Addis Ababa University
School of Graduate Studies
Faculty of Science

MODELING AND FORECASTING AWASSA LAKE LEVEL FLUCTUATION

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Abstract

Lake Awassa is located in the central main Ethiopian rift valley. The Lake is important water resource in the study area and is used for irrigation, municipal and domestic water supplies as well as recreational purposes. Beside its importance, the level of the lake has changed dramatically over the past two decades. Because of this, the lake has attracted considerable attention in recent years especially when the lake flooded the surrounding area including Awassa town which is established adjacent to the lake. Fundamental for understanding the lake level fluctuation requires knowledge of the lake's water balance and its response to human induced and climatic changes in the hydrologic regime.

The present study develops a water balance forecast model for Lake Awassa. The model uses annual values of surface runoff (gauged and ungauged), evaporation, precipitation and groundwater outflow to simulate past lake levels. For this reason, the model was calibrated using multiple linear regressions and ARIMA model fit using SPSS software. The calibrated model was verified and used to forecast future lake level based on various selected applications and assumptions.

The model result shows that the surface runoff and evaporation accounts about 81% and 38% in short term lake level fluctuation but in long term lake level fluctuation precipitation and evaporation accounts 45% and 73%respectively. This is mainly the result of land use/cover changes which causes the runoff to increase and evaporation to decrease. If this continues the lake would be a treat to the surrounding area and the town might be at risk if remedial measures are not considered.

Although the environmental implications of a given lake level are beyond the scope of this study, the model provides an essential tool for water policy and management decisions in the Awassa catchment.

CHAPTER ONE

INTRODCTION

1.1 Background

Lakes are one of humanity's most important resources, especially in the tropics, where they are often viewed as highly productive biological systems. They provide water for consumption, fishing, irrigation, power generation, transportation, recreation, and a variety of other domestic, agricultural, and industrial purposes.

Ethiopia is gifted with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance.

Lake Awassa, one of the lakes of the rift valley basin, provides extra beauty to the Awassa town. The level of the lake shows dramatic changes in the last few decades. The increasing in size and level for the last three decades is attributed to combined effect of land use and climatic changes (Ayenew and Yemane, 2006)**.** Due to these phenomena the lake inundated some parts of the town. The inundation has caused significant damages to the properties such as residential houses, recreational parks, Wabi-shebelle resort hotels, agricultural and grazing areas etc. Recently, the flooding incidents which occurred in different parts of our country have taken the lives of many Ethiopians, and damaged many buildings and infrastructures. This is mainly due to the lack of information on the temporal variation of river and lake level changes**.** Therefore, proper assessment and modeling water level rise of the lake is important for future water resource management in the region. In this regard, proper mitigation measures of the exiting lake level raise demands the use of environmental modeling tools to provide a predictive model of the lake.

Thus, this study backed up with adequate data & supported by multidisciplinary techniques to come up with the result, so that it can be able to recommend on proper water resources utilization and give possible remedial measures in the context of water and land resources sustainability**.**

1.2 Previous works

As far as previous works are concerned, the area has been a major interest for local and foreign researchers in the past. Different issues related to geology, hydrogeology, engineering, environmental, geothermal, paleoclimatological, land degradation, etc are conducted in the area.

The main works related to hydrogeology are: The hydrogeology of the MER conducted by Geological Survey of Ethiopia(GSE) (Tesfaye Cherent, 1982); The hydrogeology of Awassa area (Dessie Nadew, 1997); Engineering geology of Awassa (Zemenu Geremew, 2000); pollution on Awassa area (Elias Gugsa, 2004) are some of them and Telford, R (1998) on the diatom stratigraphies of Lake Awassa. These have characteristics of more regional or general and purpose oriented; recent works are done related with the rise of lake level by Water Works Design and Supervision Enterprise (WWDSE, 2001) ,Geological survey of Ethiopia (Zenaw Tessema, 2003) and on the assessment of the Water Balance of Lake Awassa Catchment (Yemane G. ,2004).

Quite a lot of studies were done; no studies have been conducted, regarding environmental systems modeling of the water level of Lake Awassa, So that, the prevailing conditions in the proposed area suggest that, the need for detailed & systemic assessment of the general water level rise of the lake for sustainable management of the resource in the region.

1.3 Research objectives

The main objective of this study is:

- To develop water balance forecast model of the Lake Awassa based on the available data, so as to come up with defined cause of lake level rise and there after to forecast lake level rise.

2.2 Specific objectives

- To estimate the various hydro-meteorological components of the lake.
- To increase awareness and understanding of environmental systems.
- To learn strategies for analyzing and using environmental systems models.

1.4 Structure of the Thesis

This thesis contains six chapters incorporating graphs, maps and data in the appendices. Chapter one and two gives a clear view of this study and the area. Chapter three describes the trend and relationships of hydrological and metrological variables where these variables are the major components of the model. Chapter four discuss about the nature of model development and chapter five contains application model and the results and discussions derived from the work. Chapter six is the conclusion and recommendations derived from the work.

CHAPTER TWO

ENVIRONMENTAL SETTING OF THE STUDY AREA

2.1 Location

The Awassa catchment is located with in the geographical co-ordinates of $6^{0}45^{1}$ to $7^{0}15^{1}$ north and $38^{0}15^{1}$ to $38^{0}45^{1}$ east latitude and longitude, 275km south of Addis Ababa, in the Main Ethiopian Rift Valley. It has an elevation generally ranging from 1680 to 2997 m. a. s. l, in which Lake Awassa occupies the lowest elevation in the catchment. The catchment can be accessed in different direction using quite a lot of weathered roads. The total area of the catchment is about 1300km^2, where 100km^2 is taken by the lake and the rest 1200 km^2 of the catchment is occupied by surface land (fig.1.1).

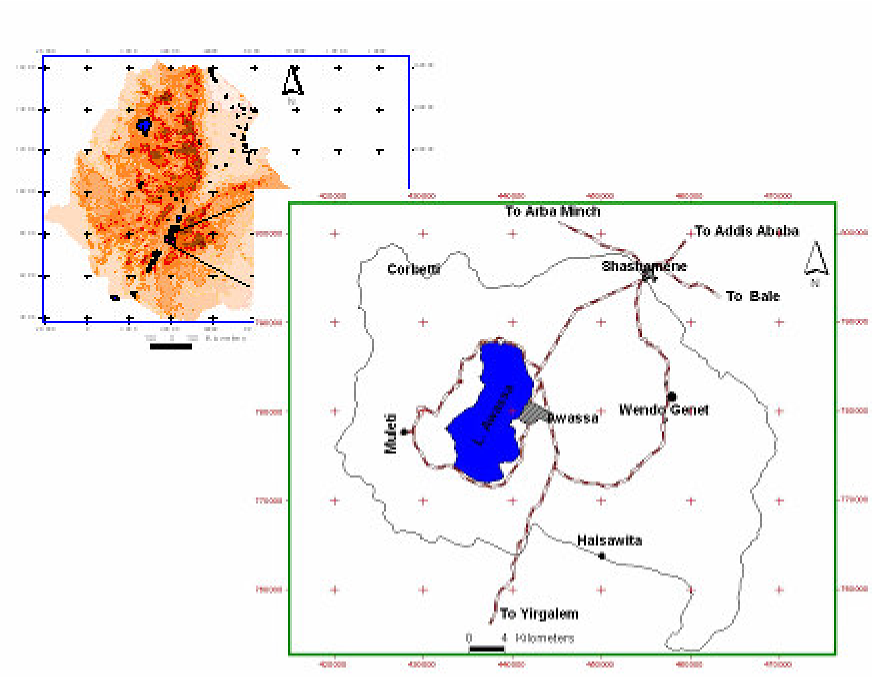

Figure 2.1 Location map of the study area (modified after Wondwossen, 2005)

2.2 Topography and drainage

The Awassa Lake catchment is found in the lake regions of the central sector of Main Ethiopian rift, which is occupied by a chain of lakes. It is bounded by the north, south, east and west Ziway-Shalla, Abaya-Chamo, Wabi-Shebelle-Genale, and Omo-Gibe Basin respectively. Awassa Lake is a caldera lake without surface outlet, which is a closed basin, formed by a volcano-tectonic depression with a 40-50km diameter. The depression is bounded by the remnants of the caldera wall, where steep slopes and faulted blocks characterize them.

Lake Awassa, which is positioned within a nested caldera complex, is the smallest in size and highest in elevation of the major MER lakes, which makes it possible for groundwater to flow from Lake Awassa to other lakes (Wondwossen 2005). Including Lake Awassa the catchment area consists of escarpments, ridges and plateau, undulating to rolling and dissected plains, depressions and swamps, and recent cracks. Eastern boarder of the catchment overlaps with the eastern escarpment of the Main Ethiopian Rift, where its average throw is about 500m and maximum elevation goes up to 2997 m.a.s.l., which is the maximum in the catchment (fig.2.2).

As long as surface water is concerned, there is none going out of the lake which makes it a Closed-catchment Lake. Lake Awassa is fed by TikurWuha River, which is the main perennial river in the catchment, joins the lake passing through Cheleleka swamp found on the east side of the lake. High discharge springs at the upstream feeds Cheleleka swamp in addition to the runoff from the eastern escarpments of the rift.

Out of the perennial streams originating from the eastern highland, Wodesa stream drains swampy area of Cheleleka with higher discharge to join TikurWuha River. TikurWuha River having 625 km^2 catchment area and 45% of the lake catchment area is the only perennial and gauged river flowing into Lake Awassa. The western part of the catchment has no significant drainage system due to the flat laying thick and fertile agricultural land infiltrating the dispersed overland flow from the highlands. (Wondowossen, 2005 and Nardos 2006).

Lake Awassa Catchment is a result of volcano-tectonic depression (caldera) as a result its drainage pattern is radial, where rivers flow in all directions away from a raised feature, which is volcano. Surface and sub-surface fracture intensities, rock and soil formation, topography and climate are the governing factors for the drainage density and pattern.

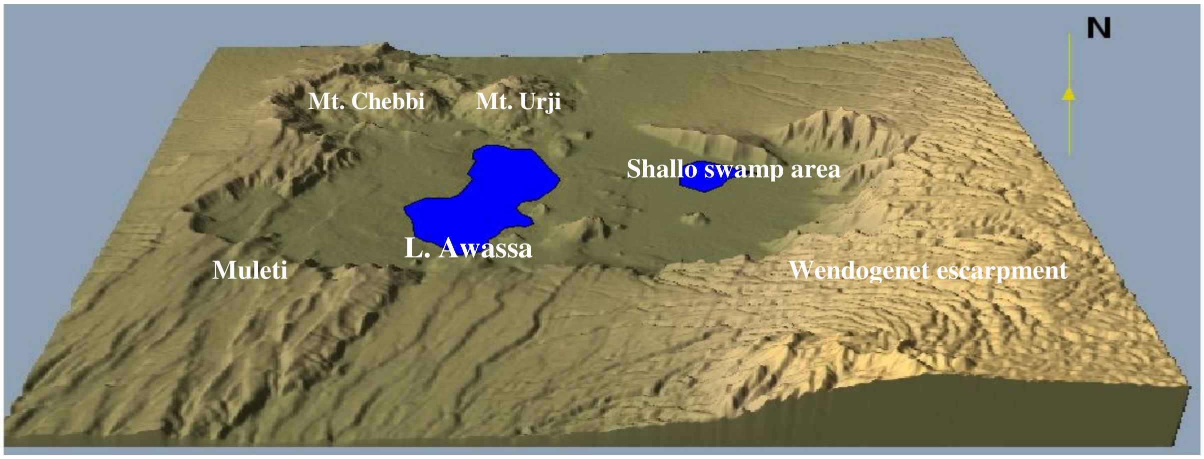

Figure2.2 Digital Elevation Model of the study area

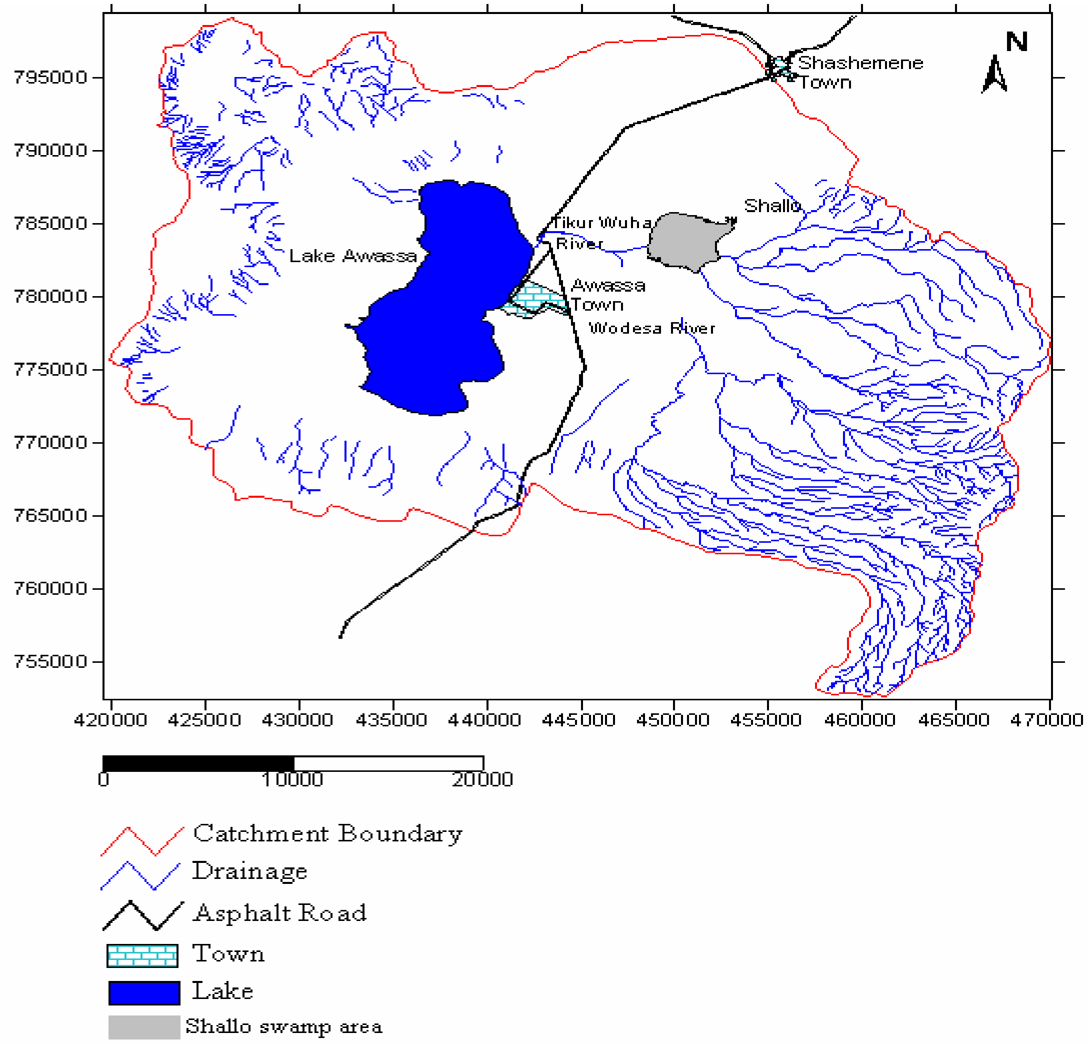

Fig. 2.3 Drainage map of the study Area (modified from Nardos, 2005)

2.3 Climate

The Awassa catchment is characterized by a sub-humid climate with annual precipitation variability. The moisture for precipitation in the area originates from south-west equatorial air stream, which moves northwards with intertropical convergence zone (ITCZ), (W.W.D.S.E 2001). The precipitation of the area based on Awassa station occurs from March-October with mean monthly rain fall varying from 19mm in December to the maximum of 119mm in August. The mean annual rainfall on bases 23 years record of 5 rainfall stations that contribute to the catchment is estimated to be 1021mm.

From the long-term temperature data, the mean annual temperature in the area is 19.5^{0}C. The hottest months are March and April where as the coldest are November and December. The long term Mean monthly Class A Pan evaporation of the catchment based on the Awassa station, taking the average 0.8 pan coefficient, ranges from102mm in July to the maximum of 152mm in January. Relative humidity records show the mean minimum monthly of 54% in February and reaches maximum 77% in September. Generally the wet season on the catchment have mean monthly relative humidity values of more than 70%. Wind speed has decreased with time according to the records found at Awassa station. Wind speed records of 23 years shows the mean monthly wind speed which ranges from 0.74-1.26m/s, where as June and July are the windiest while October and November are the least. Long-term mean monthly values of climatic variables are presented in the following figures.

