z	0	3500	0.841E-01
4	Blai	0.5	10	0.428E-01
5	Canmx	0	100	0.272E-01
6	Slope	-25%	25%	0.243E-01
7	Cn2	35	98	0.121E-01
8	Epco	0	1	0.328E-02
9	Ch_N2	-0.01	0.3	0.257E-02

6.2.2 Calibration

Historical observed stream flow of Tikurewuha River at Awassa Bridge was calibrated from a period of 1998-2002.

6.2.3 Validation

An independent data set from a period of 2004- 2006 has been used to ensure that the calibrated parameters perform reasonably well under this data set.

Table 6-5: Initial and final adjusted value of optimized parameters for gauged catchments.

S.No	Parameters	Description	Initial and Default Value	Final Value
1	REVAPMN	Threshold depth of water in shallow aquifer for “revap” or percolation to the deep aquifer to occur	1	0.116
2	GWQMIN	Threshold depth of water in the shallow aquifer required for return flow to occur	-500	30
3	SOL_K	Saturated hydraulic conductivity (mm/hr)	890	60
4	ALPHA_BF	Base flow alpha factor (days)	0.048	0.1
5	ESCO	Soil evaporation compensation factor	0	0.1
6	EPCO	Plant uptake compensation factor	0	0.1
7	CANMX	Maximum canopy storage	0	10
8	RCHRG_DP	Deep aquifer percolation fraction	0.05	0.016

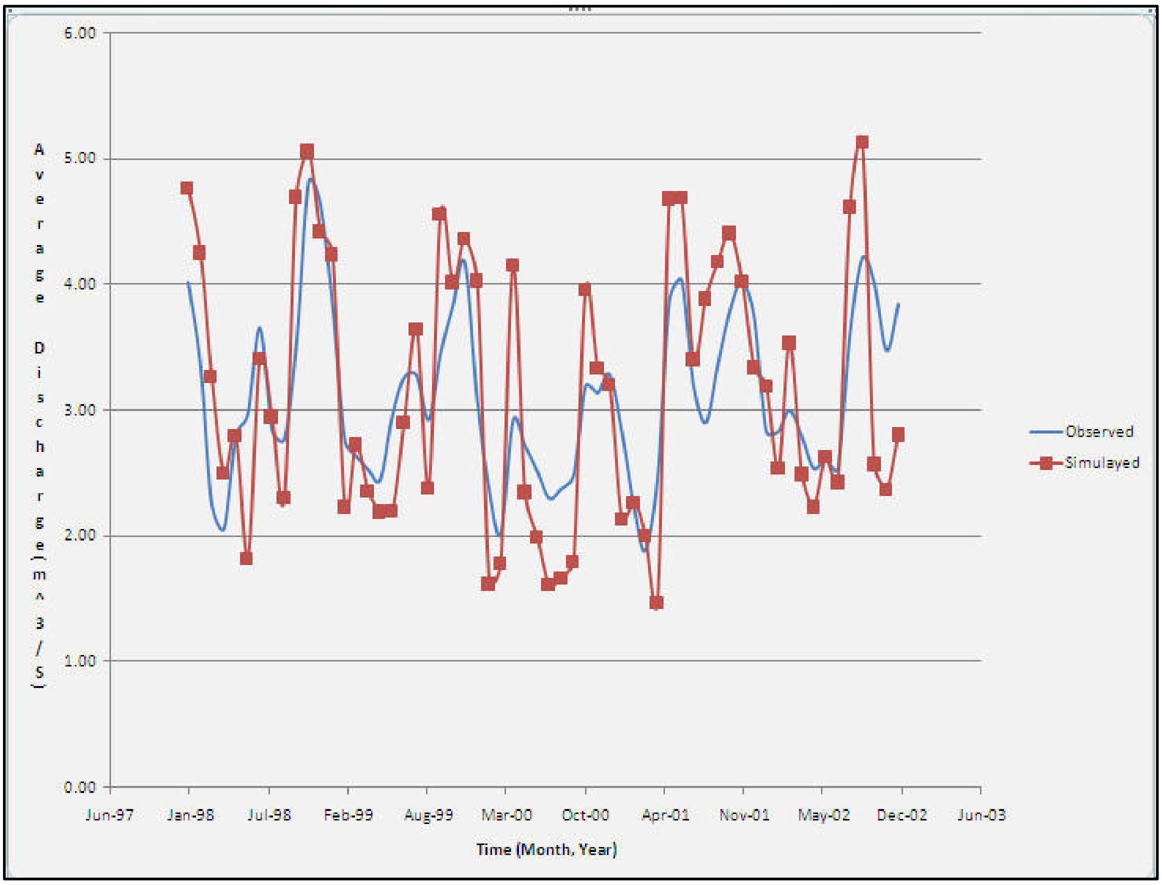

Figure 6-4: Calibrated of Observed and Simulated hydrograph of Tikurewuha River at Awassa Bridge, Period (1998-2002)

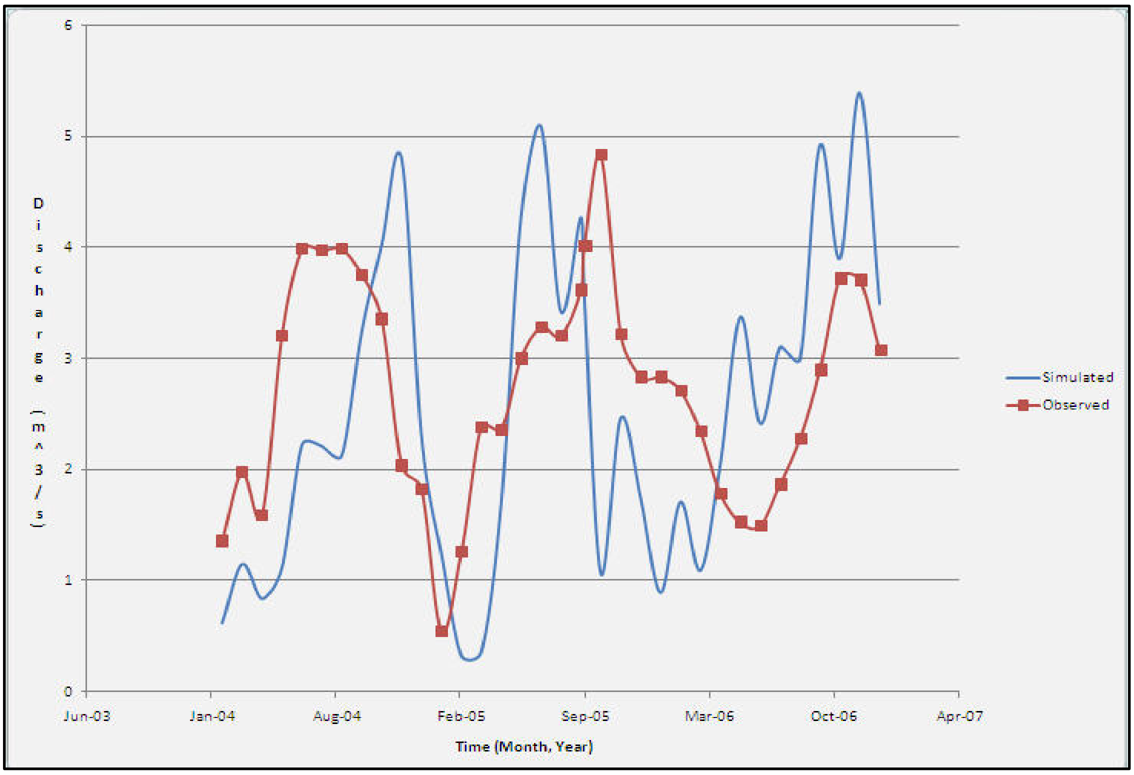

Figure 6-5: Validation of Observed and Simulated flow Hydrograph of Tikurewuha River at Awassa Bridge, Period (2004-2006)

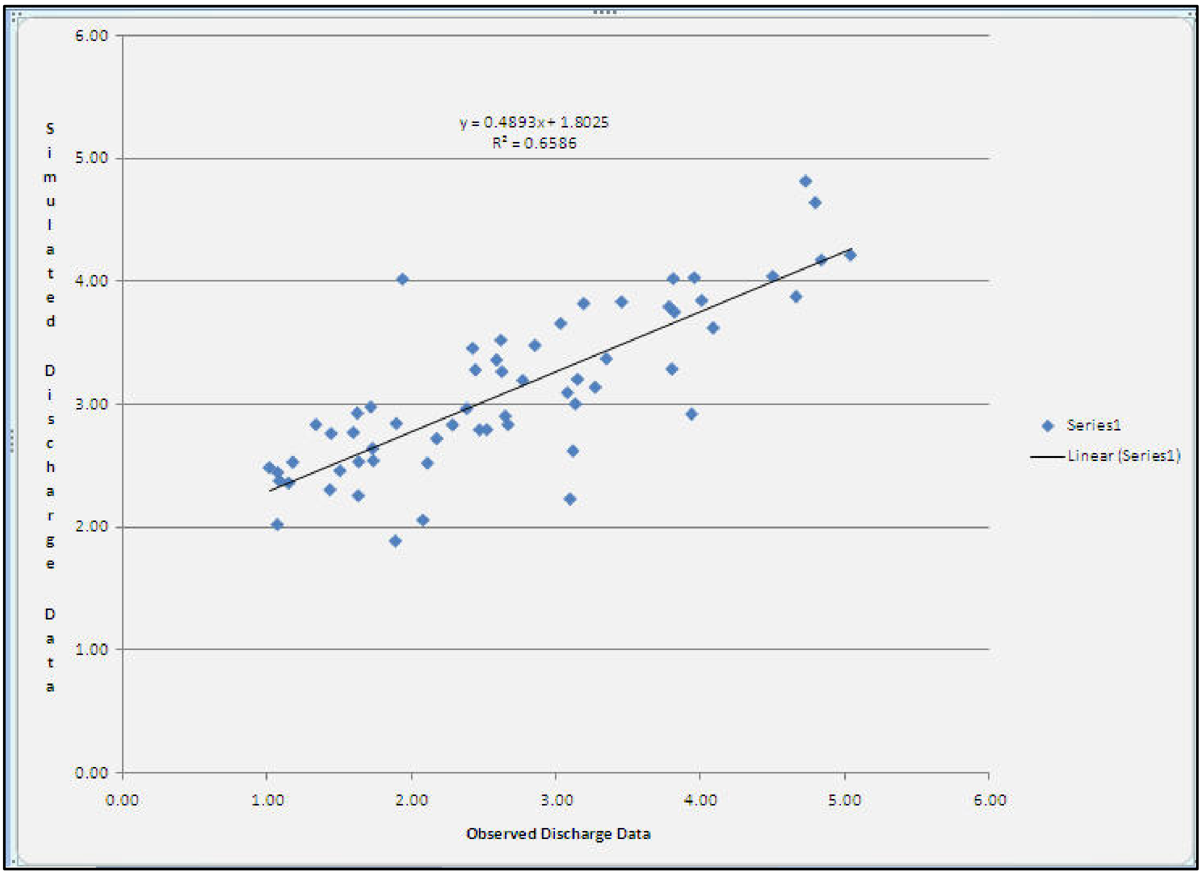

Figure 6-6: Scatter plot of Observed and Simulated discharge for Tikurewuha River during calibration period

Since modeling studies predict results with some error, it is useful to evaluate the general accepted level of model performance.

Over the calibration period 1998-2002 and validation period 2004-2006, Tikurewuha catchment shows that the performance in simulation of trends NSE, in simulation of residual variation (RSR) and in simulation of volumetric fit in all cases good performance was rated.

As it was indicated in calibration and validation results, NSE values for the monthly stream flow of validation and calibration ranges from 0.62 to 0.67. According to the model evaluation guide lines, the model simulated the stream flow trends good in both calibration and validation period. These values indicate that the model performance for stream flow residual ranged good in both periods. The volumetric fit (% D), value also varied from 10.30 % to 4.34 % during calibration and validation period indicates that the model simulated the stream flow volumetric fit as good to very good range of performance during validation and calibration period.

Table 6-6: Annual basin water balance components of Tikurewuha River

S.no.	Hydrologic Parameters	Simulated Value (mm) Period (1998-2002)
1	Precipitation	956.9
2	Surface Runoff	74.06
3	Lateral flow	443.59
4	Ground Water flow (Base flow)	70.98
5	Revap. Shallow aquifer recharge	10.63
6	Deep aquifer recharge	10.6
7	Transmission losses	1.91
8	Total Water yield	588.63
9	Evapotranspiration	519.8
10	Potential Evapotranspiration	814.9

Note: Total water yield= (Surface runoff) + (Lateral flow) + (Ground water flow) – (Transmission losses)

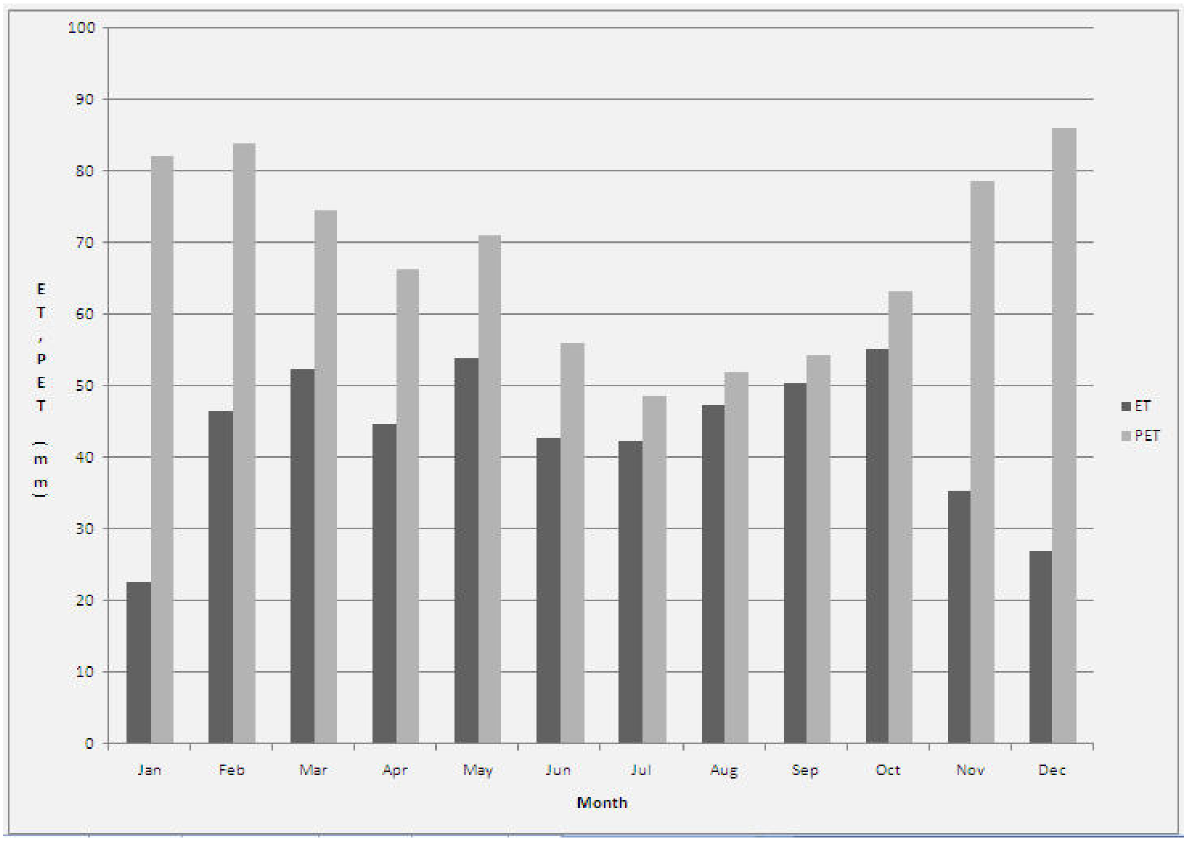

Figure 6-7: Monthly Average Potential Evapotranspiration and Evapotranspiration of Tikure Wuha catchment. Period (1998-2004)

6.3 Runoff estimation for un-gauged catchments

Un-gauged catchments are catchments with no or little river flow data. In Lake Awassa basin as it was indicated in previous sections, most of the rivers inflow in to the Lake are not gauged and the runoff generated from un-gauged watershed was not accurately estimated. To estimate the runoff from this un-gauged area, the optimized parameters that have been obtained during calibration was transferred to un-gauged part by simulation mode used in SWAT model.

SWAT model has great advantage to estimate runoff for un-gauged catchments by assigning HRUs in the sub-catchments. Sub-catchments with the same HRUs have the same responses for runoff generation and in this research work, after modeled the gauged watersheds lumped parameters were transferred directly to un-gauged part and hence, runoff from un-gauged part has been estimated.

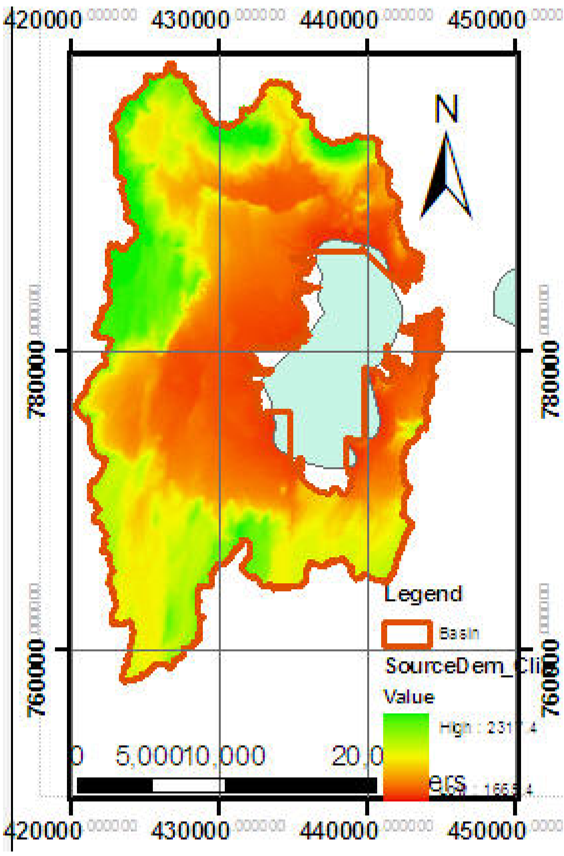

Figure 6-8: Un-gauged part of Lake Awassa watershed

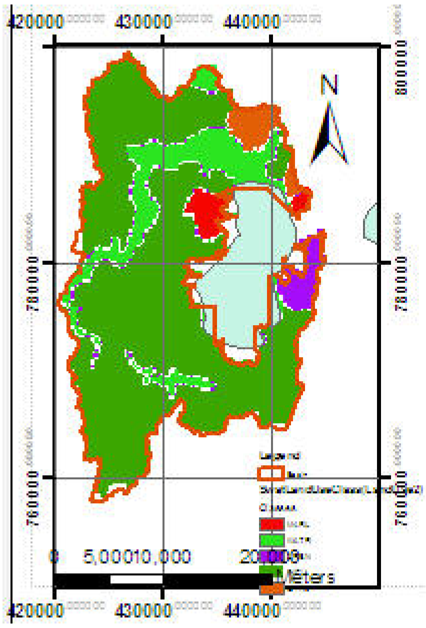

Figure 6-9: Land cover map of 1998

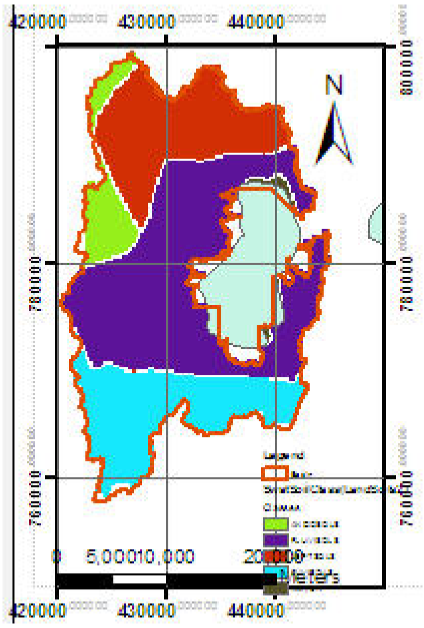

Figure 6-10: Soil Classified map of un-gauged part of Lake Awassa watershed

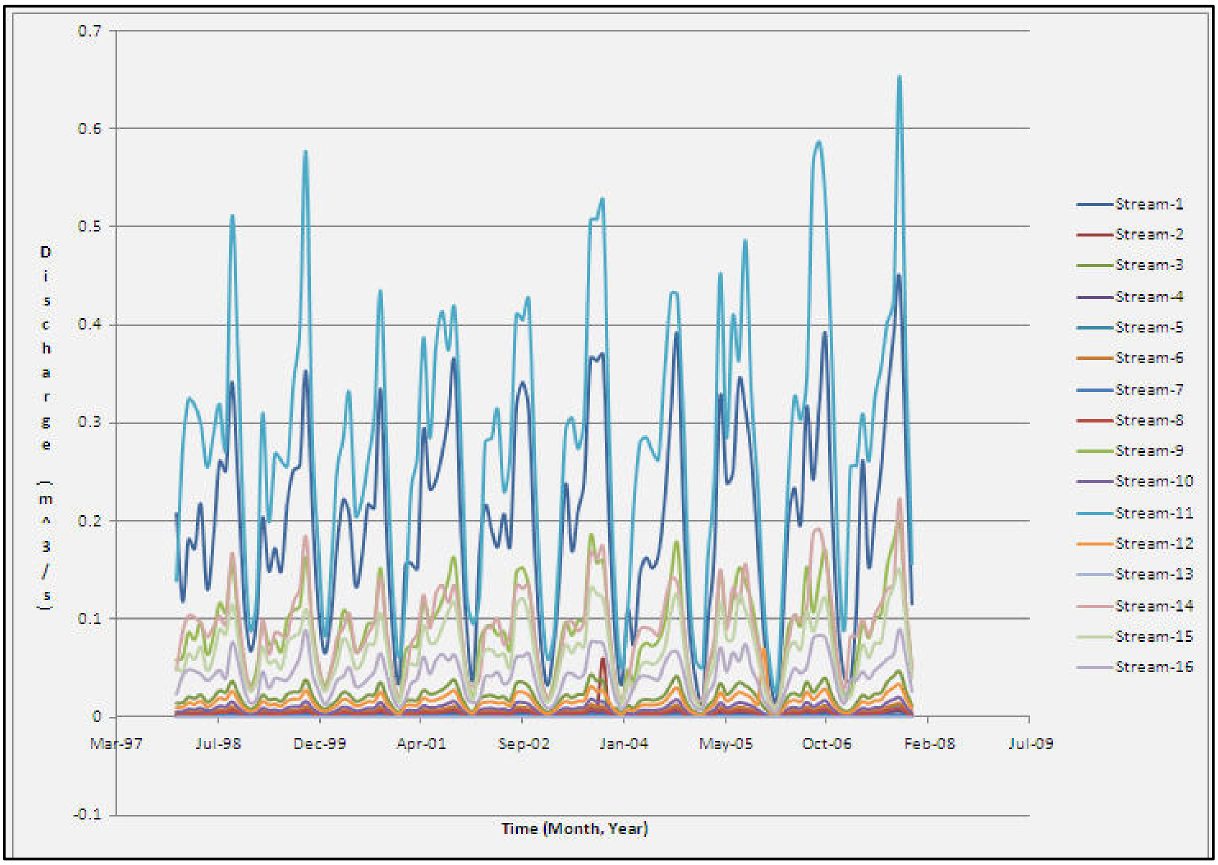

Figure 6-11: Hydrograph of un-gauged catchments

6.4 Runoff contribution from gauged and un-gauged catchments

From the model output it has been observed that over the calibration period (1998-2002) Tikurewuha catchment was contributed 54.9 MCM/year. From the total average rainfall, this was falling on gauged catchments about 11.83% of it converted into surface runoff and the rest percentage mainly converted into Evapotranspiration and Ground water.