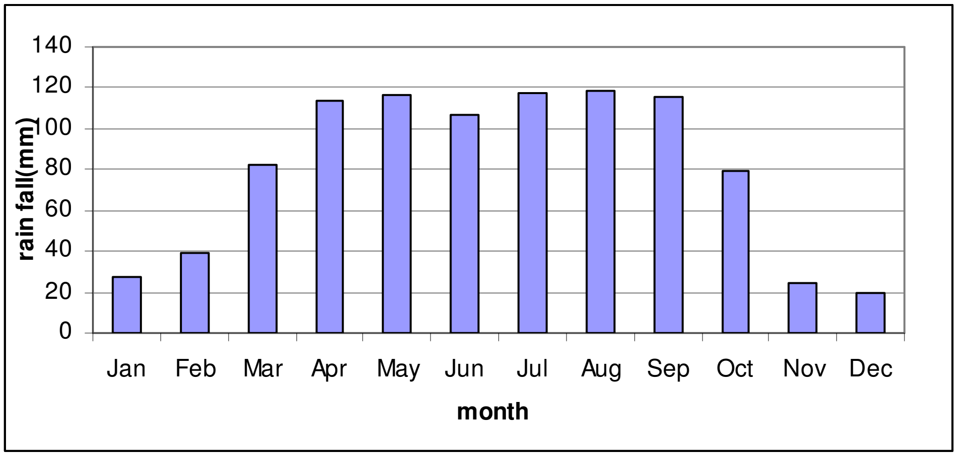

Figure 2.4 Mean Monthly Rain fall at Awassa station

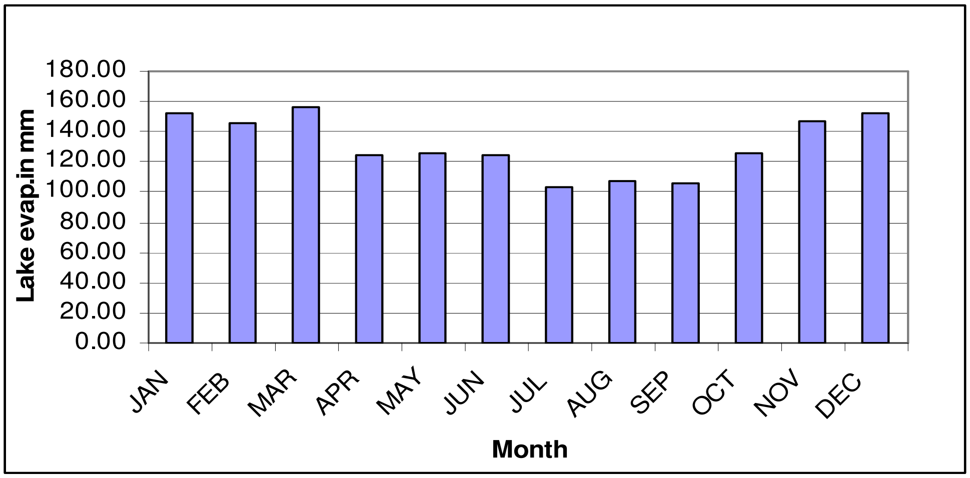

Figure 2.5 Mean Monthly Lake Evaporation at Awassa station

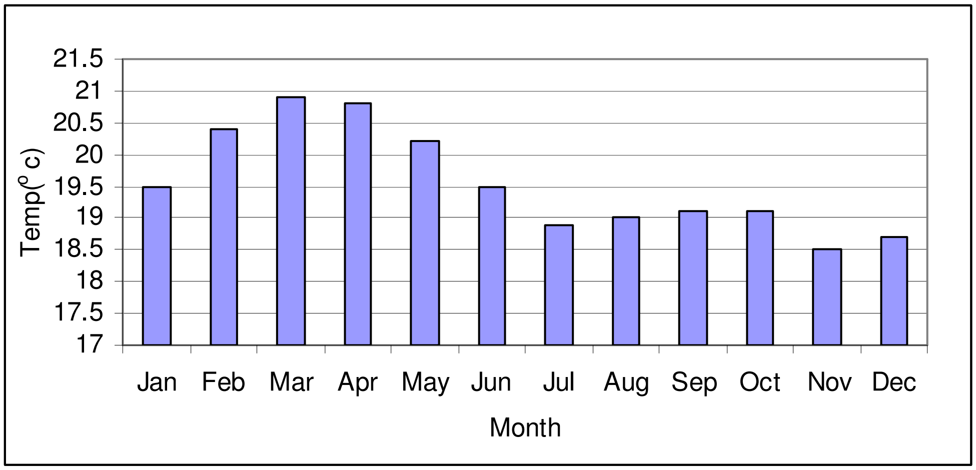

Figure 2.6 Mean Monthly air Temperature of Awassa

2.4 Geology

The great east African rift system is one of the most remarkable features of the African continent. The rift forms a more or less continuous scar from Israel and Jordan in the south western Asia to Mozambique in southeastern Africa (Ase etal, 1986).

The geology of the study area is part of the central sector of the Ethiopian rift (MER), which is the northern segment of the great east African rift system running NNE-SSN direction.

The MER is 80km wide and about 800km long extending from Lake Abe, Afar triple junction and Lake Stiffen rifts south of Lake Chamo.

The MER is characterized by a great number of faults, which produced a total altitude difference of the plateau and the floor of the rift. According to Mohr,(1967) Dipaola,(1972), all these normal step faults of various dimensions and throws, are commonly arranged in an echelon style and trending mainly along NNE-SSE and rarely along NE-SE, N-S and NW-SE directions. The youngest structural deformation of the Ethiopian rift valley is the wonjji fault belt (WFB), which is characterized by the prominent N-S to NNE - SSE trending rift floor normal and accossinally dilation faults, Mohr,(1962). The WFB has been forced into an echelon transposition in order to remain with in the rift marigin envelop (Woldegebriel,etal, in press). These sites of transposition is characterized by very recent and closely spaced normal faults, extensional fractures, Chorowicz et al, (1994) and other fault oriented open structures with significant volumes of fissural basalts and related differentiation products of very recent age and historical, Di paola (1976). According to Mohr and Wood (1978), the rift floor comprises calderas that are generally elliptical in plan view with the long axes with length between 2 and 17 km.
Based on structural features the main Ethiopian Rift System is divided into three geographic areas where the Awassa lake basin belongs to the Central (Nazret Awassa) Sector, which is a symmetric rift basin where both sides of the rift margins are fully defined with the exception of the regions between Gurage and Sodo of the western escarpment and the Shashemene area of the eastern margin. The rest two are Northern (Fentale Nazret) and Southern (Awassa-Konso) sectors.
The closed basin of the nested Awassa-Korbetti caldera complex is a giant elliptical depression 30-40kmswide.The Korbetii caldera, which is found northwest of Lake Awassa, is nested caldera with in Awassa caldera. It has two volcanic centers of Urgi and Chebbi. The Urges centre is a source for the formation of pumice in the vicinity and Chebbi is a center of formation of obsidian, which covers the Chebbi Mountain.

(Dessie 1995), stated the main formations in the area subdivided in to four lithologic units as follows;

1. Volcano lacustrine deposits, which cover most part of the floor of the depression, composed mostly of volcanic origin (tuff, pumice, ash) with small amount of diatomite;
2. Recent acidic volcanics, which covers large part of the north and north-western part of the catchment where glassy rhyolitic rocks superimposed and form massive domes and thick obsidian flows;
3. Basaltic lava flows, scoria and hyaloclastites, which are observed sprinkled on the flat catchment floor forming conical shapes.
4. Ignimbrite of the rift floor and the rift scarp, which is common rock type for the region and covers the east, southwest and the southern part of the catchment where the top few meters of the rock is weathered and fractured in places with columnar joints.

2.5 Soils

Water Works Design and Supervision Enterprise have classified the soil based on the physical and chemical characteristics. Depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons, reaction to 10%HCl and ph value are some of the classification criteria based on which soil map has been produced (fig.2.8).

Cambisols, Andosols, Vertex cambisols, Vertic luviosols, Regosols, Gleysols, Alisols, and Leptosols are some of the soil types described by W.W.D.S.E with respect to their position in a different relief intensity and slope. Generally based on their dominant characteristics these soils of the study area are classified in to four groups as clay loam, fine sand, fine sandy loam and silty loam (Wondwosen Mekonnen, 2005).

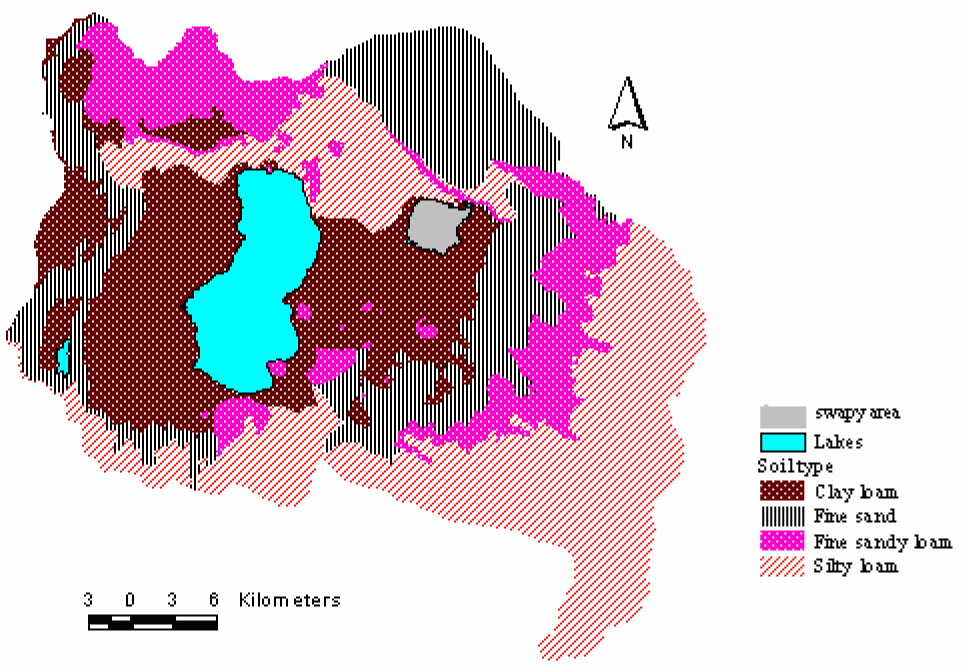

Figure 2.7 Simplified Soil map of the study area (modified after WWDSE, 1999)

2.6 Land use cover

The land use of Lake Awassa catchment has been changed progressively due to extreme deforestation as a result of increase in population which results in replacement of vegetation cover by cultivation land and other activities. The land use /land cover of the catchment is analyzed by comparing the maps prepared by WWDSE (2001) and Yemane (2004) which both are presented in Yemane (2004) as shown in the fig and . According to WWDSE, the cultivation activities up to 1965 were limited to the northeastern and southern halves of the lake and hardly any in the west. The figure shows, the Open bushy woodland with cultivated land found on the floor and southern part of the area; Cultivated land with exposed bare rock and soil found on southwest corner of the area; Open grassland with bare soil covers the eastern escarpment western caldera rims; Open grassland with open bushy woodland on the volcanic hills are the main land cover condition of the area.

The situation in 2004 shows serious depletion of natural vegetation and accompanying land degradation in the catchment with exceptionally better trend in areas between Wajagra and Wendogenet in the east (Gesses et.al, 2006). Moreover, the eastern belt has created more stable grazing possibilities for considerable livestock population, despite increased depression and consequent disappearance of Lake Chalalaka.

In general, the land use/land cover changes in the catchment portrayed significant damaging effect especially on the lands previously covered by total vegetation. The greatest change as stated earlier, has been noticed on open bushy woodland, which according to the analysis results experienced about 37% of the overall effects in the catchment. Dense woodlands and dense bushy woodlands also suffered 20% and 16% of the changes, respectively (table 1.1).

The land cover changes the study area happen as a result of changes in the purpose of land utilization. Human factors play dominant roles in influencing the changes that take place over a period of time. The increase in population which increases the demand of wood for fire, charcoal, construction materials, and household furniture has highly influenced the change in land use/land cover condition of the lake catchment.

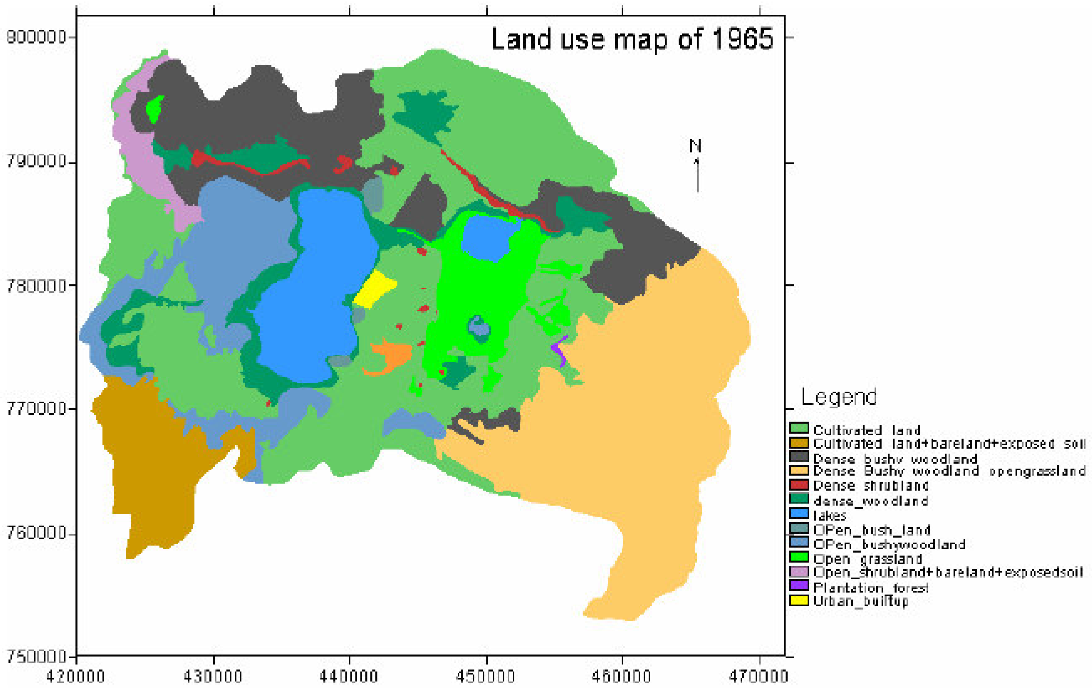

Figure2.8 Land use map of Lake Awassa catchment 1965 (adopted from WWDSE, 2001)

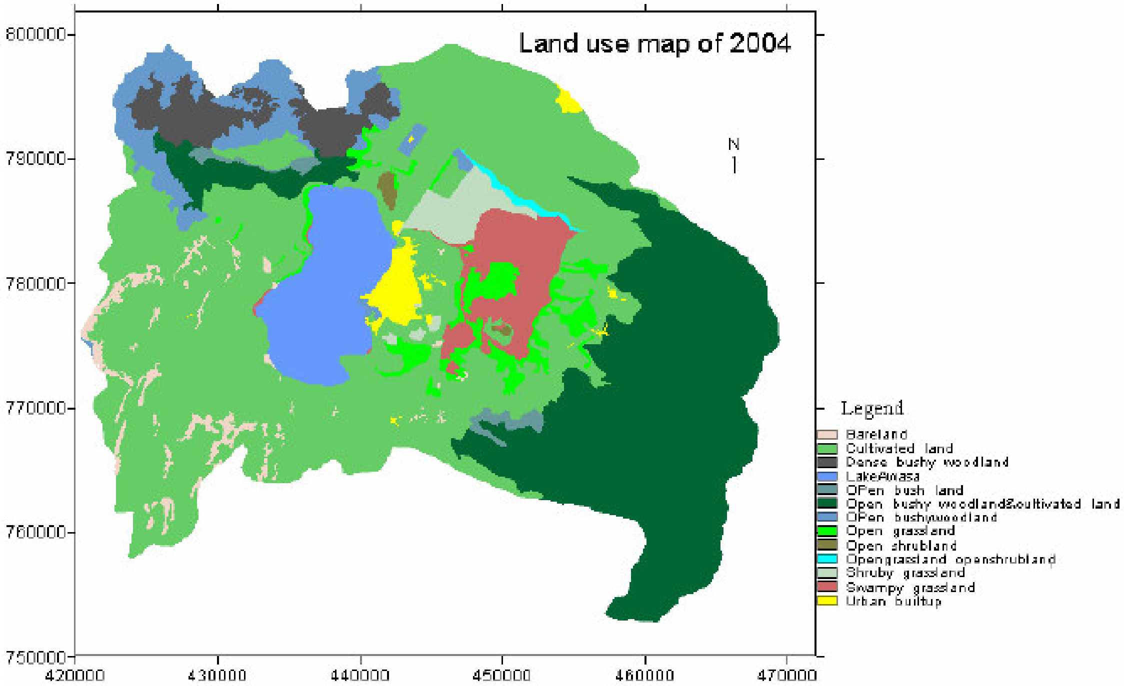

Figure 2.9 Land use map of Lake Awassa catchment-2004 (adopted from Yemane, 2004)

As the deforestation of the natural vegetation cover continues soil loss due to erosion will result and it is aggravated where the slope is higher especially on the escarpments. This erosion could be one of the reasons for the rise of Lake Awassa water level. The following table shows percentage of changes observed from the period 1965-2004.

Table 1.1 Land use/land cover changes in lake Awassa catchment, (1965-2004)

No.	**Land Cover Units in 1965**	**Area in hectare**	**Change in %**
1	Open Bush Land	405.6	1.3
2	Dense Bushy Woodland	4,985.70	15.8
3	Open Bushy Woodland	11,278.40	37.2
4	Plantation Forest	60.1	0.2
5	Open Grassland	957.4	3.2
6	Dense Shrub Land	110.6	0.4
7	Dense Woodland	5,955.40	19.6
8	Open Bush Land and Open Grassland	1,811.70	5.6
9	Dense Bushy Woodland and Open Grassland	1,711.70	5.6
10	Open Shrub Land and Bare Land	350.50	1.1
11	Open Shrub, Bare Land and Exposed soil	209.40	0.7
12	Open Woodland and Open Grassland	2,777	9.2
Total		**30,613.50**	**100**

CHAPTER THREE

AWASSA LAKE LEVEL CHANGE AND HYDRO-METEOROLOGICAL DATA ANALYSIS

3. Meteorological and Hydrological data

3.1 Meteorological data

3.1.1 Rain fall (mm)

Rainfall data starting from 1981 was obtained from National Meteorological Service Agency. The mean annual Rainfall is about 962 mm (fig 3.1). The wettest years on record were 1983, 1986 and 1996 with annual rainfall amount of 1160mm, 1192mm and 1189mm respectively. During those years, significant rises in lake level were registered with the exception of 1986. The rise in 1986 did not mark the wetness of the period and this could be as a result of the antecedent conditions of the preceding two years, i.e. 1984 and 1985 which had rainfall amounts below the long term mean value. The highest rainfall amount recorded was about 243mm in June 1983. This could have resulted in rapid rise of the lake level during the same year.