Table 6-7: Surface runoff generated from un-gauged catchments

Catchment	Un-gauged area (sq.km)	Net Surface runoff (mm/year)	Net Surface runoff (MCM/year)
Stream-1	148	138.7	12.66
Stream-2	2.12	138.7	0.18
Stream-3	13.5	138.8	1.16
Stream-4	1.83	138.7	0.16
Stream-5	3.29	138.8	0.28
Stream-6	4.15	138.7	0.36
Stream-7	0.72	138.8	0.06
Stream-8	2.43	138.8	0.21
Stream-9	57.2	138.1	4.87
Stream-10	5.65	138.7	0.48
Stream-11	175	138.6	14.96
Stream-12	9.64	138.7	0.82
Stream-13	14	88.97	0.77
Stream-14	55.7	131.1	4.50
Stream-15	42.7	83	2.19
Stream-16	25.6	49	0.77
Total	**561.53**		**44.44**

From the total average rainfall falling on un-gauged catchments, about 13.1% i.e. 44.44 MCM/year of the rainfall was converted into surface runoff. Larger portion of the rainfall was converted into Evapotranspiration and the rest portion is to the ground water contribution. From the overall semi distributed modeling approach it can be conclude that the dominant hydrological variable in Lake Awassa basin was the Evapotranspiration in which the greater portion of rainfall loss through it.

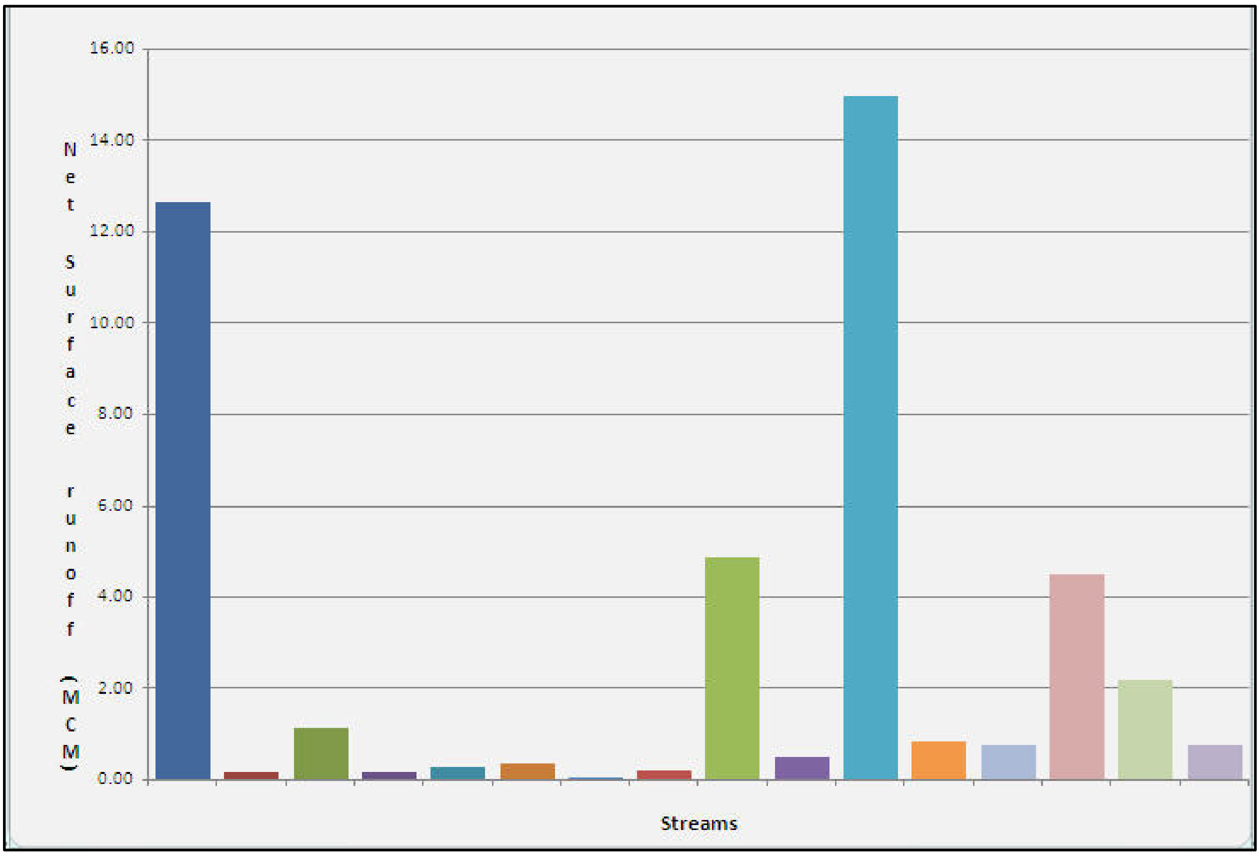

Figure 6-12: Net surface runoff generated from un-gauged catchments

6.5 The Evaporation and Rainfall over the Lake

Monthly evaporation and monthly rainfall over the Lake have been estimated using Aerodynamic method and gage Awassa's station respectively. The annual average rainfall over the lake found to be 998.5mm/year and from Aerodynamic method the average annual evaporation from the lake found to be 1787.93mm/year. The detail of monthly areal rainfall and evaporation values are found in water balance result appendix-I

$$E_a = B(e_{as} - e_a) \ (mm/day)$$

E_a is Evaporation from open water surface area

Where; $B = \frac{0.102u_2}{\left[ln\left(\frac{z_2}{z_0}\right)\right]^2}$ (mm/day.Pa)

u_2 is velocity (m/s) measured at height z_2 (cm) and z_0 is 0.001

$$e_{as} = 611exp\left(\frac{17.27T}{237.3 + T}\right) \ (Pa)$$

T=air temperature (^{0}C)

$$e_a = R_h e_{as}\ (Pa)$$

In which R_h is the relative humidity ($0<=R_h<=1$)

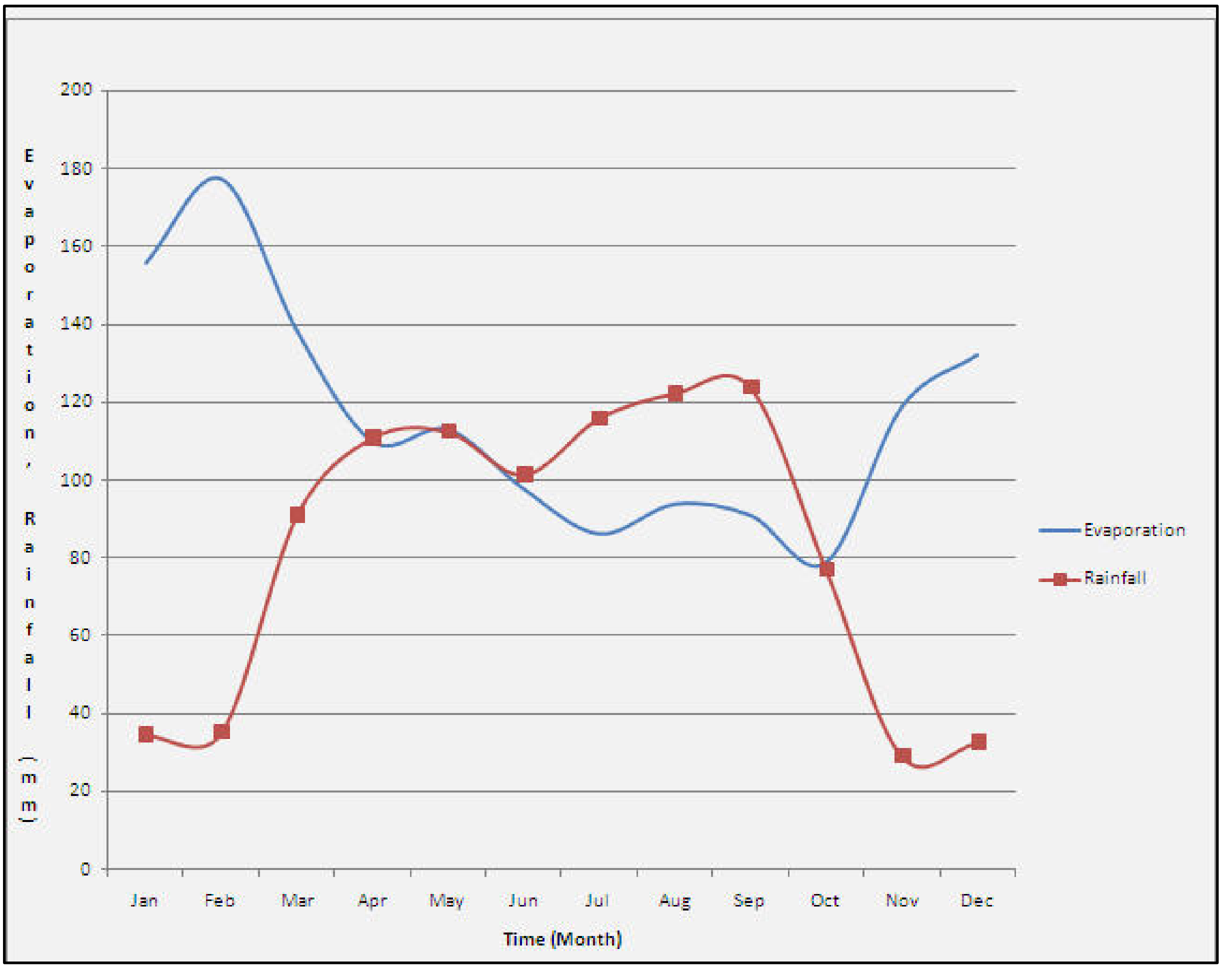

Figure 6-13: Average Monthly Rainfall and Evaporation over Lake Awassa

6.6 Water Balance Simulation

The basic equation used in the water balance:

Change in storage = Total inflow – total outflow - losses

$$S_t = S_{t-1} + I(t) + P(t) - O(t) - E(t) + G_{in} - G_{out}$$

Where: S_t = Lake storage volume at the end of current month

S_{t-1} = Lake storage volume at the end of previous month

I (t) = Simulated inflow volume from gauged and un-gauged catchments at current month

O (t) = Outflow volume at the lake outlet

P (t) = Areal rainfall volume on the lake surface

E (t) = Evaporation volume on the lake surface

G_{in} = Ground water inflow into the Lake at the end of current month

G_{out} = Ground water outflow from the Lake at the end of current month

The water balance terms were computed using EXCEL spread sheet model.

6.6.1 Lake level Volume/ Surface area relationship

Mathematical expressions relationship were obtained by which lake level Area/ Volume parameters were calculated in the lake water balance spread sheet model. (WWCSE, 2001)

The equations are:

A = 4E + 06 *h + 9E + 06 with regression coefficient R^2=0.99 and

V = 2E +06 *h^2 +1E + 07 *h – 5.95E +07 with regression coefficient R^2=0.99

Where, h=relative height of the lake level [m]

A=Lake area [m^2]

V= lake volume [m^3]

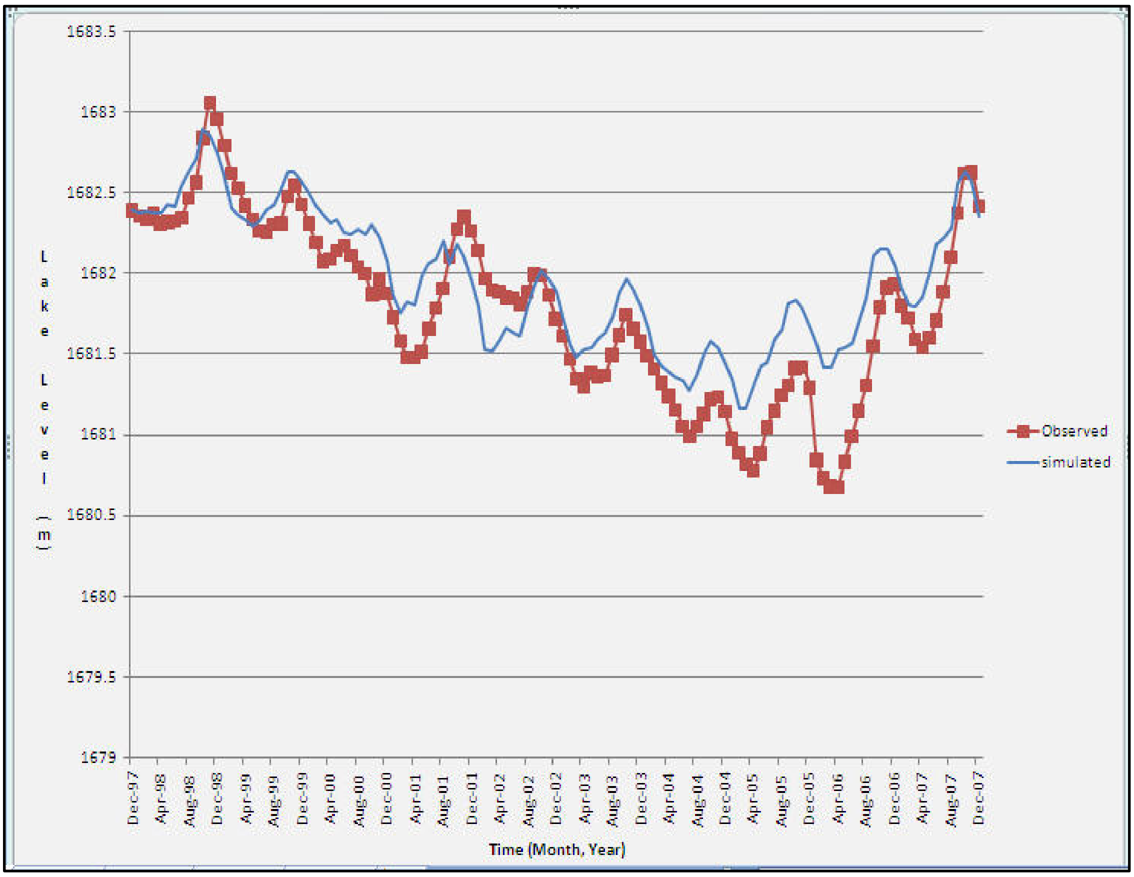

Figure 6-14: Observed and Simulated Lake Level for the period 1998-2007

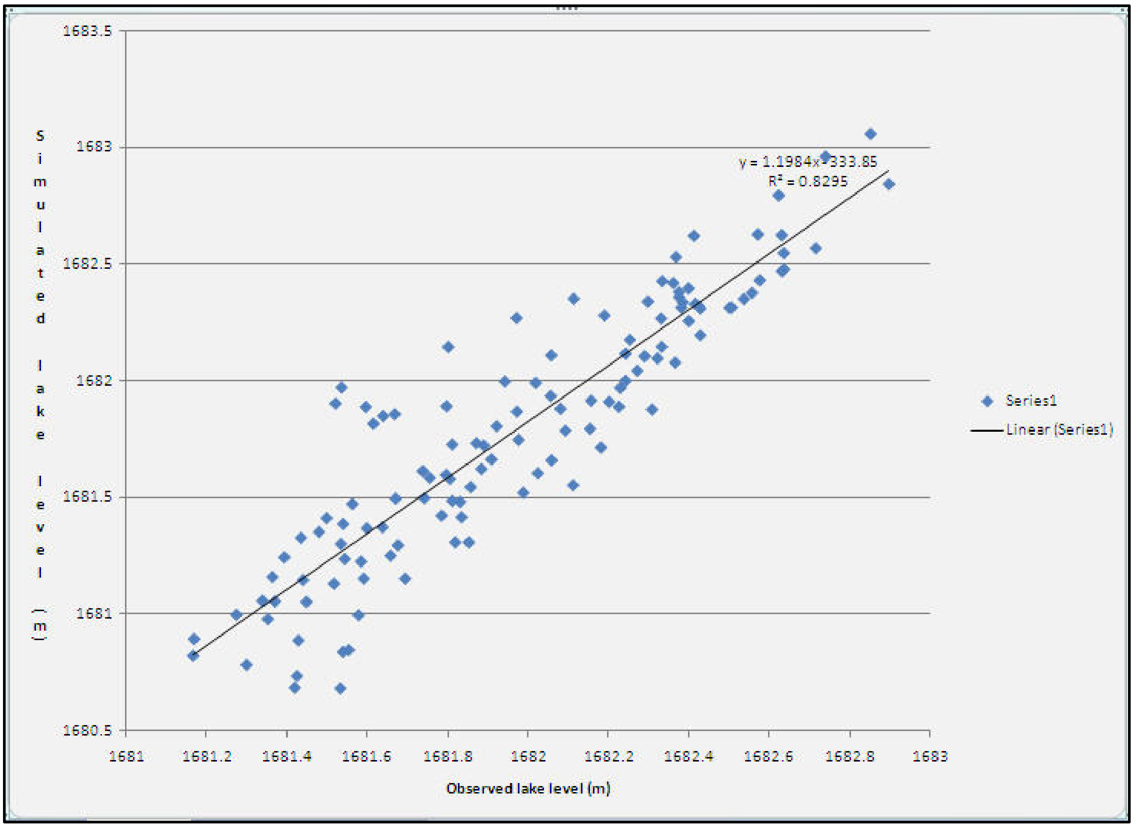

Figure 6-15: Scatter plot of Observed and Simulated Lake Awassa Water Level

Table 6-8: Lake Awassa Annual water balance components simulated from 1998-2007

Water balance components	mm/year	MCM/Year
Lake areal rainfall	+988.5	+98.9
Gauged River inflow	+549.1	+54.9
Un-gauged river inflow	+444.4	+44.44
Lake Evaporation	-1787.93	-178.93
Change in storage	+192.7	+19.27

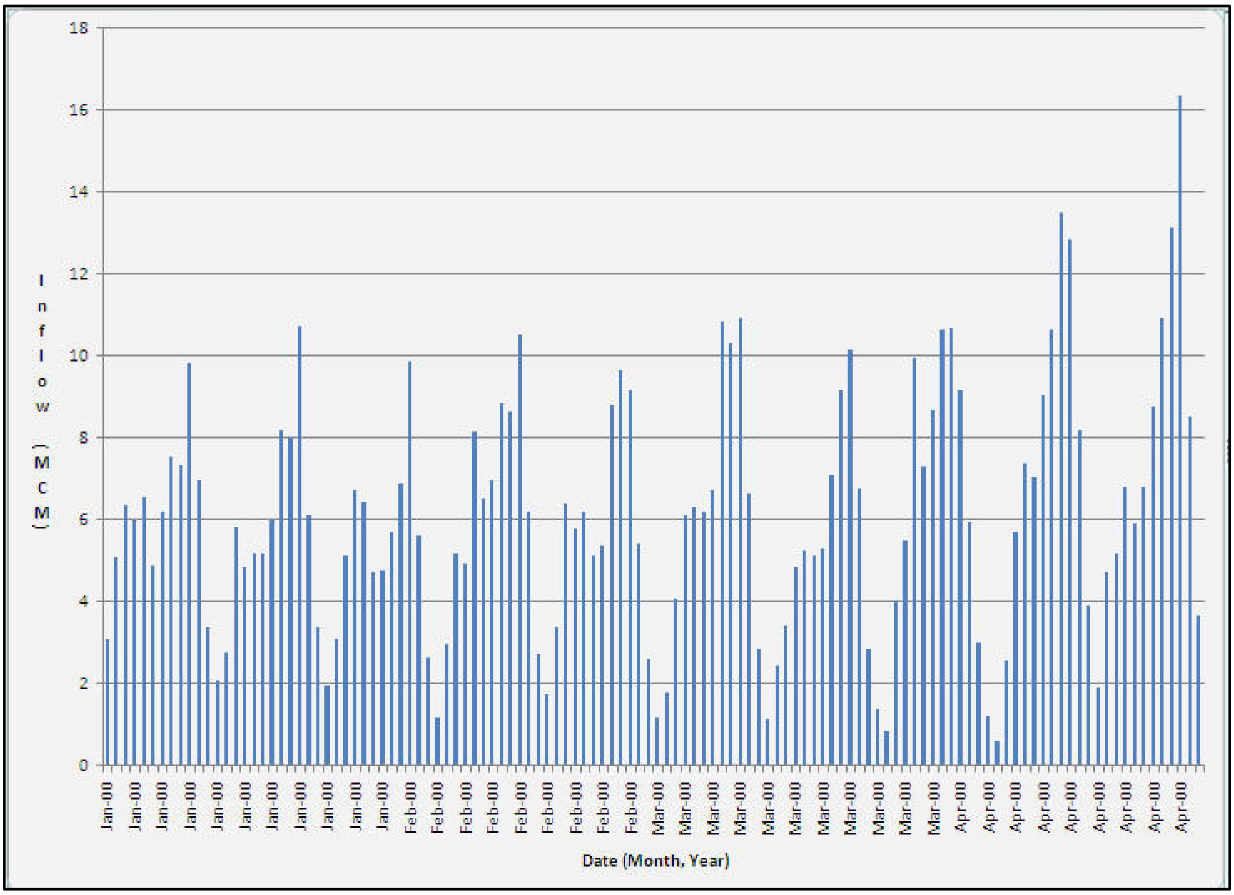

Figure 6-16: Inflow graph of Lake Awassa

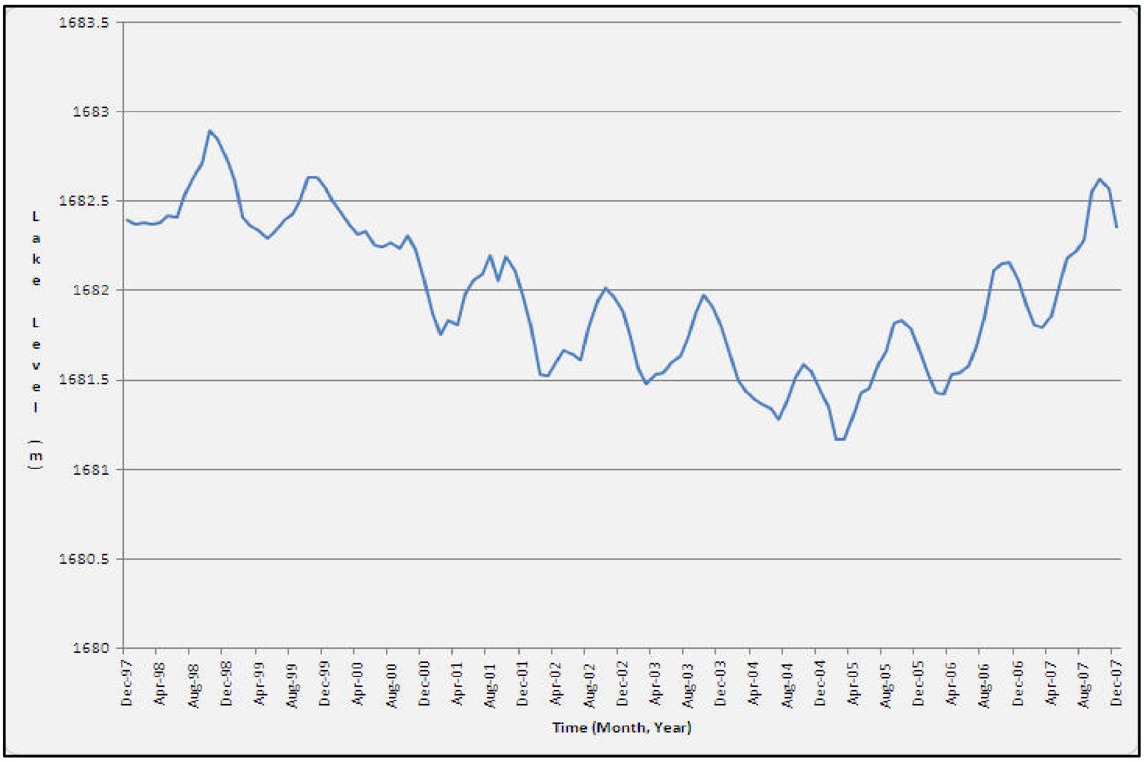

Figure 6-17: Simulated Lake Awassa level

CHAPTER SEVEN

7 Land use Change Simulation

7.1 Introduction

In order to have a basis for assessing future impacts of land use change is necessary to obtain a quantitative description of the expected changes. Land cover refers to the surface cover including geographical features like vegetation, urban, infrastructure, water, barren land, inland water bodies, etc. Land cover is a fundamental variable that impacts on and links many parts of the human and physical environments. (Barnsley 2001) refers to land cover as “the physical materials on the surface of a given parcel of land (e.g. grass, concrete, water).” Land cover change is highly affected by human-induced activities rather than natural events. Today, mainly agricultural expansion, burning activities or fuel wood consumption, deforestation, expansion of grazing land, some construction works and urbanization cause land cover changes. Consequently, such changes may have great impacts on the catchment by altering hydrological processes such as infiltration, groundwater recharge, and base flow and run-off and assessing such is at the core of this work.

7.2 Land use Change Scenario

Whilst the work undertaken on mapping land use change in phase 1 resulted in an understanding of historical and current land use change, it was apparent that many changes were not mappable due either to their nature (woodland degradation for instance is difficult to discern) or scale (the conversion of small areas of grazing land to cultivation is not mappable except at very large scales). The driving forces behind land use change or the dynamics of land use change have therefore been assessed by interviewing land users and woreda staff in representative areas of the sub-basin.