The rainfall is well distributed throughout the rainy season, unimodal pattern, starting from March to October. From this pattern about 47% of the mean annual rainfall occurs during the months of June-September and about 71% occur from April-September. Generally the area gets more than 87% of the total rainfall during the eight rainy months and only 13% during the dry months. The monthly rain fall coefficient ranges from 0.3 (January) to 1.6 for the months of July, August and September (Dessie Nidaw, 1997).

Long-term mean monthly records from five stations are taken from National Meteorological Service Agency (NMSA) in order to analyze the spatial and temporal variations in precipitation with in the catchment.

There is an eight month long rainy season from March to October with mean monthly range of 50-150 mm and the area gets high amount of rainfall in April, May and September (fig 3.2). As it is seen from the graphs there is no as such high variability spatially in the area where the maximum amount of mean annual rainfall reaches 1120mm at Wendogenet where as the minimum is 931mm at Shashemene.

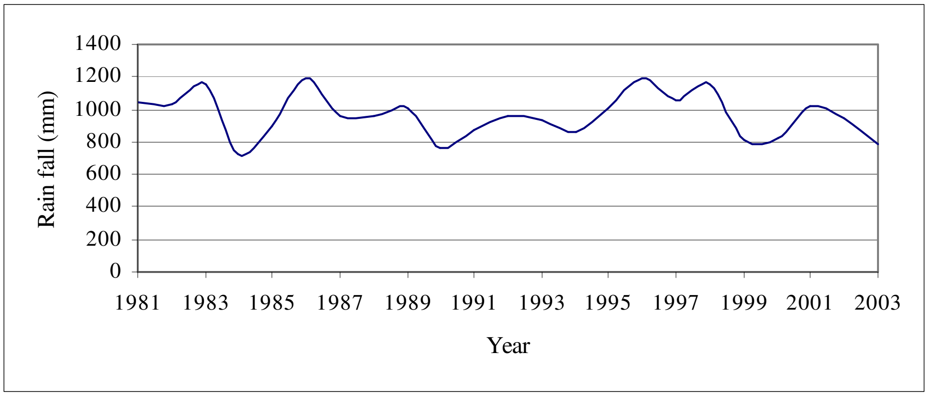

Figure 3.1 Annual Precipitation at Awassa Station (1981-2003)

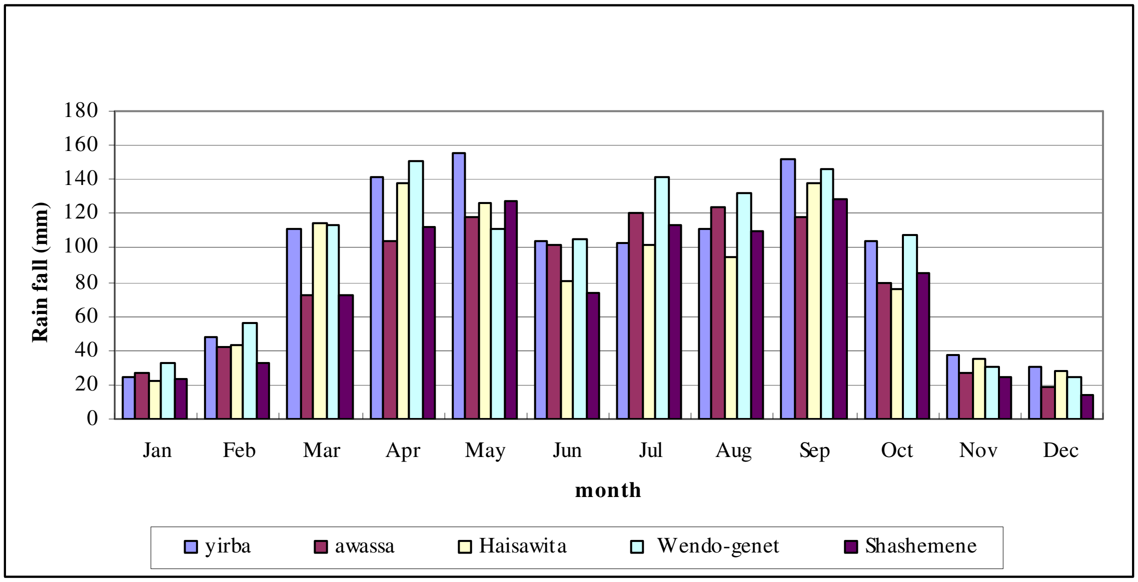

Figure 3.2 long term mean monthly precipitation at Awassa catchment

The long-term mean annual rainfall in the area poorly correlated with the variation in altitude (Fig. 3.3). From Awassa to the East and southwest, the rainfall variability correlates with the variation in altitude, however to the south (Haisawita station) doesn't correlated with altitude, which might be due to the quality of the data and/or orographic effect but generally on the rift rainfall with altitude is highly correlated (Tenalem Ayenew, 1998). In general there is no correlation between rainfall and altitude.

Table 3.1 Long-term mean monthly precipitations and altitude in the catchment

Stn No.	NAME	Altitude (m)	Mean Annual RF (mm)
1	Awassa	1750	962
2	Wendogenet	1800	1120
3	Aje	1860	1272
4	Shashemene	1950	931
5	Yirba	2000	1087
6	Haisawita	2240	1006

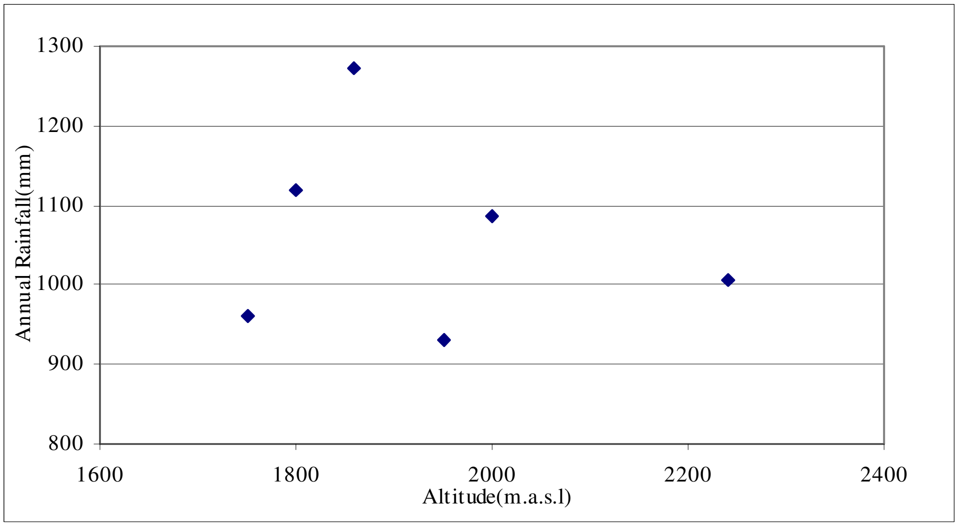

Figure 3.3 Altitude- rain fall relationship

The aerial depth of precipitation was estimated using arithmetic mean, and Theissen polygon methods (table 3.3, and fig. 3.4). Based on the arithmetic mean method the catchment precipitation is estimated to be 1022mm (table 3.2). From the results of the Theissen method shown in table 3.4, the total annual precipitation over the catchment is 1038mm.

Table 3.2 the arithmetic mean annual precipitation of Lake Awassa catchment

Stn No.	NAME	Altitude (m)	Mean Annual RF (mm)
1	Awassa	1750	962
2	Wendo genet	1800	1120
4	Shashemene	1950	931
5	Yirba	2000	1087
5	Haisawita	2240	1006
Arithmetic mean			1022

Table 3.3 Theissen polygon areas and average annual precipitation of Lake Awassa catchment

Stations	Mean annual rainfall (mm)	AREA	Area (%)	Theissen mean
Haisawita	999.00	229.5	16.68	166.6
Wendogenet	1151	282	20.49	235.9
Shashemene	918	147.6	10.73	98.5
Yirba	1120.00	178.5	12.97	145.3
Aje	1272.00	79.4	5.77	73.4
Awassa	953.00	459	33.36	318
	Total area	1376		1037.7

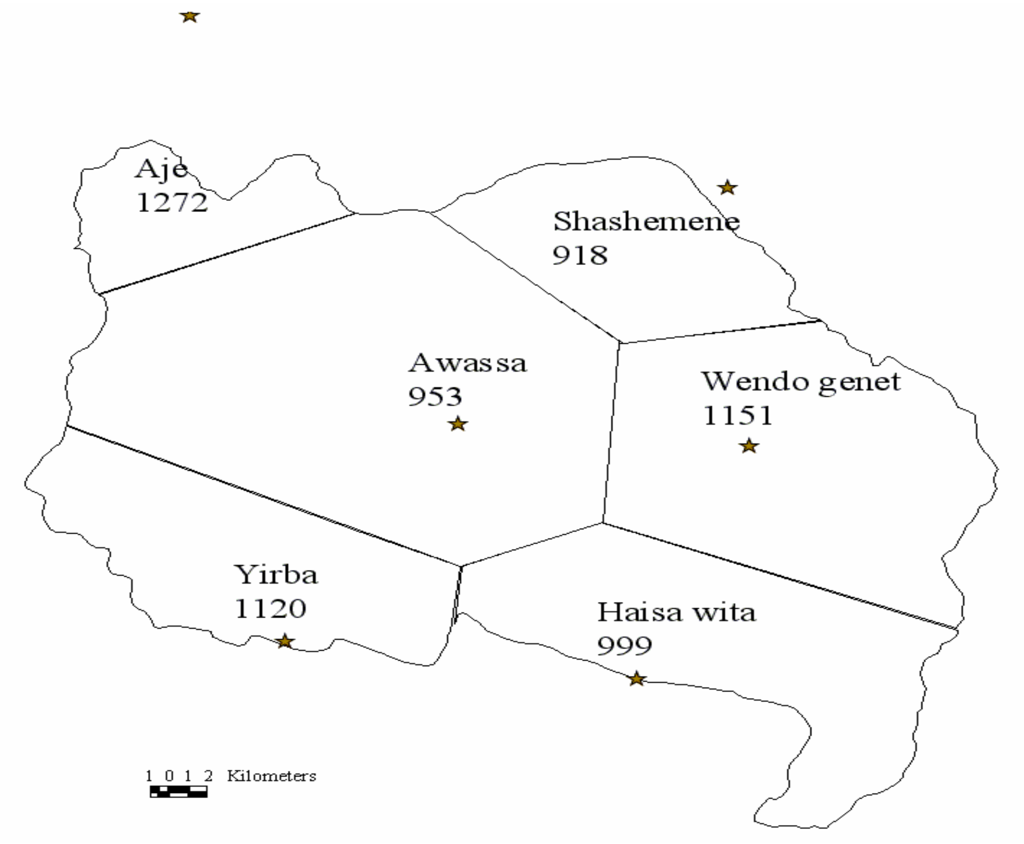

Figure 3.4 Theissen polygons of the Lake Awassa catchment

3.1.2 Evaporation

Class A pan evaporation starting from 1986 has been collected from National Meteorological Service Agency (NMSA). The pan is placed 500m to 1 km east of the lake where the pan receives large quantities of energy from radiation and conduction through its base and sides because it is exposed to air and sun. Thus, correction factors are usually used to approximate the measured evaporation rates to natural open water-surface evaporation. Pan coefficients of 0.75 to 0.85 are commonly used for class A pan (Zemanu, 2000; Yemane, 2004; Nardos, 2006). Taking the average 0.8 coefficient mean annual lake evaporation is estimated to be 1572mm. As shown in figure 1.5, evaporation is below average since 1996. This could be the effect of the increased rainfall during these times, which has increased the humidity of the area slightly and also the slight decrement of wind speed (Zemanu, 2000). There may also be errors introduced in measuring evaporation rate (Yemane, 2004).

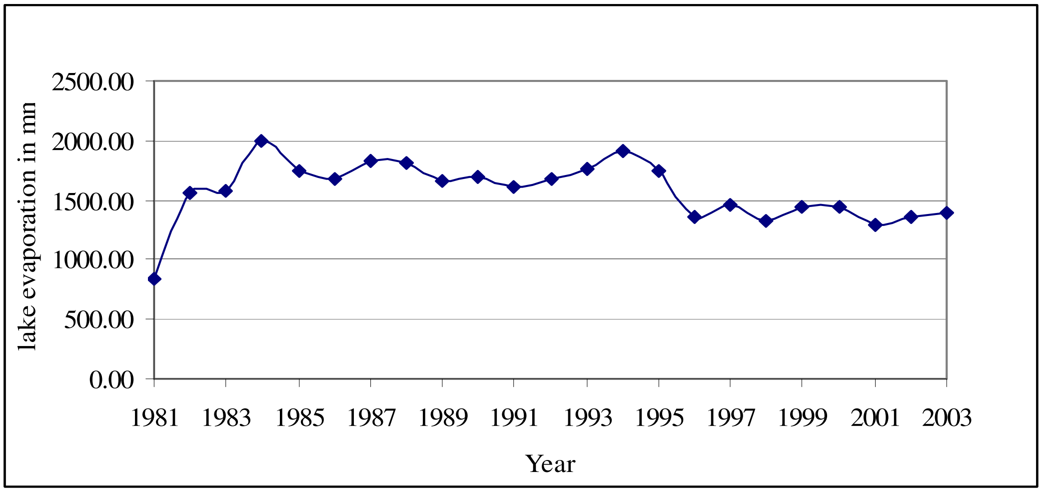

Figure 3.5 Annual Pan Evaporation at Awassa station

The mean monthly lake evaporation of Awassa is estimated to be 131mm. The minimum evaporation is 102mm in the month of July and the maximum is 156mm in the month of March, which is also the hottest month (fig 3.6).

Table 3.4 Mean monthly Lake Evaporation of Awassa

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	191.03	182.71	195.46	156.29	157.23	155.86	128.23	134.8	133.05	156.44	183.94	190.3
SD	54.09	56.91	59.97	45.98	45.20	25.57	26.00	20.66	20.36	32.00	34.86	32.08
Lake evap.	152.82	146.17	156.37	125.03	125.79	124.69	102.58	107.8	106.44	125.15	147.15	152.2

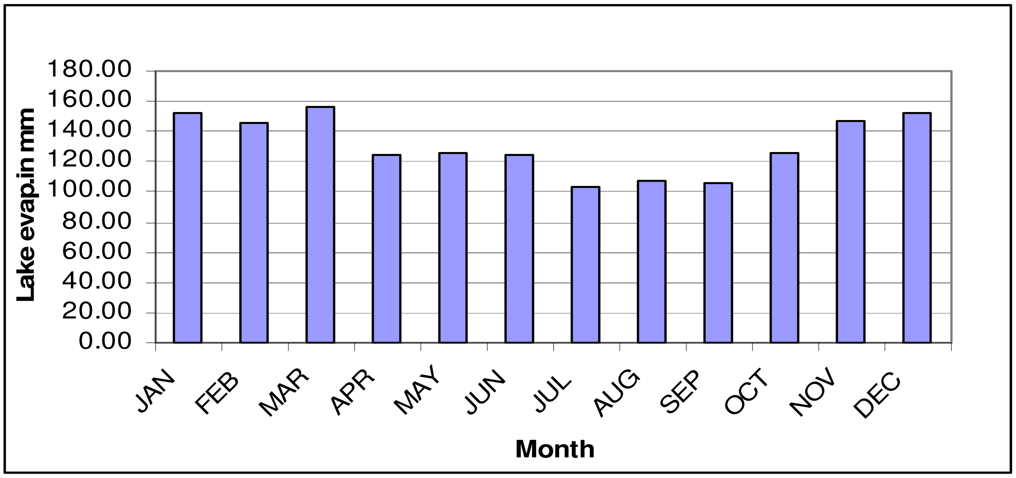

Figure 3.6 Mean Monthly Pan Evaporation at Awassa station

3.1.3 Air Temperature (^{0}C)

Temperature records since 1981 has been obtained from National Meteorological Service Agency (NMSA). The annual mean minimum and maximum temperature is 12 ^{0}C and 27 ^{0}C, respectively. The hottest and coldest months are March and November, respectively (fig 3.7).