According to the Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project reports, during their field visit in early March 2008 the woredas of Shalla, Awassa Zuria, Malga and Wendo Genet were visited and the Natural Resource/ Land Use specialists and woreda heads were interviewed wherever possible. The information gathered in this way was corroborated wherever possible in the field by interviewing land users in specific locations of interest.

This has resulted in a clearer understanding the land use dynamics of the sub-basin that can be grouped under four main headings even though they are all interrelated to some degree:

- Population pressure
- Climate change
- Government policy
- External influences

7.2.1 Population Pressure

Population pressure was cited in all woredas visited as the primary land use issue. This has resulted in historical deforestation, soil erosion, land degradation and soil fertility decline. In addition it has resulted in places, in a decrease of household plot size resulting in increasing food insecurity. The loss of grazing land through conversion to cultivation was cited by most woredas as a recent land use change brought about by increasing population pressure.

Deforestation was recognized as a major land use issue by Awassa Zuria, Wondo Genet and Malga although it was accepted that much of the deforestation was historical and that soil erosion, land degradation and water shortages through decreasing spring flows had occurred as a result of deforestation.

Soil erosion, land degradation and soil fertility decline are seen as a result of population pressure with the intensification of cultivation on productive land and increasing cultivation of more marginal lands. This has also resulted in plot fragmentation to the extent that in parts of Awassa Zuria, Malga and Wendo Genet the average household holding is not able to support a family every year and food insecurity is increasing. This is resulting in a recent and ongoing conversion from cereal crops to enset in Awassa Zuria and a conversion to hoe rather than animal powered cultivation in the more hilly areas of Malga where there has also been a conversion from enset to chat.

All woredas report a relatively recent conversion of grazing lands to cultivation to the extent that most report that there is a severe shortage of grazing land and forage and that animals are now being increasingly fed on crop residues. In Malga free grazing is still practiced and is reported to be a major factor in soil erosion, land degradation and the siltation of Cheleleka. In Wendo Genet free grazing is banned on the hills and is managed on Cheleleka grasslands by the surrounding communities.

7.2.2 Climate Change

According to Halcrow reports, all woredas report that water shortage is a constraint and Wendo Genet and Awassa Zuria also indicated that rainfall is becoming more erratic. This, coupled with population pressure, has led to the conversion of cereal crops to enset in Awassa Zuria (although frost is also becoming more of a constraint) and they recognize that perhaps the relatively recent development of pastoral land to cultivation will not be sustainable in the long term, particularly with more erratic, less reliable rainfall.

7.2.3 Government Policy

Government policy is often reactive and influences land use change largely through reacting to other influences such as population pressure and climate change although it can be proactive in promoting specific land uses in certain areas.

Government policy influences the land use dynamics in the sub-basin in a number of ways. Insecurity of tenure has always been assumed to be a major factor in the high levels of erosion and land degradation since farmers were not prepared to invest in soil and water conservation measures. Evidence suggests that this is true in areas where redistribution has occurred and that farmers may favor short term investments in land management (fertilizer, tree planting) but hinder long term investments such as terracing. In other areas land fragmentation (the expected sharing of land among family members) and farmers' resource poverty had a greater impact.

7.3 Area at risk of land cover change in the future

From the study of Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, the most vulnerable areas in land cover change are deforestation and plantation expansion. According to their studies the future were mapped from selecting the predicted medium and high probability classes for each of these two changes. It is percentage forest area at risk of deforestation and plantation encroachment in future calculated by linear regression of percentage of land use in 1965 to 1998.

Table 7-1: Forecasting the change in land use at 2017

Land use type	land use of 1965 (ha)	land use of 1998 (ha)	land use of 2017 (ha)
Urban	490	1800	2554.242
Cultivated Land	40586	61247	73142.73
Natural vegetation	67198	55430	48654.48

7.3.1 Simulation Result

In the first attempt of implementing the land use change scenario, taking forest area decreases in 11,768 ha, cultivated land increases in 20,661 ha and urban area increases by 1,310 ha in period of 1965 to 1998. From this, fraction of the plant growing (FRGRW1) for the case of Cultivated land and Natural vegetation changes by a rate of its corresponding land cover change, and also for the case of urbanization the fraction total impervious area in urban land type (FIMP) multiply by its corresponding land cover change.

Table 7-2: Correction factor of the land cover data

Land use type	FRGRW1 OF 1998 (Default value)	FRGRW1 OF 2017
Cultivated Land	0.15	0.11
Natural vegetation	0.05	0.08

Land use type	FIMP 1998 (Default value)	FIMP2017
Urban	0.4	0.63

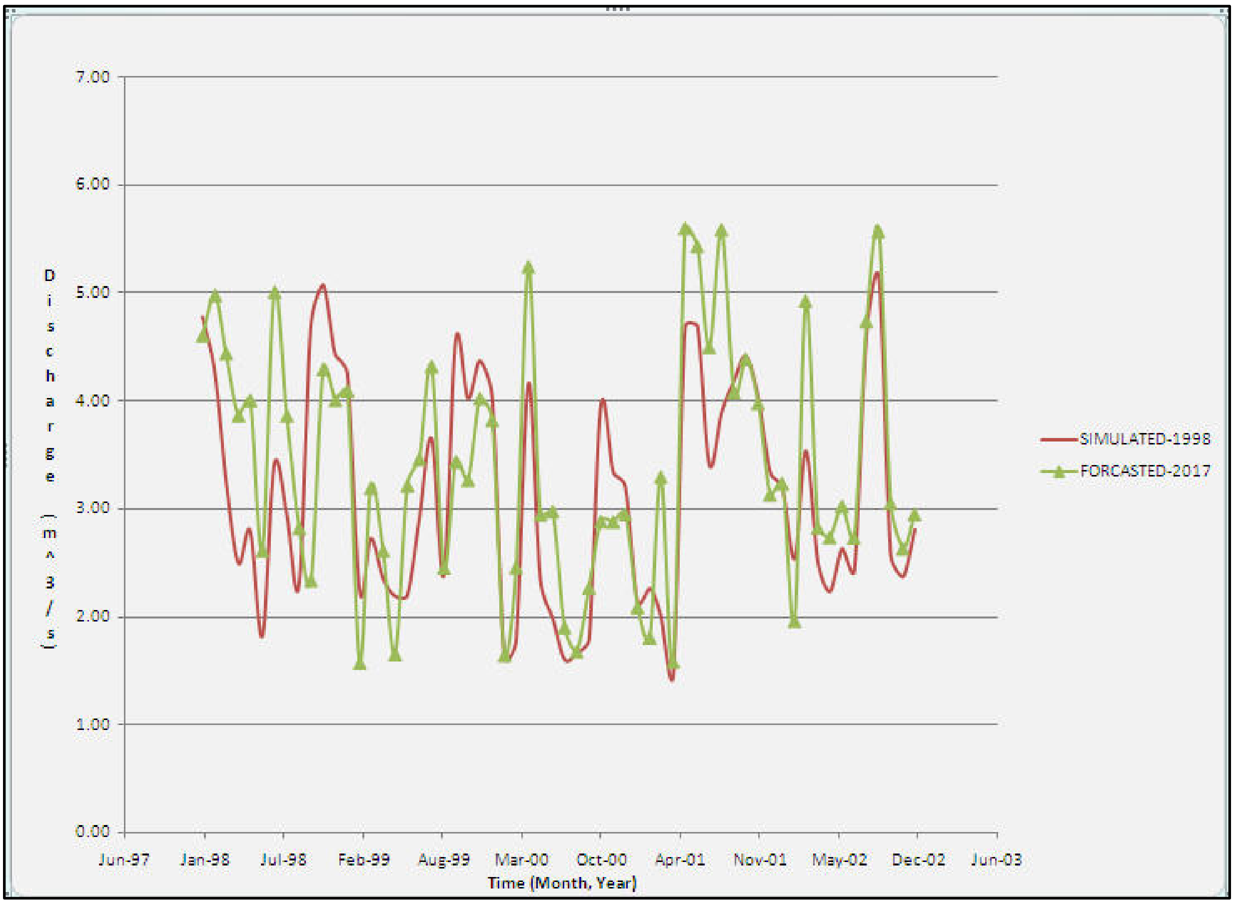

Figure 7-1: Simulated and Forecasted Discharge

In the graph, the value of discharge with land use change is slightly greater than that of land use change of 1998. The 1998 land cover has an average discharge 3.15 m^3/sec where as the simulated land cover 2017 has an average discharge 3.50 m^3/sec. This is the expected output, because with the expansion of urban and deforestation, the result is increasing surface runoff, which has effect of lake level rise.

CHAPTER EIGHT

8 Conclusion and Recommendation

8.1 Conclusion

In this study work due emphasis have been given for the estimation of runoff contribution from gauged and un-gauged catchments using semi distributed model known as SWAT. Based on SWAT watershed delineation the catchment area was found to be1, 412sq.km. Considering the whole watershed in the basin about 54.81 % of the total watershed is gauged and 45.19 % is un-gauged.

After modeling the gauged watershed, calibrated parameters were transferred to un-gauged watershed by lumping the parameters having the same hydrologic response unit (HRUs). The model output indicates that, the annual inflow volume estimated to be 54.9 MCM (55.51%) contributed from gauged watershed and about 44.44 MCM (44.49 %) contributed from un-gauged watershed. Annual average potential evapotranspiration, actual evaporation of the catchment, precipitation also estimated to be 814.9, 519.8, 956.9 mm respectively.

Sediment yield carried into the lake and the water abstraction from the lake, were neglected in the calculation in this research.

The correlation between calibrated hydrological model and the measured lake water level was (R^2) = 0.8295. Parameters such as soil properties, Hydrological Response Units, sub-basin and water use properties calibrated manually. The parameterization and calibration required "trial and error" process, which consumed a lot of time.

The result of sensitivity analysis also shows that Alpha_Bf is the most sensitive parameter in the catchments.

This study has paramount importance as it is new and original contribution using SWAT semi distributed modeling approach, to mainly estimate runoff from gauged and un-gauged part of the catchments and to study the Lake Water balance.

A general assessment of the role of the future land use change and variability on the lake water level was provided by incorporating the past trend of deforestation, plantation and urbanization.

Generally, the data base created would enable for further research improvement or new research in monitoring Lake Water quality and sediment studies in the basin. SWAT model is applicable in Lake Awassa basin and the result can be used for planning and management of water resources in the basin.

8.2 Recommendation

- SWAT model calibrated using observed flow data at gauging station. In order to improve the model performance, the weather stations should be improved both in quality and quantity. Hence, it is highly recommended to establish a good network of both hydrometric and meteorological stations.
- The study aims to estimate the runoff contribution from gauged and un-gauged catchments based on a semi distributed modeling approach. However, in water balance components, the sub-surface condition for the Lake Awassa was not considered. Therefore, detail research work, which incorporates ground water, is recommended to understand the interaction of surface and sub-surface condition and Lake Water balance.
- Areal rainfall of the Lake used metrological station of Awassa for this study. In order to improve the result additional station should be established.
- The database created in this study has paramount importance to conduct further research on water quality modeling and sediment studies. Therefore, it is recommended to use the database for further research work in the basin.
- SWAT is appropriate to model the whole complexity of hydrological process of the study area, although it should be improved by defining those parameters, which were assumed in this research.
- Good quality of daily climate data will increase the capability to understand the hydrological process; also detailed measurement of daily precipitation, temperature, solar radiation will be useful to give better insight of the land use behavior. More Data Loggers, which can measure daily data, should be installed in the area. Data collection, which becomes very essential for the management of the water resources, has not been a major concern in the area.
- Water incremental of lake would have significant effect to the dwellers surround the lake, such as Awassa town. The annual net ground water outflow from Lake Awassa to adjacent basins is estimated as $58*10^8 m^3$ (Tenalem, 2007), which was not incorporated in the model, obviously will accelerate lake water depletion.

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(http://www.brc.tamus.edu/swat/soft_links.html)

APPENDIX

Appendix-A Location of Meteorological station in the study area.