Table 3.5. Mean monthly minimum, maximum, and average air temperature at Awassa Station (1988-2003).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Min	10.4	11.7	12.6	13.6	13.8	13.9	14	13.7	13.1	11.7	9.3	9.3	12.26
Max	28.5	29.1	29.2	27.9	26.6	25.1	23.6	24.1	25	26.4	27.5	27.9	26.74
Mean	19.45	20.4	20.9	20.75	20.2	19.5	18.8	18.9	19.05	19.05	18.4	18.6	19.5

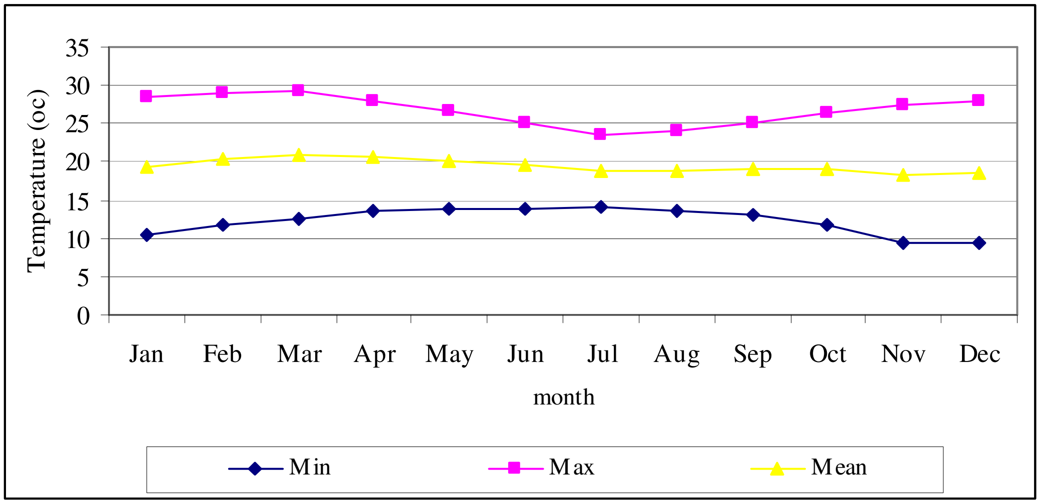

Figure 3.7 mean monthly minimum, maximum and average temperature at Awassa Station

3.1.4 Relative humidity (%)

Relative humidity in the Awassa basin shows a decreasing trend since 1981. This has been mainly attributed to deforestation (Yemane, 2004). The mean monthly relative humidity ranges from 54% in February to 77% in September (fig. 3.8)

Table 3.6 Mean monthly relative humidity (%) at different hours in Awassa

Hrs	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6:00	84.56	81.75	88.19	92.25	93.69	92.14	92.00	92.00	94.93	93.80	88.20	86.50
12:00	44.06	43.63	46.44	52.63	58.94	62.87	67.80	65.29	61.27	53.27	43.20	43.64
18:00	38.75	37.81	51.06	59.81	63.38	60.73	65.33	66.07	72.80	61.93	42.80	39.57
Mean	54.36	54.10	61.90	68.23	73.00	71.91	75.04	74.45	77.033	69.67	59.07	57.57
SD	25.06	23.87	22.89	21.11	18.91	17.55	14.74	15.20	17.11	21.34	26.10	26.00

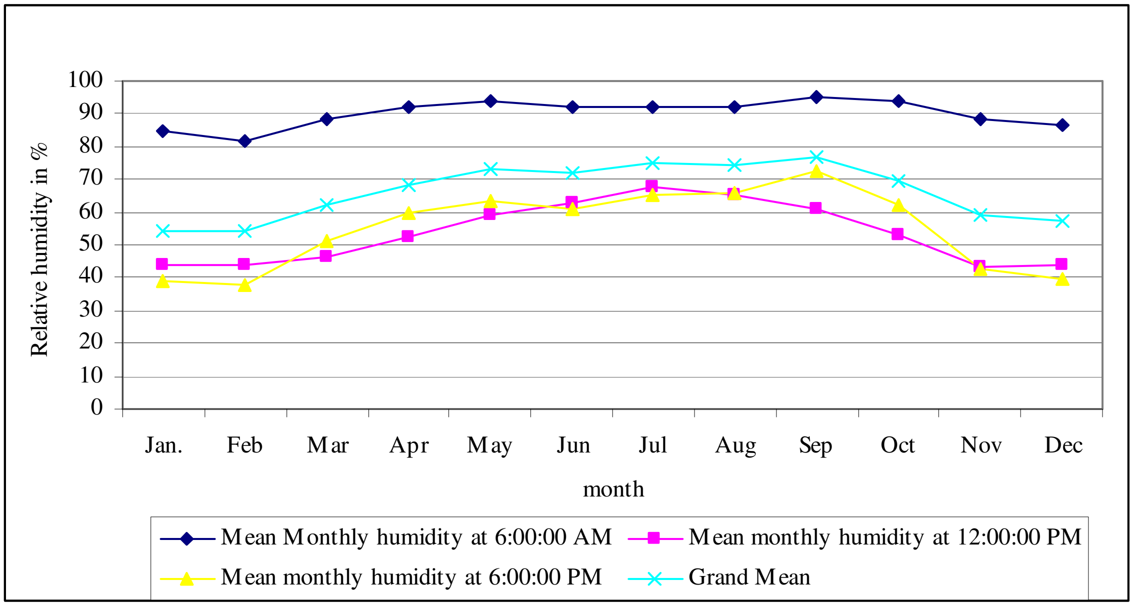

Figure 3.8 Mean monthly relative humidity (%) at different hours in Awassa Station.

3.1.5 Wind speed (m/s)

Wind speed for the study area since 1981 was obtained from NMSA.

The mean annual wind speed (fig.3.9) shows a decreasing value from 1.3m/s in 1984 to 0.8m/s in 2003 with a missing data in between. The minimum recorded value is 0.1m/s in 1989 and no explanation could be given for such big decline. The decreasing trend is mainly due to deforestation and building of construction around the Lake (Yemane, 2004).

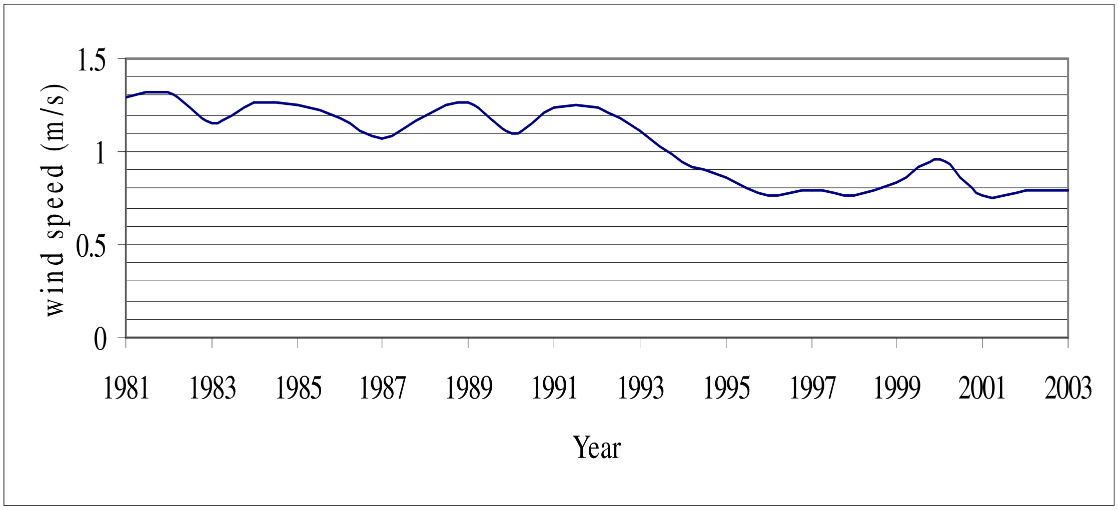

Figure 3.9 Mean annual wind speed at Awassa station (1981-2003)

3.1.6 Sunshine hours

The sunshine hours for the study area since 1981 were obtained from NMSA. The sunshine hours vary from 4.9hrs in July to about 9.1 hrs in December (fig. 3.10).

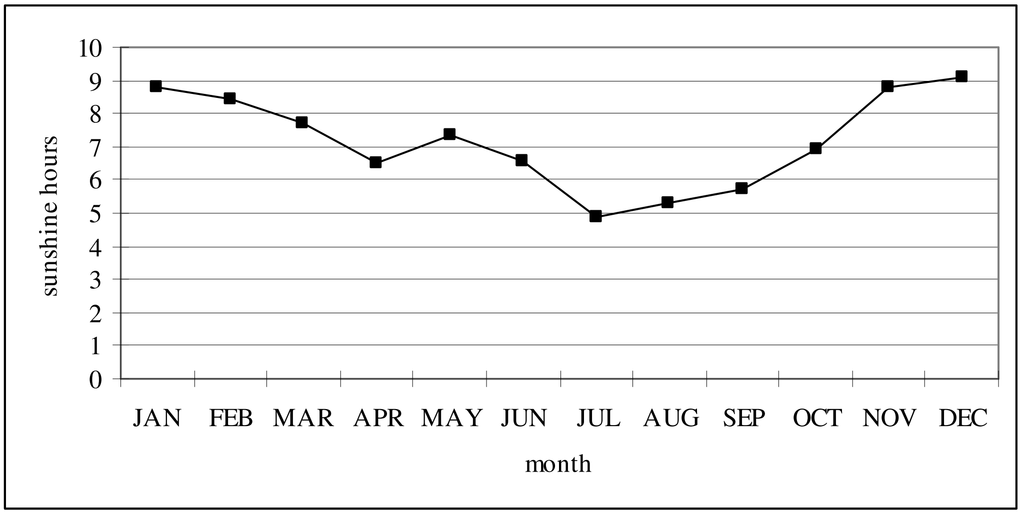

Figure 3.10 Mean Monthly sunshine Hours at Awassa Station (1981-2003)

3.2 Hydrological data

3.2.1 Runoff

Considering the Awassa basin as a whole, no river flows out of the catchment and no river drains out from the catchment(Dessie Nidaw,1997). However, if we consider the surface drainage within the catchment, the runoff from the catchment area feeds Lake Awassa in two different ways. The northern, southern and Western part of the basin areas are poorly drained and feed the lake as an overland flow without well defined channel except in the Southwestern part where few gullies are developed (Zemenu, 2000). The flat laying, thick and fertile agricultural land infiltrates the dispersed overland flow from the highlands. Due to the flatness of the plain agricultural land, west of the lake, no significant surface runoff can be expected to enter the lake (Yemane, 2004). While the eastern and southeastern part of the drainage area has a relatively dense drainage pattern and all the runoff from these catchment feeds Lake Shallo (Cheleleka) and the adjacent swampy area, over flow from lake Shallo drains into lake Awassa through Tikurwuha river (Zemanu, 2000).

3.2.2 Tikurwuha River

Tikurwuha River is the only perennial river gauged at Dato village, up stream of the lake, since 1981.The available monthly summary of river flow data has been collected from Ministry of Water resource, department of Hydrology. The data starting from 1981 till 2003 shows an increasing trend. This is mainly due to climatic reasons, an increase in rain fall, and land use changes, transformation of Lake Cheleleka into swamp. This transformation leads to a decrease in the storage capacity of Lake Cheleleka which, in turn, leads to an increase in the flow of Tikurwuha River into Lake Awassa (W.W.D.S.E, 2001 and Yemane, 2004).

The mean flows of TikurWuha River for the periods 1981-1989 and 1990-1998 were about 64.304mcm and 114.03mcm, respectively. There was an increase of about 50% of the flow magnitude in the period 1990-1998 over the period 1981-1989, Since then the discharge rate shows a decreasing tend but not below its base period average(fig.3.12).

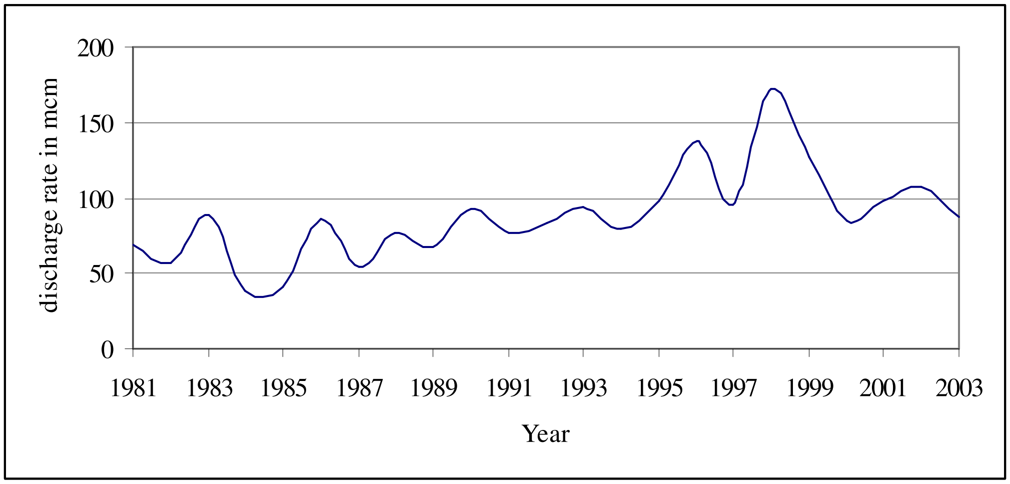

Figure 3.11 Annual Tikurwuha River discharge (1981-2003)

3.2.3 Awassa Lake level

The Awassa Lake level has been monitored since 1969 by the Ministry of Water Resources, department of hydrology. The lake level shows a general increasing trend (fig 3.13). However, in the present analysis, data starting from 1981 is utilized as the data since then is more complete with respect to other parameters. The summary is stated below;

- From the period 1981- 1990 (9 years) the lake level rise was about 0.924m
- From the period 1981- 1999 (18 yrs) the lake level rise was about 2.05m.
- For the period 1995- 1998, a 1.86m rise in level was registered.
- For the period 1999-2003 a 0.8m decrease in level was registered.

During the period of lake level observation starting from 1981, the level was fluctuating at an average of 1.3m until 1988 since then the lake level was never been below its base period average 1.94m with the exception of the years 1991, 1992 and 1995 with a 1.6,1.4 and 1.8m record, respectively.

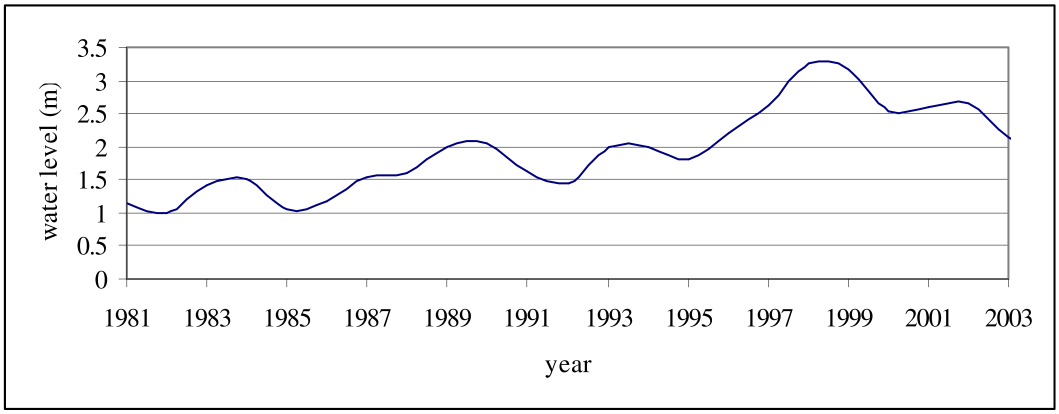

Figure 3.12 Awassa Lake Level Fluctuations (1981-2003)

The Awassa lake level and rain fall depth of the catchment shows a negative correlation with the value of R= -0.079 (fig 3.13). Whereas Awassa lake level and discharge of Tikurwoha river shows a good correlation with the value R=0.58 (fig. 3.14). As shown in the figure 3.15, both are increasing whereas rainfall in the region is decreasing. The decreasing trend in rainfall is related with the aridity of the region, where as stream discharges are increasing due to increase in overland flow (runoff) as a result of change in land use, particularly deforestation (Zenaw, 2003).