S.No	Station Name	X-Coordinate	Y-Coordinate	Elevation
1	Awassa	444783.65	782990.76	1680.00
2	Shashemene	453994.82	792194.26	1890.00
3	Wendo Genet	463189.39	782974.26	1800.00
4	Yirba	417144.80	764602.01	1790.00

Appendix-B1 Weather generator (WGEN) parameters used by the SWAT Model

Legend of the parameters used in the weather generation		
S.No	Symbol	Description
A	TMPMX	Average or mean daily maximum air temperature for month (ºC).
B	TMPMN	Average or mean daily minimum air temperature for month (ºC).
C	TMPSTDMX	Standard deviation for daily maximum air temperature in month (ºC).
D	TMPSTDMN	Standard deviation for daily minimum air temperature in month (ºC).
E	PCPMM	Average or mean total monthly precipitation (mm H2O).
F	PCPSTD	Standard deviation for daily precipitation in month (mm H2O/day).
G	PCPSKW	Skew coefficient for daily precipitation in month
H	PR_W1	Probability of a wet day following a dry day in the month.
I	PR_W2	Probability of a wet day following a wet day in the month.
J	PCPD	Average number of days of precipitation in month.
K	SOLARAV	Average daily solar radiation for month (MJ/m2/day).
L	DEWPT	Average daily dew point temperature in month (ºC).
M	WNDAV	Average daily wind speed in month (m/s).

TMPMX (mon): Average or mean daily maximum air temperature for month (ºC).

Calculated based on following formula:

$$\mu mx_{mon} = \frac{\sum_{d=1}^{N} T_{mx,mon}}{N}$$

Where μmax_{mon} is the mean daily maximum temperature for the month (ºC),

$T_{mx,mon}$ is the daily maximum temperature on record d in month mon (^{0}C), and N is the total number of daily maximum temperature records for month mon.

TMPMN (mon): Average or mean daily minimum air temperature for month (ºC).

Calculated based on following formula:

$$\mu mn_{mon} = \frac{\sum_{d=1}^{N} T_{mn,mon}}{N}$$

Whereμmn_{mon} is the mean daily minimum temperature for the month (^{0}C), $T_{mn,mon}$ is the daily minimum temperature on record d in month mon (ºC), and N is the total number of daily minimum temperature records for month mon.

TMPSTDMX(mon): Standard deviation for daily maximum air temperature in month (ºC)

Calculated based on following formula:

$$\sigma mx_{mon} = \sqrt{\frac{\sum_{d=1}^{N} \left(T_{mx,mon} - \mu mx_{mon}\right)^2}{N-1}}$$

Where σmx_{mon} is the standard deviation for daily maximum temperature in month mon (ºC), $T_{mx,mon}$ is the daily maximum temperature on record d in month mon (ºC), $\mu_{mx,mon}$ is the average daily maximum temperature for the month (^{0}C), and N is the total number of daily maximum temperature records for month mon.

TMPSTDMN(mon): Standard deviation for daily minimum air temperature in month (ºC). Calculated based on following formula:

$$\sigma mn_{mon} = \sqrt{\frac{\sum_{d=1}^{N}\left(T_{mn,mon} - \mu mn_{mon}\right)^2}{N-1}}$$

Where σmn_{mon} is the standard deviation for daily minimum temperature in month mon (ºC), $T_{mn,mon}$ is the daily minimum temperature on record d in month mon (ºC), $\mu_{mn,mon}$ is the average daily minimum temperature for the month (^{0}C), and N is the total number of daily maximum temperature records for month mon.

PCPMM (mon): Average or mean total monthly precipitation (mm H2O). Calculated based on following formula:

$$R_{mon} = \frac{\sum_{d=1}^{N} R_{day,mon}}{yrs}$$

Where R_{mon} is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitations for record d in month mon (mm H2O), N is the total number of records in month mon used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSTD (mon): Standard deviation for daily precipitation in month (mm H2O/day).

Calculated based on following formula:

$$\sigma_{mon} = \sqrt{\frac{\sum_{d=1}^{N}\left(R_{day,mon} - R_{mon}\right)^2}{N-1}}$$

Where σ_{mon} is the standard deviation for daily precipitation in month mon (mm H2O), R_{mon} is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitation for record d in month mon (mm H2O), N is the total number of records in month mon used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSKW (mon): Skew coefficient for daily precipitation in month. Calculated based on following formula:

$$g_{mon} = \frac{N\sum_{d=1}^{N}\left(R_{day,mon} - R_{mon}\right)^3}{(N-1)(N-2)(\sigma_{mon})^3}$$

Where g_{mon} is the skew coefficient for precipitation in the month, N is the total number of daily precipitation records for month mon, $R_{day,mon}$ the amount of precipitation for record d in month mon (mm H2O), R_{mon} is the average precipitation for the month (mm H2O), and σ_{mon} is the standard deviation for daily precipitation in month mon (mm H2O).

PR_W (1, mon): Probability of a wet day following a dry day in the month.

Calculated based on following formula:

$$P_1\left({}^{W}/_{D}\right) = \frac{days_{W/D,i}}{days_{dry,i}}$$

Where Pi (W/D) is the probability of a wet day following a dry day in month i, $days_{W/D,i}$ is the number of times a wet day followed a dry day in month i for the entire period of record, and $days_{dry,I}$ is the number of dry days in month i during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PR_W (2, mon): Probability of a wet day following a wet day in the month.

Calculated based on following formula:

$$P_1\left({}^{W}/_{W}\right) = \frac{days_{W/W,i}}{days_{Wet,i}}$$

Where Pi (W/W) is the probability of a wet day following a wet day in month i, $days_{W/W,i}$ i is the number of times a wet day followed a wet day in month i for the entire period of record, and $days_{wet,i}$ is the number of wet days in month i during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PCPD (mon): Average number of days of precipitation in month.

Calculated based on following formula:

$$d_{wet,i} = \frac{days_{wet,i}}{yrs}$$

Where $d_{wet,i}$, is the average number of days of precipitation in month i, $days_{wet,i}$ is the number of wet days in month i during the entire period of record, and yrs is the number of years of record.

SOLARAV (mon): Average daily solar radiation for month (MJ/m2/day).

Calculated based on following formula:

$$\mu rad_{mon} = \frac{\sum_{d=1}^{N} H_{day,mon}}{N}$$

Where μrad_{mon} is the mean daily solar radiation for the month (MJ/m^2 /day), $H_{day,mon}$ is the total solar radiation reaching the earth's surface for day d in month mon (MJ/m^2 /day), and N is the total number of daily solar radiation records for month mon.

DEWPT (mon): Average daily dew point temperature in month (ºC).

Calculated based on following formula:

$$\mu dew_{mon} = \frac{\sum_{d=1}^{N} T_{dry,mon}}{N}$$

Where μdew_{mon} is the mean daily dew point temperature for the month (ºC), $T_{dew,mon}$ is the dew point temperature for day d in month mon (ºC), and N is the total number of daily dew point records for month mon.

WNDAV (mon): Average daily wind speed in month (m/s).

Calculated based on following formula:

$$\mu wnd_{mon} = \frac{\sum_{d=1}^{N} \mu_{dry,mon}}{N}$$

Where μwnd_{mon} is the mean daily wind speed for the month (m/s), $\mu_{wnd,mon}$ is the average wind speed for day d in month mon (m/s), and N is the total number of daily wind speed records for month mon.

Appendix B2- Weather Generator Statistics and Probability Value

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PR_W1	0.14	0.12	0.31	0.37	0.45	0.54	0.58	0.61	0.72	0.30	0.07	0.08
PR_W2	0.38	0.44	0.75	0.70	0.69	0.48	0.68	0.65	0.75	0.73	0.52	0.48
TPMAX	28.5	30.4	29.6	28.5	27.30	25.70	24.60	24.90	25.6	26.7	28.1	28.1
TPMIN	11.8	11.8	13.2	14.1	14.30	14.40	14.60	14.50	13.9	13.1	10.3	10.2
PCPMM	34.5	35.2	90.9	110.8	112.4	101.4	115.9	122.2	123.8	77.1	29.4	32.3
WINDAV	0.76	0.79	0.72	0.72	0.82	1.04	1.04	0.88	0.94	0.58	0.65	0.77
SOLARAV	8.74	9.39	7.74	6.57	7.52	6.09	5.09	5.56	5.93	6.69	8.84	9.17
RAINHHMX	11.4	6.30	7.40	6.60	4.80	10.40	10.40	15.50	12.7	8.90	7.40	7.40
TMPSTDMX	1.50	1.64	2.10	2.18	1.69	1.36	1.69	1.56	1.41	1.97	1.43	1.37
TMPSTDMN	2.95	2.67	2.32	1.94	1.64	1.59	1.59	1.51	1.50	2.49	2.52	2.90
PCPSTD	4.9	4.78	5.82	8.08	6.84	7.93	7.29	9.34	7.35	5.60	5.33	6.90
PCPSKW	7.7	5.95	3.22	3.74	2.89	4.54	2.98	6.51	4.22	4.22	9.67	10.1
PCPD	5.6	5.00	14.7	16.4	18.10	15.50	20.00	19.60	22.4	15.8	4.20	4.20

APPENDIX-C1 Monthly Precipitation Data

Metrological Station - AWASSA
1998-2007

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	92	140	90.8	86.4	88.4	56	172.9	108.3	109.6	193.3	10.6	0
1999	19.8	0.4	105.5	27.1	64.7	99.8	135.1	83.8	115.4	120.4	20.1	16.8
2000	1.1	0	11	132	145.1	36.4	80	179.3	87.6	110.7	29	9.3
2001	1.8	39.9	122.7	67.2	233.7	137.5	93.4	131.7	89.7	80.2	2.6	21.3
2002	52.5	2.4	128.7	119.6	85.2	91.9	76.6	190.4	83.2	37.3	0	51.5
2003	30.4	2	78.2	179.1	40.4	110.5	74.5	76.1	85.5	53.4	6.2	152.6
2004	46.2	94.2	42	83.1	81.5	75.7	75.4	117.1	116	57.1	94.2	15.2
2005	81.1	7.7	120.9	156	144.5	73.2	150.9	61.3	122.2	28.4	46	10.4
2006	1.7	9	139.2	145.9	74.4	108	171.1	169.3	194.9	56.9	79.2	48.3
2007	18	56	70.4	112	166.1	225.4	129.1	105.1	233.8	33.1	3.7	0

Metrological Station – SIYIRBA
1998-2007

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	81	57.9	4.2	139.6	113.1	188.7	167.4	110.7	93.9	239.5	11.5	0
1999	0.7	0	176.2	91.5	110.3	186.6	41.4	72.3	41.9	220.8	8.9	27.6
2000	5.7	-	14.2	139.1	143.1	150.3	81.1	128.8	69.2	55.3	13.8	15.3
2001	59.8	0.7	67.8	158.6	272.6	119.7	114.3	98.1	46	99.3	9.6	0
2002	20.2	28.4	123.7	117.5	148.1	98	93.6	107.2	94	201.5	24	71.8
2003	24	7.7	49.5	111.1	93.9	94.4	120.9	184.5	97.7	9.6	17.5	67.4
2004	34.3	36.9	93.5	126.7	93	77.9	142	135.3	137.9	24.4	44.1	26.5
2005	34.5	24.1	-	-	-	28.2	144.5	125.8	108.1	75	17.5	-
2006	3.2	50.5	23.6	82.3	75.4	141.1	106	152.7	43.3	150.8	71.7	49.9
2007	7.5	0	0	155.9	302.7	168.6	187.9	132.8	100.2	59.3	-	-

Metrological Station – SHASHEMENE
1998-2007

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	48.6	96.1	-	76.6	126	73.5	162.4	149.9	156.1	186	12.9	0
1999	14.5	0	50.3	37.5	122.3	119.1	119.2	10.1	162.7	166.2	4.3	6.5
2000	0	0	3.3	257	244.7	45.6	92.3	52.3	105.4	150.8	21	13.9
2001	0	6.8	151.1	37.6	89.9	92.9	-	-	-	-	-	-
2002	-	8	14	41.1	-	33.5	18.5	60.5	67.9	9.5	0	39.8
2003	7.3	22.3	68.3	90.1	19	61.9	70.8	88.8	117.7	8.3	10.3	34.9
2004	35	29.5	25.9	116.2	70.1	80.4	93.6	97.7	49.6	48.3	5.3	8.5
2005		3.2	71	129.3	71	7.3	72.7	46.3	66.4	39.6	39.8	23
2006	0	19.2	71.3	92.6	91.6	32.2	78.6	45.3	121.9	40	11.5	10.4
2007	3	11.4	64.8	91.6	96.6	65.8	44.3	63.7	117.9	28.3	1.2	0