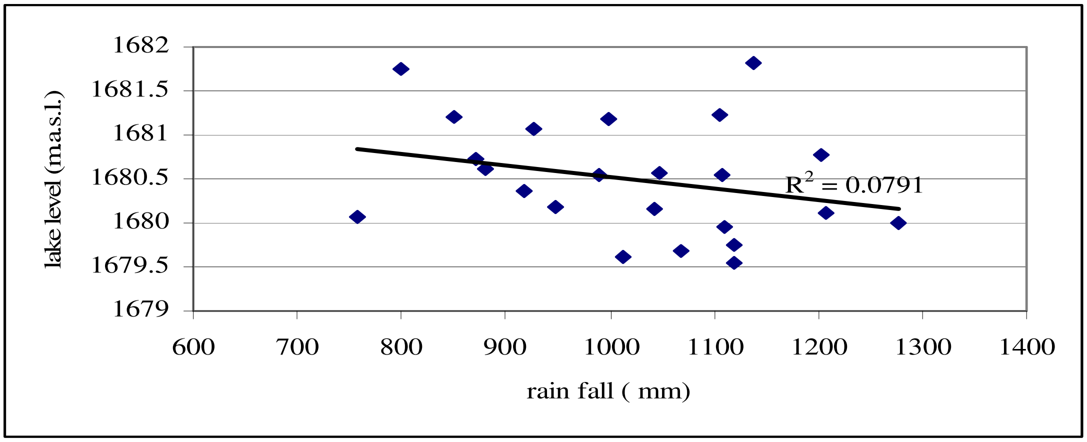

Figure 3.13 Correlation between lake level and average rain fall depth of the catchment

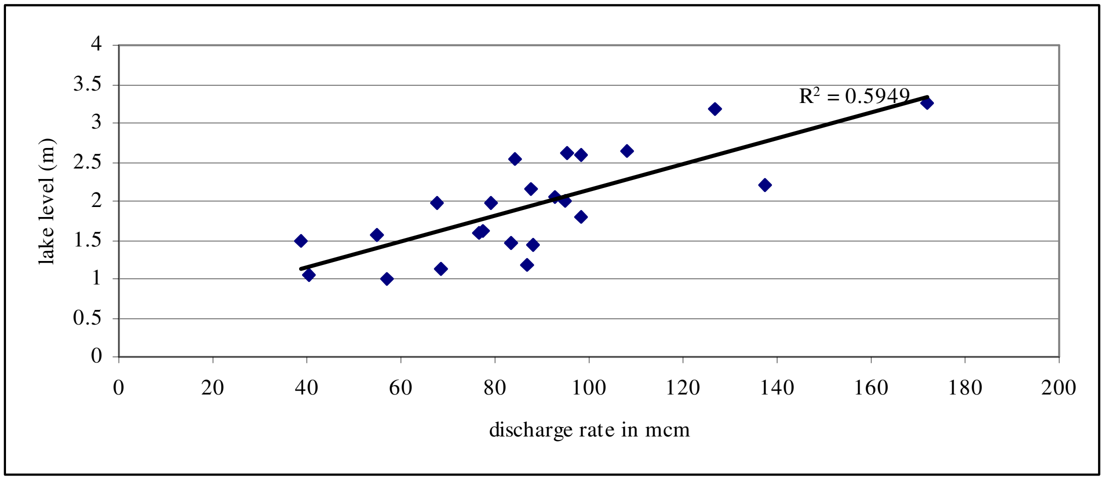

Figure 3.14 Correlation between lake level and Tikurwuha river discharge

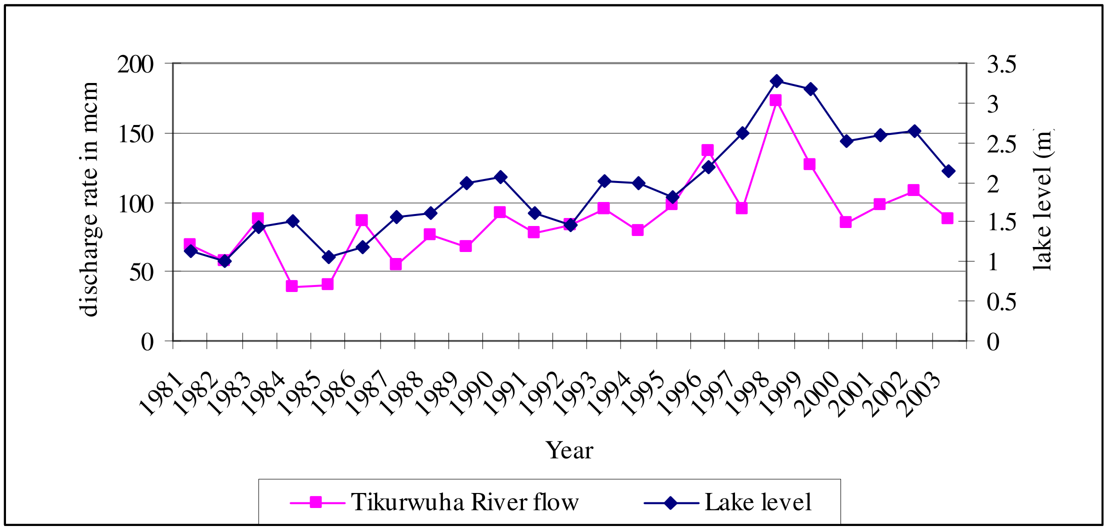

Figure 3.15 long term trend of Awassa lake level and discharge of Tikurwuha River

CHAPTER FOUR

THE AWASSA LAKE WATER BALANCE MODEL

4.1 WATER BALANCE THEORY

The water balance equation for lakes at any time interval is a continuity equation. According to the law of conservation of matter, there is equilibrium between inflow components, outflow components and the change of water volume for each interval of time. This equilibrium is described by the water balance equation (UNSECO, 1974):

$$I_S + I_G + P_L - E_L - O_S - O_G \pm A = \Delta S \text{ ....(1)}$$

Where

$I_{S=}$ Surface inflow into the lake (I_{Sg} and I_{Sug})

I_G = Ground water inflow

P_L = precipitation on the surface of the lake

E_L = evaporation from the lake

O_S = surface out flow from the lake

O_G = Ground water outflow from the lake

± A = Abstraction (agricultural, industrial etc.)

Δ S = change in the water storage in the lake for the balanced period.

Lakes can be divided into two main categories: open (exorheic) lakes with outflow, and closed (endorheic) lakes without outflow. For closed lakes, where the underground flux components (I_G and O_G) don't contribute significantly to the balance, the equation for mean water balance under equilibrium can be written as:

$$I_S + P_{L\,=}\, E_L \text{ ....(2)}$$

However, many studies showed the importance of groundwater flux in estimating water balance of lakes (Winter, 1976a in Tenalem Ayenew, 1998). In this study the components of groundwater flux are considered in the water balance of Lake Awassa. According to Darling et al. (1996) and Telford and Tenalem (1998) the groundwater outflow from lake Awassa is significant compared to the groundwater inflow. Thus the equation can be rewritten as (since there is no significant amount of abstraction from the lake):

$$I_S + P_L - E_L - O_G = \Delta S \text{..............................(3)}$$

In practical application of the equation there are errors involved in the estimates of the various components. If the variables are defined as measured or estimated values (as opposed to true values) these errors may be lumped in a discrepancy term “E”, so that the above equation is rewritten as (UNESCO, 1974):

$$I_S + P_L - E_L - O_G \pm E = \Delta S \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

It must be emphasized that “E” represents the net effect of all component errors and that some may cancel each other. "E" also includes components not taken into account. Thus, a zero or low value of the error term is no assurance that the values of the components are correct. Winter (1981) observed that the component error and the overall error are often neglected in a water balance but they are a general problem in its practical application especially since "water budgets determined by poor methodology without estimates of errors can be very misleading; can give a false sense of security about how well the budget is known; and can lead to considerable waste of lake management and restoration money."

By using the relationship of lake level to volume (as determined by the lake basin morphometry), a lake level change is forecasted by adding the lake storage change calculated by equation 4 to a known lake volume. The following balance equation expresses the forecasting relationship:

$$V_{Initial} + \Delta S_{calculated} = V_{New} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

Equation (5) is the basic equation for a water balance lake level forecast model as each V_{New} becomes the $V_{Initial}$ in each succeeding time interval. Although other models have been used to forecast terminal lake levels, a model based on the water balance is the best method because:

(1) It is conceptually simple and scientifically correct;

(2) Its accuracy is limited only by the accurate development and prediction of the inflows, outflows and errors;

(3) Its results are conditioned by previous lake levels;

(4) It allows the forecast to be short or long term (day, month, and year) as the data permits (James et al., 1979).

4.2 MODEL DEVELOPMENT

Ideally, the water balance forecast model should be developed using a systematic procedure that allows its accuracy and reliability to be evaluated. According to McCuen (1972); cited in UNESCO [1974] and Voster [1985], the general modeling process - formulation, calibration, verification and application are the best guidelines for developing a reliable terminal lake level forecast model (fig 4.1).

4.2.1 Formulation

Water balance formulation is a multi-step process that results in the identification and quantification of the model's components. Thus, the forecast model is formulated through a quantitative assessment of the inflows (precipitation on Lake Surface and runoff - gauged and unguaged), outflows (evaporation and groundwater outflow) and storage changes within the lake. The steps should include the specification of the water balance "free-body," time interval, and base period (Hayes et al., 1980 and Peters, 1972) so that the components are properly identified (Winter, 1981). These steps are outlined below.

4.2.2 The free-body- is defined as the area for which the water balance is derived. An ideal free-body should have a boundary that is fixed over time and whose flows are measurable or easy to estimate across its boundary (Peters, 1972). The Awassa Lake is taken as the free-body for forecast model. Most of the inflow to the lake is surface runoff from the catchment. Thus we have a clear boundary of the lake which facilitates a more accurate delineation and estimation of the water balance components.

4.2.3 The time interval- is the unit of time for a single execution of the water balance equation. Water balances may be computed for any time interval depending on the purpose of the water balance and the availability of data. Forecast models used to specify future operational plans may require a weekly or monthly time interval, while the prediction of long-term trends in the lake surface elevation usually requires only an annual time interval. The shorter time intervals require more detailed accounting of the storage and movement of water and have more precise computational requirements. The choice of the time interval is often determined by the longest time interval required for an accurate estimation of a water balance component. Terminal lake water balances, like Lake Awassa, are most commonly developed using an annual time interval because it is difficult to make accurate estimates of evaporation or groundwater flow (in and out flow) for shorter time spans (UNESCO,1974).

4.2.4 The base period- is the time period, consisting of successive time intervals in the historic record, for which the components are quantified. According to Peters (1972), the base period ideally would:

(a) have wet and dry periods,

(b) minimize changes in storage,

(c) have long, continuous data sets.

Awassa Lake is determined by the availability of reliable measurements of inflows and outflows .The principal inflows to the lake are Tikurwuha River and precipitation which have a relatively consistent data since 1981. The evaporation rate, an outflow component, has relatively good data since 1981. Thus the period from 1981-2003 is selected as base period.

An analysis of the physical and hydrological characteristics of the free-body, combined with the specification of the time interval and base period provides the basis for choosing the components that should be quantified.

Accurate quantification of the water balance components is extremely difficult. It is important, then, to analyze the overall water balance error and to estimate the individual component error, especially since errors in component quantification may not necessarily be reflected in the overall water balance error (due to the canceling effect of component errors). Analysis of the component and overall error should be a fundamental part of model development (UNESCO, 1974; Winter 1981).

The overall error, the sum of the component errors, is called the residual or discrepancy term (UNSECO, 1974). In a lake level forecast model, this is equal to the difference between the simulated lake storage change resulting from the computed inflows and outflows and the actual (calculated) lake storage change that results from the observed lake level change. This can be expressed as:

$$E = \Delta V_S - \Delta V_C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where:

E = overall error

ΔV_S = Simulated storage change

ΔV_C = Calculated storage change

According to UNESCO (1974), the overall error should not exceed the square root of the sum of the square of the error limits of the individual water balance components.
i.e.

$$E \leq \sqrt{e_1^2 + e_2^2 \ldots\ldots + e_n^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Where E equals the overall error and $\mathbf{e_1^2, e_2^2, e_n^2}$ equals error limits of individual components.

4.3 Calibration

In order to make the water balance model operational for the purpose of forecasting it must first be calibrated (Sooroshian, 1983: cited in Voster [1985]). Calibration of a lake level forecast model is the process of logically adjusting the Component model values so that the difference between the calculated and simulated lake storage change is minimized, because the difference is attributable to the overall water balance error.

The model should be calibrated for a portion of the base period that is long enough to contain data considered fairly well representative of the various phenomena the system experiences and that the model intends to simulate (Sooroshian, [1983] as cited in Voster [1985]). Ideally a portion of the base period is excluded from the calibration so that it can be used to verify the model.

4.4 Verification

Verification tests whether or not the calibrated forecast model is an accurate predictor of lake levels. This is done by calculating lake levels for a time period not used in calibrating the model or simply by comparing the difference between the observed and simulated level.

4.5 Application

The forecast model is applied to determine (estimate) past and future lake levels. Hydro-meteorological conditions specified as model input that determine the values of the model components. Assumptions about the rate can be represented as a time series sequence of values that can either be modeled as constant value or values that differ or equal to the base period average.

In the following sections each storage, inflow, and outflow process is examined separately and each quantifiable component is identified separately so that independent determinations of each component's annual value in the 1981 - 2003 base period can be made.

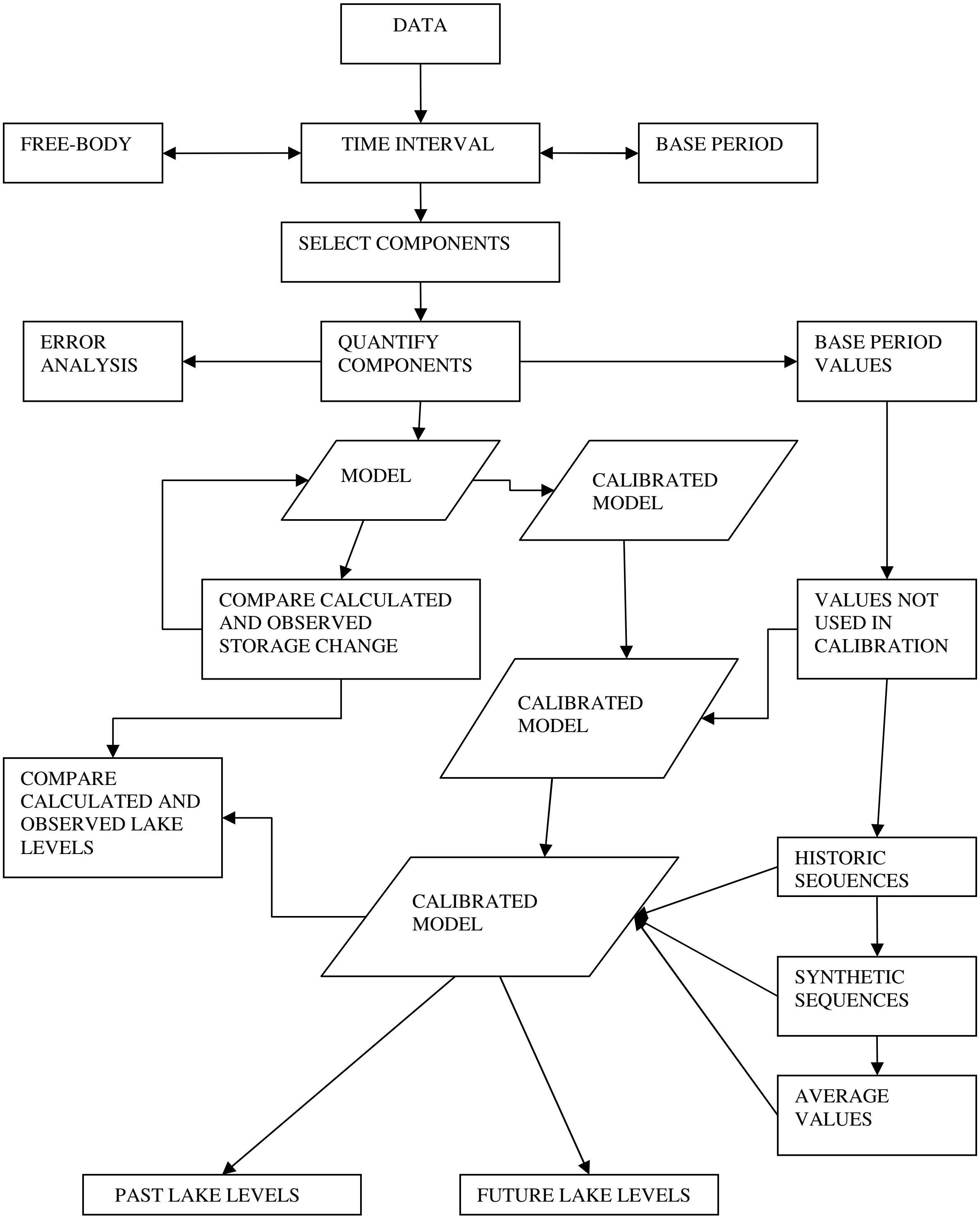

Figure 4.1 flow chart for development of lake level forecast model

4.6 Quantification of Inflow components

4.6.1 Precipitation on Lake Surface

The rainfall station located at Awassa town has been selected due to its influence on the lake thus, the available rainfall record for the period 1981-2003 has been considered for computing the inflow magnitude to the lake. Since the water balance is conducted on the basis of yearly time interval, annual rain fall series have been adopted. The following formula is used for computation:

$$P_L = PPt * A$$

Where:

P_L = precipitation on lake surface (mcm)
PPt = precipitation in mm
A = Mean surface area of the lake in Km^2

4.6.2 Runoff from the unguaged catchments

Discharge from the unguaged catchment is computed using the following analogue methods

i. Selection of river analogue in the Awassa catchment. The only river analogue in the catchment is Tikurwuha River which is gauged at Dato village since 1969. It has a drainage area of 625 km^2 (Zenaw, 2000). The annual rain fall of the drainage area, based on Theissen polygon, is the mean annual rain fall of the four stations namely Awassa, wondogent, Haisawita and shashemane stations.

ii. By Calculating runoff coefficient (K) from the gauged catchment using the following formula

$$K= I_T / A_T * PPt_T$$

Where

K = runoff coefficient
I_T = Annual discharge of Tikurwuha river in mcm
A_T = Drainage area of Tikurwuha river in km^2
PPt_T = Annual precipitation on the area

4.6.3 Guaged Tikurwuha River flow to the lake (I_T)

The flow records of Tikurwuha River from 1981-2003 have been obtained from Ministry of Water Resources, Department of Hydrology and are considered in the water balance computation.

4.6.4 Groundwater inflow

According to W.W.D.S.E, the groundwater inflow to the lake is estimated to be 2 mcm, which is insignificant as compared to the outflow magnitude from the lake to the groundwater system. Therefore, the inflow component is neglected.

4.7 Quantification of Outflow components

4.7.1 Evaporation

The available measured class A pan evaporation has been used in estimating Lake evaporation by applying pan coefficient of the order of 0.8 as discussed in the previous chapter.

Lake evaporation has been computed from the following equation.

$$E_L = E_P * A * C$$

Where:

E_L = Lake evaporation in mcm
E_P = pan evaporation in m
A = mean surface area of the lake in km^2
C = pan coefficient

4.7.2 Groundwater outflow from the lake

Groundwater outflow values from previous studies are used to get a rough estimation. Though no detailed estimates of its outflow have been published, outflow estimation was reported by different researchers using different techniques. According to darling et al(1996), around 50% of the lake volume flows outside the caldera to the east and Northeast based on isotope techniques while Tenalem (1998) estimated about 12.345m3/day on the same direction from groundwater modeling.

According to Telford (1998) cited in Dessie Nadew estimated an outflow of about 7% by volume of the lake to ward lake Shalla using chemical modeling. Based on the report of W.W.D.S.E (2000), groundwater outflow is estimated to be 71.5 mcm/year on average using water balance method. These figures are far from each other signifying the subjectivity of the methods and assumptions used in the analysis. In the present study the water balance method is used to get a rough estimation during the water balance computation.

4.7.3 Lake Abstraction

Lake water abstracted for different purposes from the catchment is assumed to be minimal comparing to the total inflow to the lake. An abstraction of $7.56*10^5$ m3/year from Kedo river Nidaw, (1995) and NAPI, [1994] cited in Yemane (2004); an approximated $9*10^5$ m3/year for Shashemene town water supply from Wosha river, (Nidaw, 1995), has been estimated. Loke cold spring (yielding 20 l/sec), which was entering the lake until it has been diverted to Awassa town water supply in 2001 could be considered as additional abstraction of $6.3*10^5$ m3/year. That means a total of close to $2.286*10^6$ m3/year of water which ultimately would have been reached on the lake could be assumed abstracted. This is almost equivalent to the groundwater inflow to the lake which is not accounted during water balance computation. This is also considered to be negligible in the lake water balance computation.

4.8. Awassa Lake storage change

In this model the annual Lake storage change is the calculated sum of all the inflows, outflows and storage changes in the lake. In order to calibrate the model and use it for forecasting purposes it is required to know the value of the Lake storage change that results from lake level fluctuations.

The amount of water stored in the Lake is a function of the Lake's morphometric characteristics. These characteristics determine the relationship between the lake's stage, area, and volume. For characterization and evaluation of the impact of the lake Awassa level rise, depth-area and depth-volume curves were used on the basis of the lake bathymetry reported by W.W.D.S.E (2000) and presented in table 4.1 and figure 4.2.

Volumes between consecutive contours (depth contours) are completed using the following formula.

$$\Delta S_{A1+A2} = \Delta h \frac{(A_1 + A_2)}{2}$$

Where,

ΔS_{A1+A2} = volume between two consecutive contours with enclosing area A_1 and A_2.

$A_1 + A_2$ = area enclosed by two adjacent contours 1 and 2.

Δh = contour interval (the distance between two adjacent contours).

Values of Area - Capacity Curves of Lake Awasa

(As computed from bathymetry survey report of W.W.S.D.E)

ELEVATION	**AREA**	**CUM.VOL**
(m a s l)	(km^2)	(MCM)
1662	6.322	157.528
1664	21.392	185.242
1666	35.538	242.172
1668	45.766	323.477
1670	54.389	423.632
1672	62.805	540.825
1674	71.681	675.311
1676	79.183	826.176
1678	86.529	991.888
1680	92.547	1170.964
1682	100.324	1363.835

Table 4.1 Values of Area - Capacity Curves of Lake Awasa

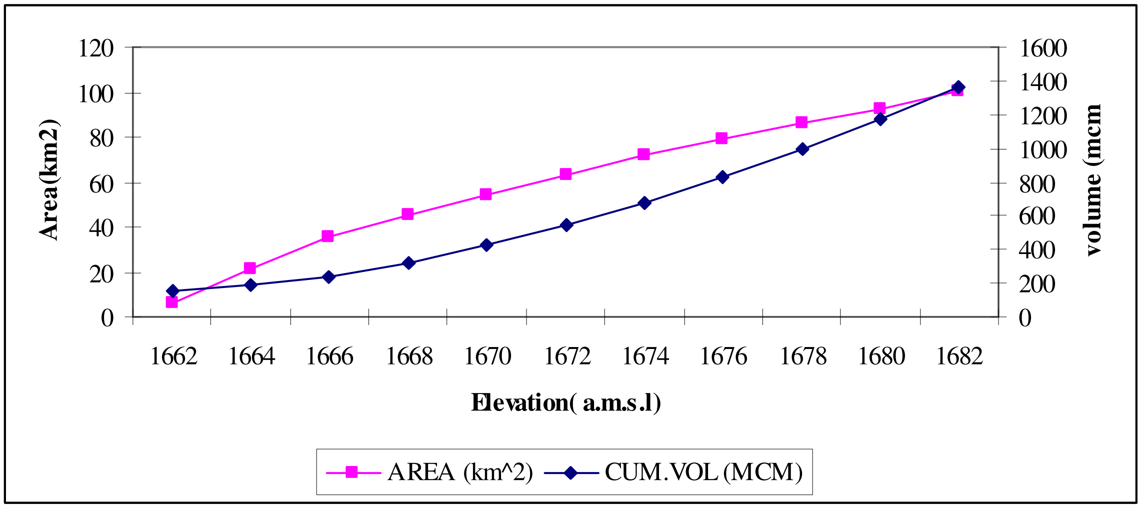

Figure 4.2 Area- capacity curves of Lake Awassa (adopted from WWDSE,2000)

The Components of Lake Water Balance are provided in the following tables and figures.

Table 4.2 **Lake Water balance components**

YEAR	Average Area (km2)	Tikur wuha river flow (mcm)	Runoff unguaged (mcm)	R.F on Lake (mcm)	Ground water outflow (mcm)	Lake Evaporation (mcm)	Simulated Storage change (mcm)
1981	92.00	68.613	62.59	95.73	89.12	148	10.2
1982	92.00	56.875	51.9	94.65	79.56	143.37	-19.505
1983	93.00	88.147	78.73	107.9	95.25	146.12	33.407
1984	93.00	38.869	35.42	67.37	19.36	140.43	-18.131
1985	91.00	40.466	36.52	82.03	49.21	158.61	-48.804
1986	92.00	86.683	80.55	109.67	105	154.56	17.343
1987	93.00	54.731	50.49	89.15	22.54	169.48	2.351
1988	94.00	76.574	71.32	89.95	25	169.74	43.104
1989	95.00	67.78	61.44	95.97	26.65	158.52	40.02
1990	94.00	92.623	83.06	71.12	81.35	158.86	6.593
1991	93.00	77.435	67.62	80.62	140	150.31	-64.635
1992	93.00	83.324	72.17	89.46	160	156.5	-71.546
1993	95.00	94.7	86.74	88.19	68	166.84	34.79
1994	95.00	79.265	68.29	81.84	41.23	178.12	10.045
1995	94.00	98.12	88.68	94.41	80	164.1	37.11
1996	96.00	137.26	125.89	114.15	144.26	129.79	103.25
1997	98.00	95.245	93.78	103.3	76.254	142.43	73.641
1998	100.00	172	159.09	114.83	168.25	132.86	144.81
1999	100.00	126.735	111.72	80.89	149.32	144.04	25.985
2000	94.00	84.184	76.46	77.22	169.12	136.08	-67.336
2001	94.00	98.421	86.43	96.03	160	121.88	-0.999
2002	93.00	107.894	96.347	87.76	175.69	126.58	-10.269
2003	93.00	87.54	92.24	73.59	169.26	129.67	-45.56
Mean	94.00	87.5428	79.8903	90.6883	99.7576	145.92	12.443348

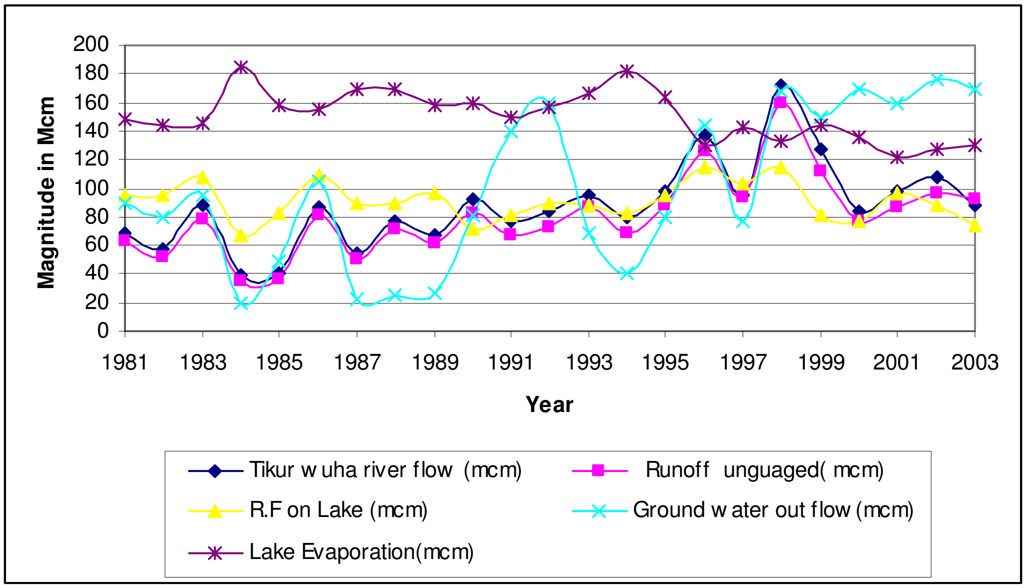

Figure 4.3 Lake Water Balance Components

Table 4.3 Simulated and Calculated storage change

YEAR	observed (Δh)	Average Area(km^2)	calculated Storage change (mcm)	Simulated Storage Change, (mcm)	simulated level (Δh) in meter	Difference (overall error)
1981	-0.47	92.00	-43.861	-10.2	0.11	33.6
1982	-0.14	92.00	-12.95	-19.505	-0.21	-6.56
1983	0.43	93.00	40.579	33.407	0.359	-7.17
1984	0.06	93.00	6.079	-18.131	-0.19	-24.21
1985	-0.44	91.00	-41.01	-48.804	-0.53	-7.79
1986	0.129	92.00	11.95	17.343	0.187	5.39
1987	0.372	93.00	34.84	2.351	0.025	-32.49
1988	0.04	94.00	4.59	43.104	0.456	38.51
1989	0.38	95.00	36.49	40.02	0.423	3.53
1990	0.076	94.00	7.10	6.593	0.07	-0.51
1991	-0.44	93.00	-41.71	-64.635	-0.695	-22.92
1992	-0.16	93.00	-15.20	-71.546	-0.761	-56.34
1993	0.55	95.00	52.26	34.79	0.3662	-17.47
1994	-0.02	95.00	-2.40	10.045	0.1062	12.45
1995	-0.169	94.00	-16.13	37.11	0.3906	53.24
1996	0.394	96.00	38.27	103.25	1.0644	64.98
1997	0.41	98.00	40.84	73.641	0.7438	32.80
1998	0.64	100.00	64.76	144.81	1.4481	80.04
1999	-0.08	100.00	-7.88	25.985	0.2678	33.87
2000	-0.65	94.00	-61.57	-67.336	-0.716	-5.76
2001	0.05	94.00	5.53	-0.999	-0.010	-6.53
2002	0.06	93.00	5.66	-10.269	-0.110	-15.93

2003	-0.49	93.00	-23.20	-45.56	-0.979	-22.35

Table 4.4 Comparison of Simulated and Observed lake level (uncalibrated)

Year	**Simulated level**	**Observed level**	**Difference**
1981	1.909272	1.13625	0.773022
1982	1.698407	0.99625	0.702157
1983	2.057622	1.432583	0.625039
1984	1.860546	1.498667	0.361879
1985	1.327169	1.050417	0.276752
1986	1.514661	1.179667	0.334994
1987	1.539805	1.552333	-0.01253
1988	1.995932	1.600917	0.395015
1989	2.419424	1.987083	0.432341
1990	2.489937	2.063083	0.426854
1991	1.794937	1.614583	0.180354
1992	1.03381	1.4528	-0.41899
1993	1.40002	2.002917	-0.6029
1994	1.506317	1.977417	-0.4711
1995	1.896948	1.807583	0.089365
1996	2.961381	2.202167	0.759215
1997	3.70523	2.61475	1.09048
1998	5.15333	3.262417	1.890913
1999	5.421216	3.181167	2.24005
2000	4.704876	2.526125	2.178751
2001	4.694191	2.585333	2.108858
2002	4.583772	2.64625	1.937522
2003	3.603987	2.147143	1.456844
Mean	**2.66403**	**1.93556**	**0.72847**
STDEV	**1.38482**	**0.64391**	

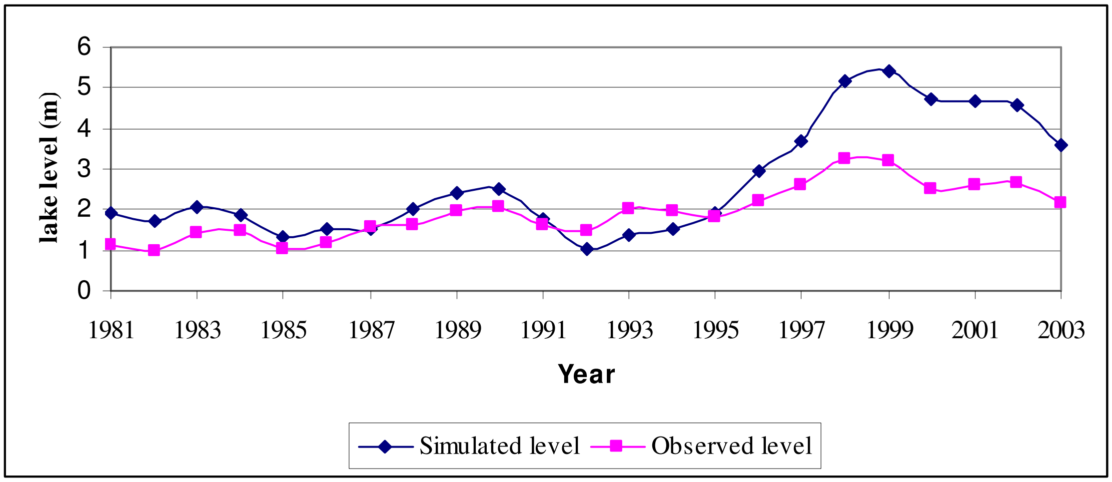

Figure 4.4 Simulated and observed lake level (uncalibrated model)

4.9 ERROR ANALYSIS

The quantification of the component values in the preceding sections involve measurements, approximations, regionalization, and assumptions that result in random and systematic error. Random error results from the measurements and estimates of the basic data and the regionalization of it to larger areas, for example, the precipitation/runoff relationship, or the evaporation estimates. Both systematic and random errors also occur as the result of the assumptions used to derive the component values (Ferguson et al., 1981). If the systematic error could be estimated with any certainty the component value would accordingly be adjusted. The random error of water balance components has been estimated in research studies that assume the true value is quantifiable. Based on a review of these studies, Winter (1981), Peters (1972), and Ferguson et al. (1981) suggest the random error magnitudes that are given in Table 2.5.

The largest percentage error is assumed for components which have little or no basic data or are difficult to estimate and smaller percentage is assumed for gauged since the error is measurement. Errors assumed for evaporation and precipitation are based measurement and instrumental error. These error ranges are used as a guide to estimate the magnitude of the random error for the components of the water balance.

Appendix I- gives the estimated error range in percentages and translates into their respective Mcm quantities. The large percentage error of most components translates into relatively small differences in the total inflow or outflow, but the uncertainty in estimating the groundwater outflow and runoff contributes more error in the water balance computation.

The maximum relative error to inflow is 18% and relative to outflow is 26%. But, in practice the researchers have the problem of deciding whether an observed error is acceptable or not.

A recommended criterion, according to UNESCO (1974) is that the overall error should not exceed the square root of the sum of the squared component error of the water balance.

Table 4.5 Range of Random Error in Estimating Water Balance Components

Component	**Error Range** **-+ Percent**	**Source**
Gaged Stream Flow	5	Ferguson et al. 1981
Ungaged Runoff	10-200	Peters 1972,
	70	Winter 1981
Precipitation		
-Annual. Volume	5-30	Peters 1972
	10-20[1]	Ferguson et al. 1981
Evaporation		
-Annual Volume	10-20[1]	Ferguson et al. 1981
-Annual Rate Using Pan	10-20	Kohler pers. comm. 1983
Groundwater Storage Change	5-40	Peters 1972

[1] Assumes well-instrumented lake basin

4.10. CALIBRATION

Before the water balance model can be applied to forecasting Awassa lake levels it must be calibrated and verified. Calibration adjusts the model in order to minimize the difference between the calculated storage change and the simulated storage change. Since this difference is equivalent to the overall error, calibration can also be viewed as "explaining" the overall error so that it can be logically predicted.

Much of the overall error is predictable because it is the result of systematic component error. If that portion can be correlated with the factors that cause or explain the systematic component error, then most of the overall error can be predicted. The simplest technique for discerning correlation among several variables is multiple linear regressions. Multiple regression is one of the few numerical methods that can be used to evaluate the effects of several factors acting simultaneously on a dependent variable. This is a well established technique for predictive purposes in hydrologic investigations. It is generally agreed that multiple regression is preferable if prediction of the dependent variable (in this case the overall error) with minimum error is the desired result (Julian et al., 1967).

4.10.1 PROCEDURE

The calibration procedure used in this model involves determining the linear relationship between the overall error (the dependent variable) and the "explaining" factors (the independent variables). A stepwise multiple linear regressions, from the Statistical Package for the Social Sciences (SPSS) are utilized for the data analysis. In the stepwise procedure the independent variables are added in "steps" which will, in combination with those variables previously included, effect the greatest reduction in the unexplained variance of the dependent variable in a single step (Julian et al., 1967).