Metrological Station – WENDOGENET
1998-2007

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	0	21.7	104	212.2	97.1	68.1	134.7	187.6	134.1	19.2	1	45.3
1999	38.9	27.4	102.8	179.2	105.4	155.9	183.1	246.4	153.3	41.3	19.2	8.2
2000	39.5	6.5	54.1	252.6	76.2	192	-	-	-	153.5	141.4	4.7
2001	91.3	157	175.1	75.5	155.1	108.1	131.9	99.8	120.9	181.1	9.1	0
2002	7.7	0	127.6	53.3	97.4	62.8	112.1	111.9	130.7	183.9	5.7	23.4
2003	0	0	6.9	114.6	104.6	29.7	83	83.4	204.2	226.8	63.7	26.6
2004	0	58.5	183.2	87.3	235.3	139.5	100.2	169.2	198.7	106.3	1.3	11.3
2005	84.7	15.8	205.3	103.6	146.4	93.4	65.1	93.6	83.6	31.7	0	75.7
2006	26.9	52.2	98.1	165.7	31.6	102	133.9	141	140.1	85.2	11.4	57.2
2007	65.7	16.4	45.4	92.7	127.2	0	0	0	0	0	0	0

APPENDIX C2 Mean Monthly Maximum Temperature Data

Metrological Station - AWASSA
1998-2007

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	27.7	28.9	29.0	29.7	27.3	26.3	24.3	24.0	25.4	25.3	27.5	28.1
1999	29.1	31.5	28.1	29.1	27.2	26.1	23.6	25.0	25.6	25.0	27.2	28.0
2000	29.5	31.8	31.8	28.8	26.1	25.7	24.7	24.8	25.1	25.6	27.2	28.3
2001	28.6	30.2	28.3	28.4	26.9	20.7	24.4	24.5	25.9	26.7	28.2	28.9
2002	27.3	30.9	28.8	28.6	27.5	25.7	26.3	25.4	26.1	28.3	29.8	28.4
2003	28.4	31.3	30.6	28.1	28.3	25.6	24.2	24.9	26.1	28.2	29.2	27.3
2004	28.9	29.8	30.2	27.3	28.6	25.9	25.3	25.5	25.5	26.7	28.6	28.6
2005	28.9	31.5	29.9	29.4	25.8	25.6	24.6	25.7	25.9	27.3	28.0	28.5
2006	30.1	31.3	29.3	26.4	27.7	26.2	24.5	24.7	25.2	26.6	27.6	27.5
2007	28.5	29.2	30.4	28.2	27.7	25.2	24.6	23.5	25.1	26.7	27.8	27.7

APPENDIX C3 Mean Monthly Minimum Temperature Data

Metrological Station - AWASSA
1998-2007

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	13.3	14.3	13.9	14.8	15.7	14.7	15.7	15.9	14.5	14.4	8.90	7.84
1999	10.2	9.93	13.8	12.5	13.6	14.0	14.3	13.7	13.8	14.0	9.30	9.35
2000	9.6	11.0	11.2	14.1	14.0	13.7	14.3	14.0	13.4	14.0	10.5	9.71
2001	11.6	11.3	14.0	14.4	14.2	14.6	14.7	14.9	13.1	13.8	10.3	10.9
2002	12.3	11.8	13.9	13.5	14.8	14.5	14.4	14.2	13.4	12.9	9.79	13.2
2003	11.8	11.6	12.3	14.3	14.2	14.3	14.6	14.5	13.9	11.9	11.2	10.4
2004	12.5	12.0	12.2	14.7	13.2	13.9	14.1	14.3	13.6	11.5	11.6	11.4
2005	11.3	11.4	13.8	13.9	15.0	14.6	14.2	14.6	14.4	13.1	9.52	7.81
2006	11.8	12.4	13.8	14.6	12.9	14.3	14.9	14.6	14.5	14.2	11.4	12.4
2007	12.7	12.9	12.2	14.2	14.8	14.9	14.8	14.6	14.3	11.1	10.7	8.98

APPENDIX C4 Mean Monthly Evaporation Data

Metrological Station - AWASSA
1998-2007

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	3.99	5.80	3.97	3.03	2.65	2.65	2.96	2.80	2.45	3.90	5.59	6.75
1999	6.15	7.78	6.57	3.25	4.22	3.34	3.18	3.32	3.37	3.44	3.00	4.78
2000	4.00	3.97	4.23	4.79	3.60	3.88	3.24	3.06	2.67	2.51	4.87	6.91
2001	7.03	8.39	4.73	4.86	4.28	4.31	3.22	3.60	3.04	2.94	5.55	6.45
2002	8.30	9.62	9.77	5.18	3.49	4.35	3.49	3.47	2.79	2.89	4.51	6.04
2003	6.71	6.32	4.66	3.94	3.36	3.12	2.97	3.01	2.58	3.31	5.63	6.51
2004	5.81	7.21	4.23	4.45	3.78	3.43	4.29	2.95	2.85	4.14	7.03	4.92
2005	5.78	6.86	6.27	4.16	4.01	3.23	2.58	2.91	2.50	4.36	6.25	5.73
2006	5.42	5.76	6.95	3.29	4.78	3.93	3.33	3.24	2.46	4.67	5.55	5.57
2007	6.11	6.98	5.00	5.28	2.58	3.33	3.13	3.93	3.05	3.76	5.38	7.20

APPENDIX C5 Mean Monthly Sunshine hour Data

Metrological Station - AWASSA
1998-2007

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	8.3	8.9	7.1	2.7	7.1	4.8	1.6	4.5	5.4	8	9.3	7.1
1999	-	10.4	8.3	6.4	6	6.8	5.5	6.6	7.1	7.1	6.8	8.6
2000	7.2	7.9	7.8	7.8	6.8	6.3	4.4	4.4	5.3	3.8	9.4	10
2001	9.4	9.7	6.7	6.9	7.5	7.1	4.6	5.9	6	5.1	8.6	9.9
2002	9.8	9.8	8.9	7	11.3	6.6	5.6	-	5.4	6.2	9.1	9.4
2003	8.8	9.1	6.5	6.9	7.5	5.8	5.5	5.2	5.8	6.8	9.1	9.7
2004	9	9.6	-	7.6	7.1	6.4	7.1	6.3	7.1	6.9	9.7	8.1
2005	9	9.5	8.3	6.8	7.8	4.3	7.3	4.8	6.2	8.5	-	9.3
2006	8.2	9.5	8.2	6	8.4	6.3	4.8	5.5	5.3	7.5	8.9	9.2
2007	9	9.5	7.9	7.6	5.7	6.5	4.5	6.8	5.7	7	8.7	10.4

Appendix D Detail of Transverse Mercator Projection (UTM) used in Lake Awassa Basin

Projected Coordinate System:	NAD_1983_UTM_Zone_37N
Projection:	Transverse_Mercator
False_Easting:	500000.00000000
False_Northing:	0.00000000
Central_Meridian:	39.00000000
Scale_Factor:	0.99960000
Latitude_of_origin:	0.00000000
Linear Unit:	Meter
Geographic Coordinate System:	GCS_North_American_1983
Datum:	D_North_American_1983

Appendix E Average simulated inflow (m3/sec) of Lake Awassa (Tikure Wuha River at Datto village) contributed from Gauged catchments, period 1998 – 2006.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1998	3.35	2.98	2.30	1.75	1.96	1.28	2.39	2.07	1.62	3.30	3.55	3.10	2.47
1999	2.98	1.57	1.91	1.65	1.54	1.55	2.04	2.56	1.67	3.20	2.82	3.07	2.21
2000	2.83	1.14	1.25	2.92	1.65	1.40	1.13	1.17	1.26	2.78	2.34	2.25	1.84
2001	1.50	1.59	1.41	1.04	3.28	3.29	2.39	2.72	2.93	3.09	2.82	2.35	2.37
2002	2.24	1.78	2.48	1.75	1.57	1.85	1.70	3.24	3.60	1.81	1.66	1.97	2.14
2004	2.16	0.78	1.16	0.94	1.13	1.91	1.90	1.84	2.63	3.17	3.71	1.95	1.94
2005	1.21	0.57	0.60	1.53	3.35	3.92	2.75	3.35	2.82	1.10	2.08	1.57	2.07
2006	0.97	1.55	1.11	1.79	2.72	2.04	2.53	2.45	3.79	3.08	4.13	2.80	2.41
Average	2.15	1.50	1.53	1.67	2.15	2.15	2.10	2.42	2.54	2.69	2.89	2.38	2.18

Appendix-F Average simulated inflow (m3/sec) of Lake Awassa contributed from un- Gauged catchments, period 1998 – 2007.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1998	0.77	0.92	1.18	1.13	1.22	0.91	1.09	1.39	1.27	2.01	1.39	0.69	1.16
1999	0.39	0.56	1.21	0.85	1.03	0.95	1.15	1.40	1.54	2.16	1.18	0.68	1.09
2000	0.37	0.61	0.97	1.23	1.26	0.82	0.91	1.14	1.23	1.83	1.10	0.52	1.00
2001	0.23	0.68	0.92	0.98	1.58	1.22	1.44	1.60	1.64	1.86	1.17	0.51	1.15
2002	0.32	0.73	1.16	1.14	1.14	1.03	1.00	1.75	1.80	1.73	1.01	0.47	1.10
2003	0.23	0.39	0.76	1.24	1.12	1.17	1.27	2.13	2.04	2.17	1.14	0.50	1.18
2004	0.20	0.53	0.65	0.99	1.04	0.99	1.01	1.35	1.78	1.98	1.22	0.51	1.02
2005	0.23	0.17	0.62	0.96	1.87	1.23	1.55	1.72	1.87	1.41	0.98	0.57	1.10
2006	0.21	0.11	0.49	1.06	1.32	1.19	1.63	1.83	2.09	2.13	1.35	0.64	1.17
2007	0.32	0.65	0.85	1.29	1.00	1.27	1.41	1.77	1.98	2.59	1.48	0.64	1.27
Average	0.33	0.52	0.88	1.06	1.28	1.05	1.23	1.59	1.69	1.92	1.17	0.56	1.12

Appendix-G Monthly Average simulated inflow (m3/sec) of Lake Awassa from 2017-2021

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2017	4.61	4.98	4.44	3.87	4.01	2.62	5.01	3.87	2.82	2.34	4.30	4.01	3.91
2018	4.10	1.58	3.20	2.62	1.66	3.22	3.47	4.32	2.46	3.44	3.27	4.03	3.11
2019	3.83	1.65	2.46	5.25	2.95	2.98	1.91	1.68	2.27	2.89	2.88	2.95	2.81
2020	2.093	1.811	3.3	1.589	5.60	5.44	4.50	5.59	4.08	4.39	3.98	3.13	3.79
2021	3.24	1.97	4.93	2.83	2.74	3.03	2.74	4.74	5.57	3.06	2.64	2.95	3.37
Average	3.57	2.40	3.67	3.23	3.39	3.46	3.52	4.04	3.44	3.22	3.41	3.42	3.55