It is important to use only a portion of the 23-year base period for calibration period because some data are needed for verification. The minimum number of years considered for a calibration time period is 12 years, close to half of the base period. After examining a number of possible calibrations time periods, the 1992 - 03 periods is chosen for the following reasons:

1) It is a period whose average error and standard deviation are closest to the average error and standard deviation of the base period;

2) It displays the widest range of hydro-climatic conditions (i.e. runoff, precipitation, evaporation), and high lake level changes during observation period.

The selected 1992-03 period fails to calibrate the model, because multiple regressions explain the variance and not the magnitude of the dependent variable. Therefore, all the factors that might cause or correlate to systematic component error which explain the variance of the overall error are initially included which means the whole period is entered for calibration. The factors and the component error they explain are shown in the table below.

Table 4.6 Factors that May Reflect Systematic Component Error

Factor	SPSS Abbreviation	Component Error Explained
Annual River flow	TKURR	Gauged Tikurwuha flow
Unguaged runoff	RNOFF	unguaged runoff to lake
Annual Rain fall	PPTL	Rain fall on Lake Surface
Groundwater outflow	GWo	Groundwater outflow from lake
Annual Evaporation	EVAPL	Evaporation from lake
OVER all Error	DCERR	Difference between observed and simulated storage change

Table 4.7 Stepwise regression of independent variables with the dependent one.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Step 1	.62(a)	0.39	0.36	26.5

a Predictors: (Constant), TKURR

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Step2	0.63	0.4	0.34	27

a Predictors: (Constant), RNOFF, TIKUR

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Step3	0.68(a)	0.47	0.38	26

a Predictors: (Constant), PPTL, TIKUR, RUNOFF

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Step 4	0.79(a)	0.63	0.55	22

a Predictors: (Constant), GWo, PPTL, RUNOFF, TIKUR

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Step 5	0.80(a)	0.646	0.55	22

a Predictors: (Constant), EVAPL, PPTL, GWo, RUNOFF, TIKUR

As shown in the above table, all are regressed in stepwise addition against the overall error. The purpose is to show the effect of the variables in changing the multiple R and adjusted R^2. The GWo and EVAPL variables show a good correlation with the overall error, meaning that a good percentage of the overall error is explained by the variation of these factors. The importance of these factors in explaining the larger magnitude error is emphasized by the significantly improved R square results, in which the factors GWo and EVAPL are changes the R^2 from 0.68 to 0.8 (table 4.7). These factors are related to the components with the greatest magnitude error and thus by extension to the magnitude of the overall error. These results are consistent with physical reasoning due to the difficulties in estimating groundwater storage change and uncertainties in annual evaporation data derived from pan measurements. This is because pans do not have significant heat storage, and thus measurements of evaporation would vary more than the actual evaporation from a nearby lake. Annual evaporation derived from these measurements would likely be systematically too high during years of high evaporation, and too low during years of low evaporation (Julian et al. 1967).

Thus, the regression step (5) is chosen for calibration because it has good correlation (R square) and relatively minimum standard error. The step (5) regression coefficients are shown in the table below.

Table 4.8 Multiple regression statistics for the period 1981-2003 five factor equation

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-11.6	91.7	-	-0.12	0.9
TIKUR	0.58	1.3	0.52	0.44	0.6
PPTL	0.36	0.43	0.14	0.83	0.41
GWo	-0.43	.166	-.7	-2.6	.01
EVAPL	-0.42	0.48	-.19	-0.88	0.39
RUNOFF	0.49	1.38	0.4	0.35	0.7

The equation that results from regression of the variables with overall error is:

$$E= TIKUR*1.3- RNOFF* 0.49 + PPTL*0.36 - Gwo *0.43 - EVAPL*0.42 -11.6 \text{........}11$$

Where E = Error, TIKUR= Tikurwuha River flow RNOFF= runoff value and EVAPL= lake evaporation, PPTL= precipitation on lake surface and GWo= groundwater outflow

The relevant statistics for the equation are shown in Table 4.8.

When "E" in equation (4) in chapter 4, is replaced by the above equation, and the appropriate inflows, outflows, and storage changes quantified in the formulated model are inserted, the resulting equation that will calculate storage changes for any given data set is:

$$\Delta S = I_S + P_L - E_L - O_G \pm E \text{ ....}(4)$$

$$\Delta S = I_S \text{ (gauged and unguaged) } + P_L - E_L - O_G - (TIKUR*1.3+ RNOFF* 0.49 + PPTL*0.36 +Gwo *0.43 + EVAPL*0.42 -11.6) \text{..........}12$$

Equation (11) calibrates the model. Equation (12) is thus a calibrated water balance model for the Awassa Lake. The figure 4.4 shows a comparison of the observed lake level with the simulated lake level using the calibrated model. Similar trend between the observed and simulated lake level has been achieved for the simulation period. But there are still errors incorporated in the simulated storage change from which the simulated lake level is calculated. Thus, further adjustment has been done to achieve the best fit. ARIMA model fit from SPSS package is utilized to bring down the errors incorporated in the groundwater outflow and lake storage change. The new model fit for the storage change then regressed against the independent variables to obtain an error equation (13). The relevant statistics for the following equation are listed in the table 4.9.

E= TIKUR*0.51+ RNOFF* 0.44 + PPTL*0.51 –Gwo *0.36 - EVAPL*0.36 -30.4........13

Where E = Error, TIKUR= Tikurwuha River flow RNOFF= runoff value and EVAPL= lake evaporation, PPTL= precipitation on lake surface and GWo= groundwater outflow

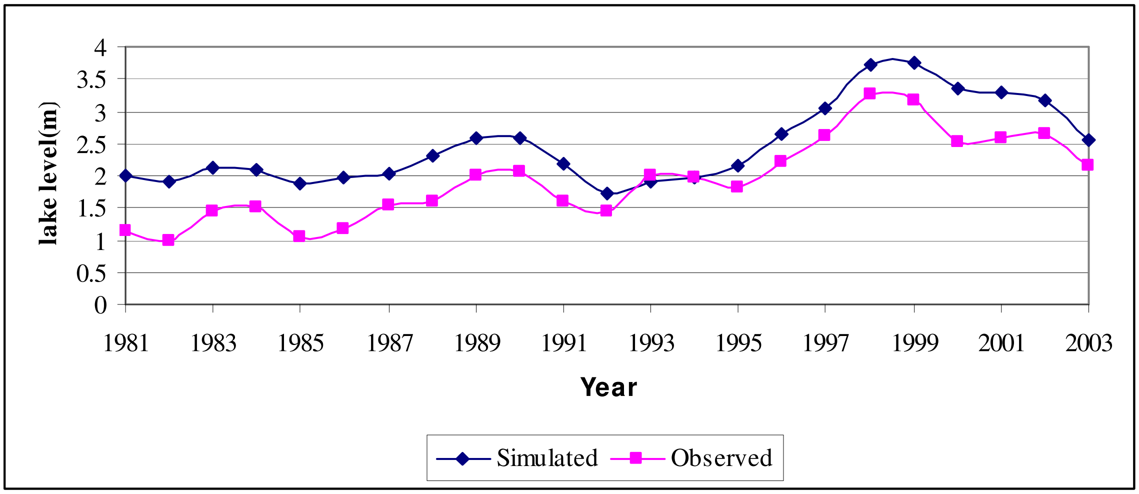

Figure 4.5 Comparison of observed and simulated lake level using the first calibrated model

Table 4.9 multiple regression statistics for ARIMA model fit

Model	Un standardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-30.4	12.7	-	-2.3	0.02
RUNOFF	0.44	0.19	-.47	2.3	0.03

EVAPL	-0.36	0.06	-.21	-5.5	0.00
TIKUR	0.51	0.18	0.55	2.8	0.01
GWo	-036	0.02	-0.76	-16.2	.000
PPTL	051	0.06	0.26	.899	.000

When "E" in equation (4) in chapter 4, is replaced by the equation (13), and the appropriate inflows, outflows, and storage changes quantified in the formulated model are inserted, the resulting equation that will calculate storage changes for any given data set is:

$$\Delta\ S = I_S\ \text{(gauged and unguaged)}\ + P_L - E_L - O_G\ - (\text{TIKUR}*0.51 + \text{RNOFF}*\ 0.44 + \text{PPTL}*0.51 - \text{Gwo}\ *0.36 - \text{EVAPL}*0.36 - 30)........14$$

Equation (14) is thus an optimized and calibrated water balance model for the Awassa Lake. The lake level calculated using equation (14) is depicted in the figure below and listed in the table 4.10.

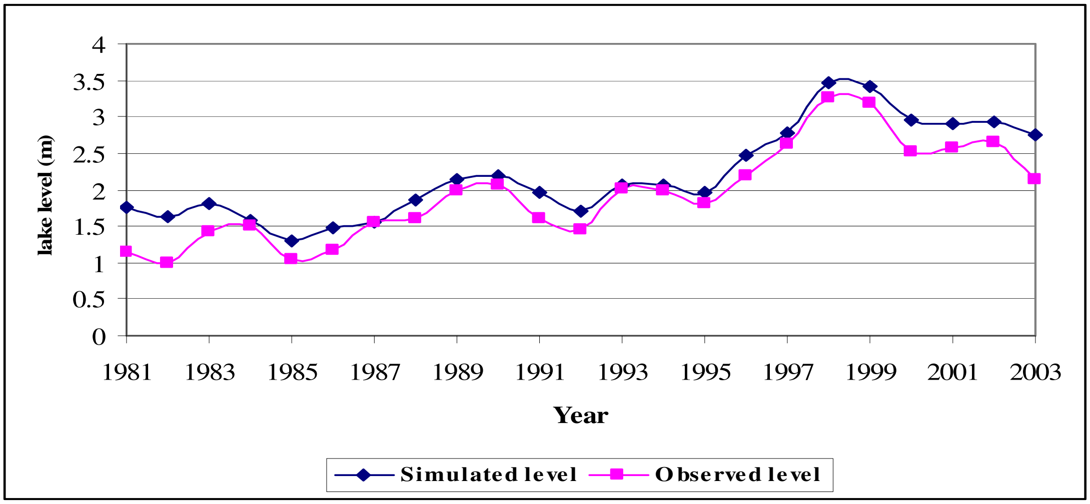

Figure 4.6 Comparison of observed and simulated lake level using the optimized and calibrated Model

4.11 VERIFICATION

In the verification phase the calibrated water balance model is used to calculate lake levels in the 1981 -03 periods. The lake levels can be calculated sequentially, i.e. the calculated lake level at the end of one water year becomes the initial lake level at the beginning of the next water year, or the lake levels can be calculated separately year-to-year, i.e. the observed lake level is always used as the initial lake level. The simulated lake levels using the uncalibrated and calibrated model are compared separately with the observed lake levels for the 1981-03 period.

Table 4.4 shows that the simulated lake level deviates more than the observed lake level using the uncalibrated model than the calibrated model (table 4.10). The average difference between the annual simulated lake level change and the annual observed lake level change is 0.3m when the lake levels are calculated sequentially with the calibrated model and 0.7m when calculated with the uncalibrated model. Although no absolute standards exist for determining the adequacy of the calibration or verification results, one test would be to compare the standard deviation and average annual difference between the observed and simulated lake level as shown in the (fig 4.6) or to take R^2 as a measure of good fitness (Julian et al. 1967). Though the second calibrated model with $R^2 = 0.87$ is taken for its better fitness during verification. The verification thus confirms that a calibrated model is a somewhat more accurate predictor of lake levels than an uncalibrated model.

Table 4.10 Comparison of observed and simulated lake level using the optimized and calibrated model

Year	**Simulated level**	**Observed level**	**Differnce**
1981	1.7628095	1.13625	0.626559
1982	1.6347495	0.99625	0.638499
1983	1.8157713	1.43258333	0.383188
1984	1.5746529	1.49866667	0.075986
1985	1.2988479	1.05041667	0.248431
1986	1.4696865	1.17966667	0.29002
1987	1.5606907	1.55233333	0.008357
1988	1.8559537	1.60091667	0.255037
1989	2.1430976	1.98708333	0.156014
1990	2.1860203	2.06308333	0.122937
1991	1.9679101	1.61458333	0.353327
1992	1.7117331	1.4528	0.258933
1993	2.0655531	2.00291667	0.062636
1994	2.0616065	1.97741667	0.08419
1995	1.956096	1.80758333	0.148513
1996	2.4643156	2.20216667	0.262149
1997	2.7880393	2.61475	0.173289
1998	3.4673063	3.26241667	0.20489
1999	3.4086862	3.18116667	0.22752
2000	2.9573837	2.526125	0.431259

2001	2.8961921	2.58533333	0.310859
2002	2.9371983	2.64625	0.290948
2003	2.7515244	2.14714286	0.604381
Mean	**2.205905**	**1.9355609**	**0.27034**
STDEV	**0.628926**	**0.6439125**	

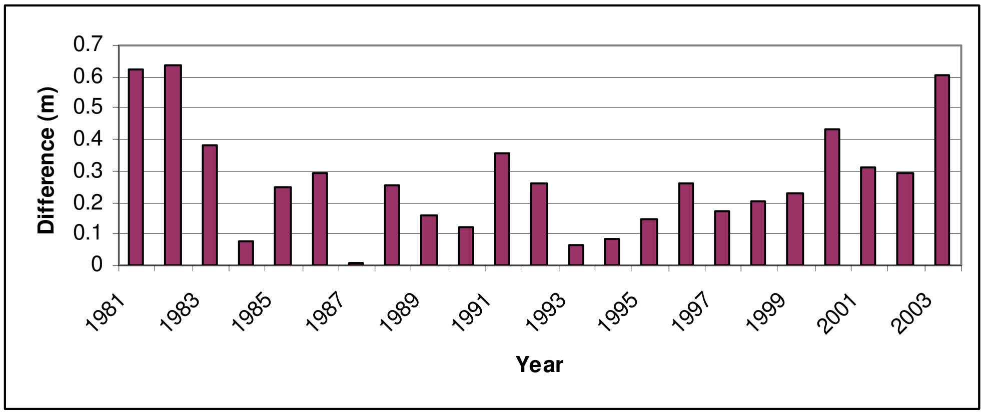

Figure 4.7 Absolute difference of the simulated level from the observed

4.12. Sensitivity

Many assumptions and estimates are used in the formulation and construction of the model. To test the response of the calibrated model to a range of values for various input parameter, a sensitivity analysis is done. Sensitivity analysis can help determine which model parameters have the greatest effect on a model. Results of the analysis can guide future data collection efforts that will reduce model errors. It is done by varying the values of one input parameter while keeping all others constant.

A simple sensitivity analysis has been made to all variables by adding a 10% increase from their base period average values. Results of the sensitivity analysis show that small errors in estimating values of the runoff and evaporation causes the model to be more sensitive. However, the model is moderately sensitive to groundwater outflow.

4.13 Model Limitations

The formulated model of the Lake Awassa provides a simulation of lake level for the past 23 years. The formulated model is a simplification of the “real world”, which is the case of all water balance models, and has corresponding limitations in model precision and how the model can be used for future applications. As a result errors are generated due in accuracy of input data. For example, missing values of evaporation and precipitation rates are filled by comparing and calculating with neighboring stations. In addition, model uncertainty could also stem from random error in optimizing the groundwater outflow during model calibration. Thus, limitations of the model should be taken into account when applying the model to water resources management.

CHAPTER FIVE

APPLICATION OF THE WATER BALANCE MODEL

In this chapter the calibrated and verified model, is used to forecast the lake level with error margin obtained using different assumptions. The basic assumption in each one is that the hydro-climatic conditions (i.e. the rate of runoff, precipitation, and evaporation) of the 1981- 2003 base period will occur in the future.

The following assumptions are common to each forecast application. The unique assumptions within each application will be presented separately.

Assumptions

1. Initial lake level change is 1.86m in December 30, 2004, obtained from MoR, Department of hydrology.
2. The average lake area is 94km^2.
3. Abstraction from the lake and groundwater inflow is assumed to be insignificant.
4. The current condition of land use/cover change will continue in the future.

5.1 Model Applications and Results

APPLICATION 1: Future lake levels using the sequence of 1981-2003 hydro-climatic sequences with the 1989-2003 conditions occurring first.

The purpose of this application is to calculate the response of lake to annually varying hydro climatic conditions. The assumption is based on the lake level trend which shows a lake level rise of 1.3m on average from 1981-1988 but it dramatically increases on average of 2.3m starting from 1989-2003. Instead of using the sequence of 1981-2003 conditions in the order that they actually occurred, the sequences are rearranged so that the 1989-2003 conditions occur first, followed by the 1981-1988 conditions.

APPLICATION 1A: In this application the total average runoff values from 1989-2003 will be used instead of the average values from 1981-1988 in the first nine years of forecast (the average total runoff is 191mcm from 1989-2003). Other components will remain the same as they actually occurred. The purpose is to show the effect of runoff in the lake level rise.

APPLICATION 1B: In this application the evaporation values from 1989-2003 will be used instead of the average values from 1981-1988 in the first nine years of forecast (the average lake evaporation is 146mcm from 1989-2003). Other components will remain the same as they actually occurred. The purpose is to show the effect of lake evaporation in the lake level changes.

Results: Plotting the result of application 1A and 1B (Fig 5.1), shows that after nine years the lake levels differ by 3.0m then fluctuates and reaches 5m by 2027. Recall, the assumption used, that an increase by 64% in runoff values causes the lake level to increase by 3m, but with original values the level increases by 0.8m which means the role of runoff during lake level rise was significant. But the result of application 1B shows minor changes in lake level. This clearly indicates that the role of evaporation alone can't make significant change in lake level fluctuations.