Appendix-H Detail of Monthly Water balance simulation from a period of 1998-2007

Month	Area (km2)	Total Inflow (MCM)	Rainfall (mm)	Evaporation (mm)	Losses (MCM)	Simulated volume (MCM)	Simulated Water level (m)	Observed water level (m)	volume (MCM)
Dec-97	101.48						1682.4	1682.4	125
Jan-98	101.45	2.69	92	142.08	-5.08	-2.39	1682.3765	1682.363	122.61
Feb-98	100.91	4.61	140	176.01	-3.63	0.98	1682.3861	1682.341	123.59
Mar-98	101.29	5.72	90.8	156.92	-6.70	-0.98	1682.3764	1682.384	122.61
Apr-98	100.91	5.39	86.4	133.92	-4.80	0.60	1682.3824	1682.318	123.21
May-98	101.14	5.94	88.4	104.34	-1.61	4.32	1682.4251	1682.325	127.53
Jun-98	102.82	4.39	56	107.62	-5.31	-0.91	1682.4163	1682.334	126.62
Jul-98	102.47	5.63	172.9	106.60	6.79	12.43	1682.5376	1682.355	139.05
Aug-98	107.17	6.81	108.3	77.03	3.35	10.17	1682.6325	1682.474	149.22
Sep-98	110.86	6.68	109.6	85.26	2.70	9.38	1682.7171	1682.572	158.60
Oct-98	114.02	8.76	193.3	88.71	11.93	20.69	1682.8985	1682.847	179.28
Nov-98	121.14	6.25	10.6	107.62	-11.75	-5.50	1682.8531	1683.063	173.78
Dec-98	119.33	3.02	0	137.19	-16.37	-13.35	1682.7412	1682.965	160.43
Jan-99	114.80	1.88	19.8	153.05	-15.30	-13.41	1682.6244	1682.799	147.02
Feb-99	110.07	2.45	0.4	233.48	-25.66	-23.20	1682.4137	1682.626	123.82
Mar-99	101.38	5.17	105.5	201.50	-9.73	-4.55	1682.3687	1682.534	119.27
Apr-99	99.59	4.41	27.1	105.27	-7.78	-3.37	1682.3349	1682.431	115.90
May-99	98.24	4.63	64.7	147.78	-8.16	-3.53	1682.2989	1682.344	112.37
Jun-99	96.80	4.67	99.8	114.81	-1.45	3.22	1682.3322	1682.271	115.58
Jul-99	98.11	5.37	135.1	121.45	1.34	6.72	1682.4007	1682.26	122.30
Aug-99	100.78	7.44	83.8	129.06	-4.56	2.88	1682.4292	1682.314	125.18
Sep-99	101.91	7.16	115.4	107.68	0.79	7.95	1682.5072	1682.318	133.13
Oct-99	104.95	9.59	120.4	81.53	4.08	13.67	1682.6375	1682.483	146.80
Nov-99	110.00	5.50	20.1	70.29	-5.52	-0.02	1682.6373	1682.551	146.78
Dec-99	109.99	3.01	16.8	104.13	-9.61	-6.59	1682.5774	1682.435	140.19
Jan-00	107.59	1.76	1.1	92.78	-9.86	-8.09	1682.5021	1682.32	132.10
Feb-00	104.57	2.76	0	99.27	-10.38	-7.62	1682.4293	1682.20	124.48
Mar-00	101.64	4.63	11	119.33	-11.01	-6.38	1682.3665	1682.08	118.10
Apr-00	99.12	6.07	35	140.14	-10.42	-4.35	1682.3226	1682.10	113.75
May-00	97.37	5.76	70	118.28	-4.70	1.06	1682.3335	1682.15	114.81
Jun-00	97.80	4.29	36.4	160.01	-12.09	-7.79	1682.2539	1682.18	107.02

Jul-00	94.59	2.29	80	114.59	-3.27	-0.98	1682.2435	1682.12	106.04
Aug-00	95.02	3.10	109.3	112.92	-0.34	2.76	1682.2726	1682.047	108.80
Sep-00	96.12	2.24	87.6	140.14	-5.05	-2.81	1682.2433	1682.004	105.99
Oct-00	94.16	6.91	110.7	118.28	-0.71	6.20	1682.3092	1681.881	112.20
Nov-00	96.73	5.03	29	160.01	-12.67	-7.64	1682.2303	1681.973	104.56
Dec-00	93.56	2.38	9.3	183.83	-16.33	-13.94	1682.0813	1681.884	90.62
Jan-01	87.46	1.07	1.8	223.32	-19.37	-18.30	1681.872	1681.737	72.32
Feb-01	78.76	2.62	39.9	189.35	-11.77	-9.15	1681.7559	1681.588	63.17
Mar-01	74.03	4.69	122.7	109.79	0.96	5.65	1681.8321	1681.485	68.82
Apr-01	76.98	4.43	67.2	144.70	-5.97	-1.53	1681.8122	1681.489	67.28
May-01	76.19	7.31	233.7	152.92	6.16	13.47	1681.9889	1681.524	80.75
Jun-01	82.88	5.89	137.5	138.19	-0.06	5.84	1682.0594	1681.663	86.58
Jul-01	85.62	6.19	93.4	131.65	-3.27	2.92	1682.0935	1681.79	89.51
Aug-01	86.96	7.98	131.7	114.91	1.46	9.45	1682.2021	1681.914	98.95
Sep-01	91.15	7.77	89.7	318.53	-20.86	-13.08	1682.0586	1682.113	85.87
Oct-01	85.29	9.54	80.2	60.16	1.71	11.26	1682.1906	1682.284	97.13
Nov-01	90.36	5.56	2.6	140.22	-12.44	-6.87	1682.1146	1682.356	90.26
Dec-01	87.30	2.45	21.3	191.81	-14.89	-12.43	1681.9722	1682.273	77.83
Jan-02	81.48	1.59	52.5	242.13	-15.45	-13.86	1681.8022	1682.149	63.97
Feb-02	74.46	2.99	2.4	308.13	-22.76	-19.76	1681.5367	1681.975	44.21
Mar-02	63.13	5.77	128.7	235.17	-6.72	-0.94	1681.5218	1681.907	43.27
Apr-02	62.54	5.18	119.6	127.00	-0.46	4.73	1681.5973	1681.892	47.99
May-02	65.45	5.58	85.2	98.63	-0.88	4.71	1681.6693	1681.861	52.70
Jun-02	68.22	4.57	91.9	188.05	-6.56	-1.99	1681.6401	1681.853	50.71
Jul-02	67.06	4.87	76.6	173.53	-6.50	-1.63	1681.6158	1681.82	49.08
Aug-02	66.10	7.88	190.4	127.60	4.15	12.04	1681.798	1681.895	61.12
Sep-02	72.93	8.70	83.2	57.40	1.88	10.59	1681.9432	1682.001	71.71
Oct-02	78.45	8.28	37.3	66.14	-2.26	6.02	1682.0199	1681.995	77.73
Nov-02	81.43	4.88	0	106.82	-8.70	-3.82	1681.973	1681.872	73.91
Dec-02	79.55	2.35	51.5	163.24	-8.89	-6.53	1681.8909	1681.727	67.38
Jan-03	76.24	1.07	30.4	196.22	-12.64	-11.57	1681.7392	1681.617	55.82
Feb-03	70.00	0.59	2	185.89	-12.87	-12.28	1681.5637	1681.476	43.53
Mar-03	64.20	1.67	48.2	157.37	-7.01	-5.33	1681.4807	1681.356	38.20
Apr-03	65.30	5.47	69.1	98.57	-1.92	3.55	1681.5352	1681.305	41.76
May-03	71.49	5.72	40.4	114.56	-5.30	0.42	1681.541	1681.39	42.18

Jun-03	71.72	5.59	90.5	109.82	-1.39	4.21	1681.5998	1681.372	46.39
Jul-03	74.76	6.06	74.5	116.89	-3.17	2.89	1681.6385	1681.376	49.28
Aug-03	76.27	9.70	76.1	99.45	-1.78	7.92	1681.7423	1681.501	57.20
Sep-03	80.27	9.21	85.5	57.73	2.23	11.44	1681.8849	1681.626	68.65
Oct-03	85.72	9.79	53.4	75.77	-1.92	7.88	1681.9768	1681.751	76.52
Nov-03	89.28	6.04	6.2	141.13	-12.05	-6.00	1681.9095	1681.667	70.52
Dec-03	86.58	2.60	12.6	146.01	-11.55	-8.95	1681.8062	1681.583	61.57
Jan-04	88.02	1.05	46.2	192.91	-12.91	-11.86	1681.6715	1681.499	49.72
Feb-04	83.36	2.17	24.2	221.78	-16.47	-14.30	1681.4999	1681.415	35.42
Mar-04	79.24	3.06	42	144.66	-8.13	-5.06	1681.436	1681.331	30.35
Apr-04	77.89	4.34	33.1	130.26	-7.57	-3.23	1681.3946	1681.247	27.12
May-04	78.23	4.71	61.5	151.68	-7.05	-2.34	1681.3646	1681.163	24.78
Jun-04	77.84	4.60	75.7	159.31	-6.51	-1.90	1681.3402	1681.061	22.88
Jul-04	76.86	4.77	65.4	192.33	-9.76	-4.98	1681.2754	1681.001	17.90
Aug-04	74.67	6.39	117.1	107.10	0.75	7.14	1681.3711	1681.058	25.05
Sep-04	78.36	8.21	116	73.97	3.29	11.51	1681.518	1681.134	36.56
Oct-04	83.96	9.08	57.1	98.23	-3.45	5.64	1681.5852	1681.229	42.19
Nov-04	86.58	6.14	94.2	205.23	-9.61	-3.47	1681.5451	1681.24	38.73
Dec-04	84.98	2.58	15.2	149.54	-11.42	-8.83	1681.4411	1681.15	29.89
Jan-05	80.76	1.26	81.1	184.56	-8.36	-7.09	1681.3534	1680.982	22.80
Feb-05	77.22	0.76	7.7	201.16	-14.94	-14.18	1681.1698	1680.897	8.63
Mar-05	69.60	3.72	110.9	166.69	-3.88	-0.16	1681.1675	1680.825	8.47
Apr-05	69.90	4.98	156	94.42	4.30	9.29	1681.3004	1680.786	17.76
May-05	74.96	8.94	144.5	134.61	0.74	9.68	1681.4295	1680.891	27.44
Jun-05	79.90	6.65	73.2	136.61	-5.07	1.59	1681.4494	1681.056	29.03
Jul-05	80.69	7.84	150.9	105.54	3.66	11.51	1681.592	1681.156	40.54
Aug-05	86.14	9.74	61.3	107.74	-4.00	5.75	1681.6587	1681.254	46.28
Sep-05	88.73	9.71	122.2	70.66	4.57	14.29	1681.8198	1681.312	60.57
Oct-05	94.89	8.41	28.4	101.32	-6.92	1.49	1681.8355	1681.419	62.06
Nov-05	95.51	5.44	46	152.57	-10.18	-4.73	1681.7859	1681.426	57.33
Dec-05	93.52	2.71	10.4	148.24	-12.89	-10.18	1681.6771	1681.299	47.15
Jan-06	89.12	1.10	1.7	136.50	-12.01	-10.91	1681.5547	1680.85	36.24
Feb-06	84.12	0.54	9	144.19	-11.37	-10.83	1681.426	1680.739	25.42
Mar-06	78.88	2.32	139.2	174.47	-2.78	-0.46	1681.4202	1680.688	24.96
Apr-06	78.66	5.16	145.9	97.99	3.77	8.93	1681.5338	1680.685	33.89

May-06	83.03	6.70	74.4	148.58	-6.16	0.54	1681.5403	1680.842	34.44
Jun-06	84.67	6.42	108	145.33	-3.16	3.26	1681.5789	1680.999	37.70
Jul-06	89.58	8.19	171.1	146.52	2.20	10.40	1681.6949	1681.156	48.10
Aug-06	95.98	9.65	169.3	111.13	5.58	15.24	1681.8537	1681.312	63.34
Sep-06	106.12	12.37	194.9	52.13	15.15	27.53	1682.1131	1681.556	90.86
Oct-06	108.84	11.71	56.9	122.39	-7.13	4.59	1682.1552	1681.798	95.45
Nov-06	108.95	7.46	79.2	145.25	-7.20	0.27	1682.1578	1681.919	95.72
Dec-06	105.24	3.56	48.3	182.82	-14.16	-10.59	1682.0571	1681.939	85.13
Jan-07	99.80	1.74	18	170.19	-15.19	-13.44	1681.9224	1681.809	71.69
Feb-07	95.26	4.36	56	212.12	-14.87	-10.50	1681.8122	1681.731	61.19
Mar-07	94.58	4.72	70.4	135.56	-6.16	-1.43	1681.797	1681.601	59.75
Apr-07	72.18	6.11	112	135.60	-1.70	4.41	1681.8581	1681.548	64.16
May-07	74.56	5.36	166.1	71.00	7.09	12.46	1682.0251	1681.608	76.62
Jun-07	80.89	6.13	225.4	143.87	6.59	12.73	1682.1824	1681.718	89.34
Jul-07	86.88	8.04	129.1	177.38	-4.19	3.85	1682.2267	1681.893	93.19
Aug-07	88.60	10.00	105.1	153.90	-4.32	5.68	1682.2908	1682.109	98.87
Sep-07	101.63	12.08	233.8	85.43	15.08	27.16	1682.5581	1682.381	126.03
Oct-07	105.52	14.99	33.1	101.42	-7.21	7.79	1682.6319	1682.629	133.82
Nov-07	103.39	7.74	3.7	137.99	-13.88	-6.14	1682.5725	1682.632	127.68
Dec-07	95.04	3.32	0	245.40	-23.32	-20.00	1682.3621	1682.423	107.68

Appendix-I Elevation-Volume-Area relationship of Lake Awassa