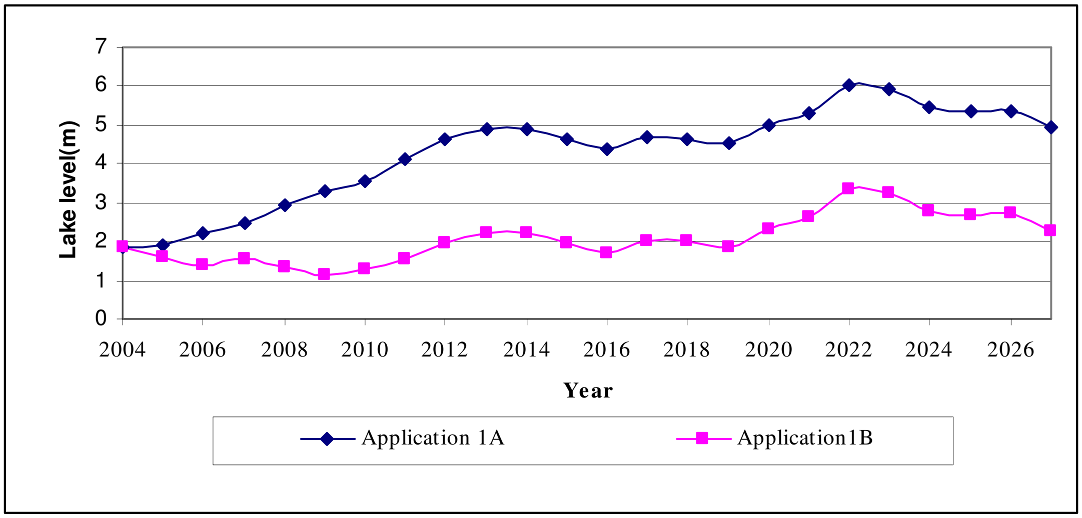

Figure 5.1 Lake level fluctuations using application one

APPLICATION 2: Future lake levels using the sequence of 1981-2003 hydro-climatic sequences with the 1996-2003 conditions occurring first.

The purpose of this application is to calculate the response of lake to annually varying evaporation values. The assumption is based on the value of lake evaporation which shows a 30% decrease from 1996. Thus, the values from 1996-2003 will be used instead of the original values from 1981-1995 and vice versa. Other components (outflow and inflow) will remain the same as they actually occurred.

Result: The result is almost the same with the application 1B, which confirms that the role of evaporation during the lake level fluctuation is insignificant comparing to the total inflow.

This can be checked by looking at the figure 5.2, which shows a decrease trend starting from 2022 which is the cumulative effect of evaporation and groundwater outflow.

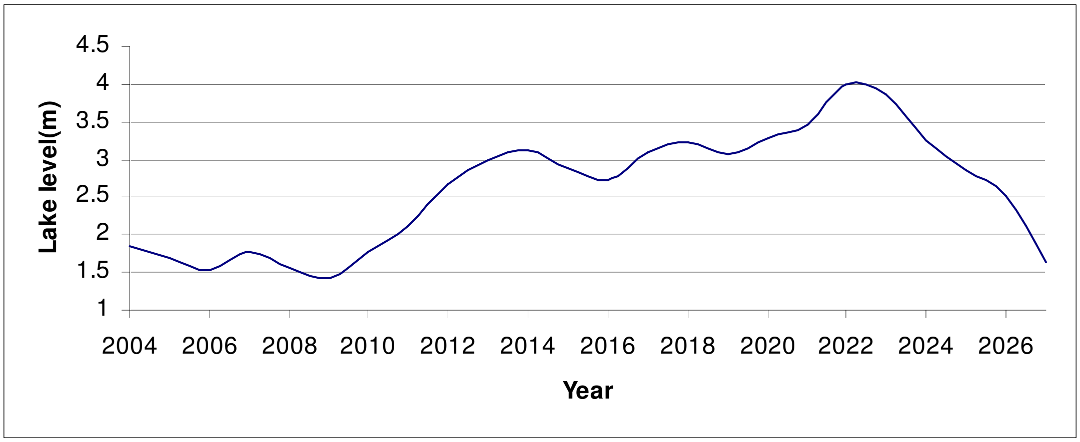

Figure 5.2 Lake level fluctuations using application two (2004-2027)

APPLICATION 3: Future lake levels using the 1981-2003 average hydro-climatic conditions in each year of the forecast.

The purpose this application is to show the response of the lake if the averages of the 1981-2003 conditions are projected into the future.

APPLICATION 3A: In this application the total runoff and rain fall on the surface of the lake are set equal to their base period average in each year of the forecast (the average total runoff, gauged and unguaged, and precipitation are 167mcm and 90mcm, respectively from 1981-2003).

APPLICATION 3B: In this application the evaporation and groundwater outflow are set equal to their base period average in each year of the forecast (the average lake evaporation and groundwater outflow are 148mcm and 97.5 mcm, respectively from 1981-2003).

APPLICATION 3C: In this application the components of the water balance are set equal to their base period average**.**

Results: In application 3A, the level shows an increase of 2.2m up to 2018 in which it reaches 4.0m (fig 5.4). After 2018 the level decreases and reaches 2m by the end of 2027. This is because of the groundwater outflow increment in those years which causes the level to decrease.

In application 3B, the forecasted level shows a decreasing trend which attains a negative value from 2013 to 2019 then starts to increase until 2027. Based on this application the lake will be empty between 2013 and 2019. This is very far from reality because the assumption is very rare to happen in nature. However, the application is useful for analyzing the response of the lake to extreme hydro-climatic conditions.

The result of application 3C is purely deterministic, i.e. for the given input (as determined by the assumption) the lake will respond as calculated. As a result the level increases annually by 0.04 meter. Plotting the results of 3A, 3B and 3C together gives a good picture how the lake level respond to average inflows and outflows components.

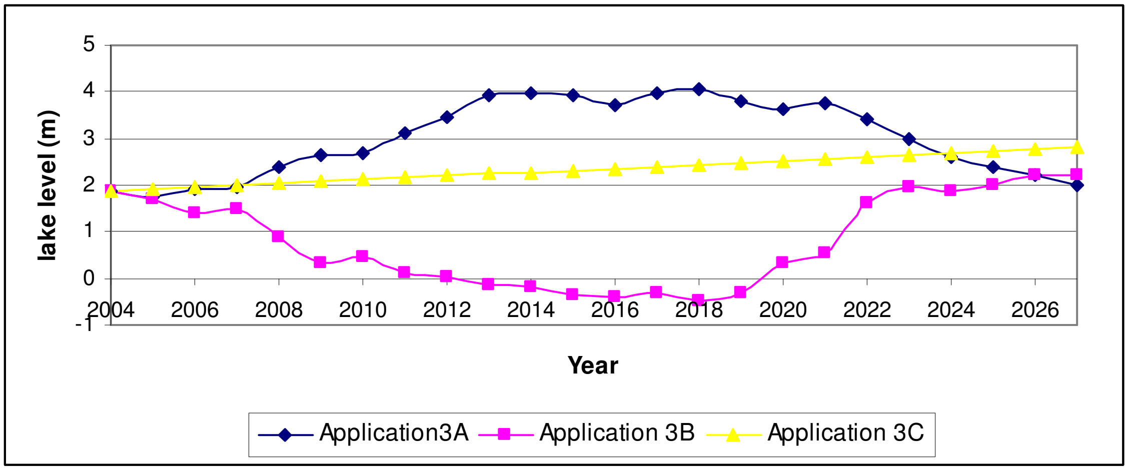

Figure 5.3 Lake level fluctuations using application three (2004-2027)

APPLICATION 4: Future lake levels using the 1981-2003 average precipitation rate of the catchment for years that have low rain fall relatively to others.

The purpose of the application is to show the response of the lake to annually varying precipitation rate in the catchment. The assumption here is to replace the low Rain fall years (1984, 1990, 1991, 1995, 1999, 2000, 2002, and 2003) by their base period average. Thus, the amount of precipitation on the surface of the lake and runoff from unguaged catchment will be changed since these components are calculated based on the amount of precipitation in the catchment.

Result: The output of this application is almost the same with the simulated lake level since the changes in the runoff and precipitation is small (fig 5.4).

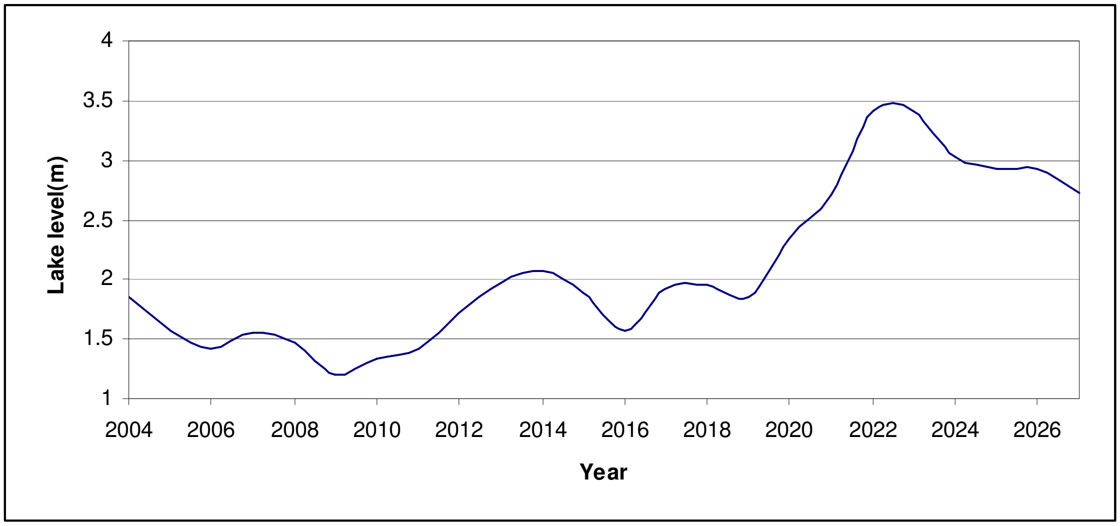

Figure 5.4 Lake level fluctuations using application four (2004-2027)

5.2 Discussion on model results

Forecasting water level of a lake requires a scenario approach for taking a long wide view that controls futures with fundamentally different hydro-climatic assumptions. The assumptions made previous are useful in understanding the effect of different elements that affect the lake level. The results of the assumption are discussed below by taking R^2 as measure of good prediction of the regression model.

Discussion on Application 1: The result of the analysis revealed that replacing the runoff of the initial sequences by the average wet years causes the lake level to reach 5 meter by 2027. One method for evaluating the result of the assumption is to compare the association of the observed and iterated Tikurwuha river discharge with their corresponding lake level.

As shown in the figure 5.5, the iterated discharge of the river and projected lake level correlate positively with $R^2 = 0.43$. This is almost the same with the correlation, $R^2= 0.56$ made between the measured Tikurwuha river and observed lake level for the period of 1981-2003. The correlation is between the range of (0.4-0.5); indicating that the model application has captured the pattern of the historical record. This pattern can also be checked by regressing the observed lake level plus the forecasted lake level and also the simulated plus the forecasted lake level. The result shows the observed and simulated correlate positively with $R^2= 0.9$ and $R^2=0.7$, respectively (fig 5.6 and 5.7).

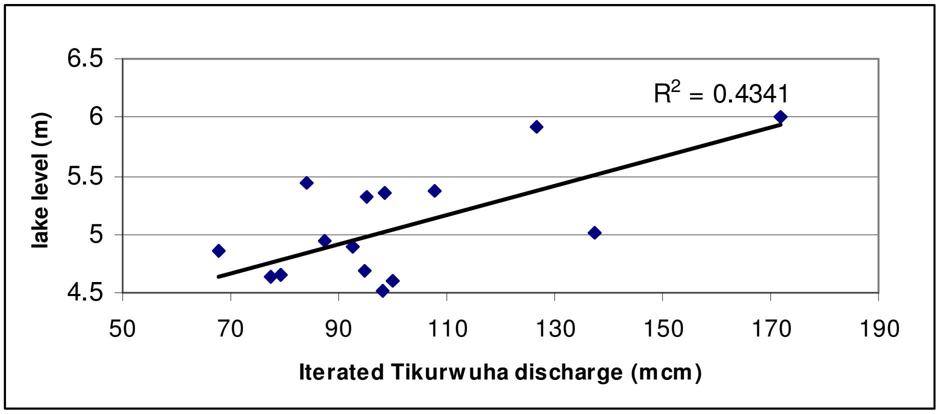

Figure 5.5 Correlation between the iterated Tikurwuha river discharge with forecasted lake level

The result of assumption 1B shows minor change in the forecasted lake level. As shown in the figure 5.6 and 5.7, the observed and forecasted lake level shows similar trend with R square 0.24 while the simulated resulted a coefficient of 0.12. Generally the assumptions show the effect of runoff and evaporation in lake level fluctuation. Thus application one could be taken as a good predicator of lake level.

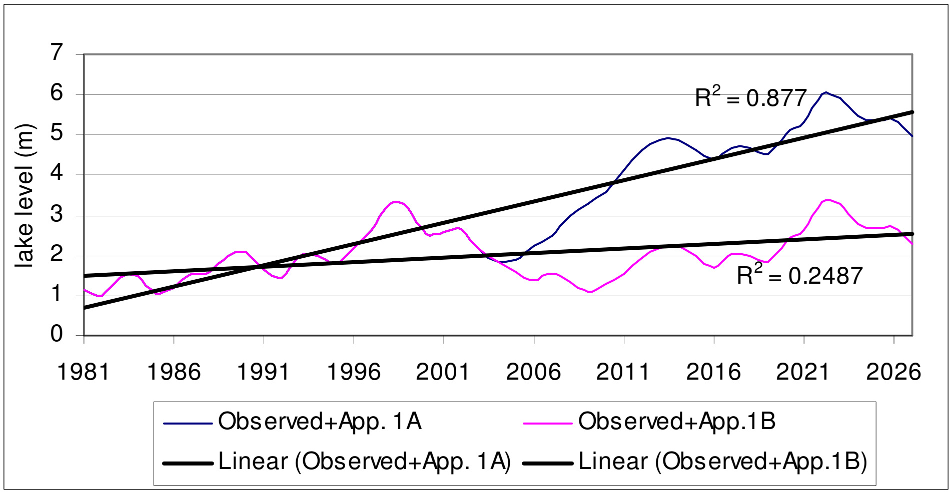

Figure 5.6 Observed and forecasted lake level based on application one

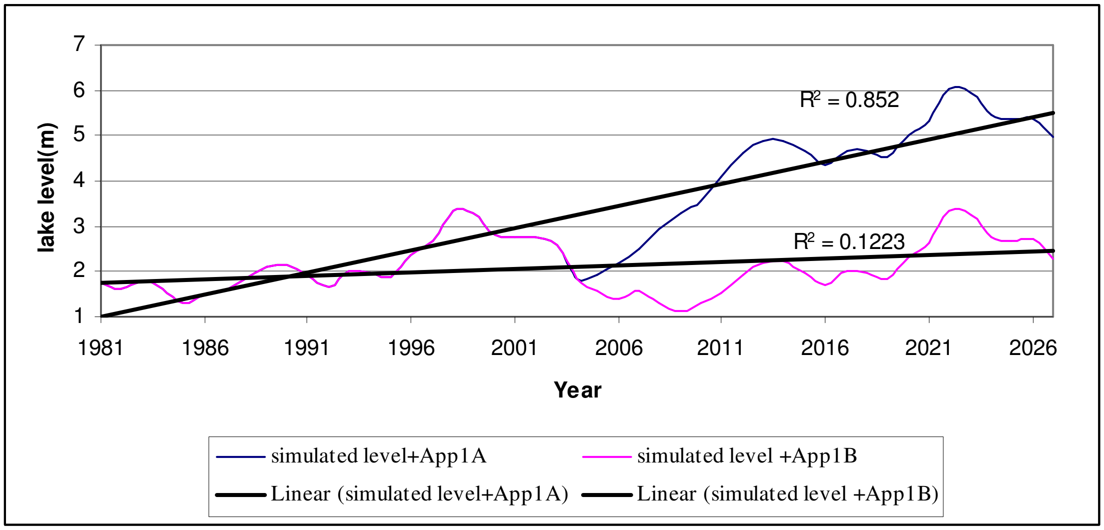

Figure 5.7 Simulated and forecasted lake level based on application one

Discussion on application 2: The result of this application is the same with that of application 1B because a 30% decrease in evaporation rate is applied only to the first 9 years. To see the effect in the long term lake level fluctuations, the evaporation values based on application two are repeated three times until 2027. As shown in the figure 5.8, the forecasted level differs by 2m with those levels forecasted based on application two and by 2.7m with those levels forecasted with the observed evaporation trend. This means that if the current decreasing trend of evaporation continues the level will reach 4.3m by the end of 2027.

The forecasted level based on the second assumption of this application resulted in R = 0.87 while those based on the first assumption of this application shows a coefficient of 0.40. Therefore this application, based on second assumption, can be taken as a good predicator of lake level because it clearly indicates the long term effect of evaporation in lake level fluctuations.

Discussion on application 3: Plotting, 3A, 3B and 3C, together with the observed and simulated lake levels give a good picture how this correlate with the projected one. They correlate almost the same (fig 5.12 and 5.13). This application answers what would happen if the average values of the components are projected into the future. The answer is the level will increase by 1 meter by the end of 2027.

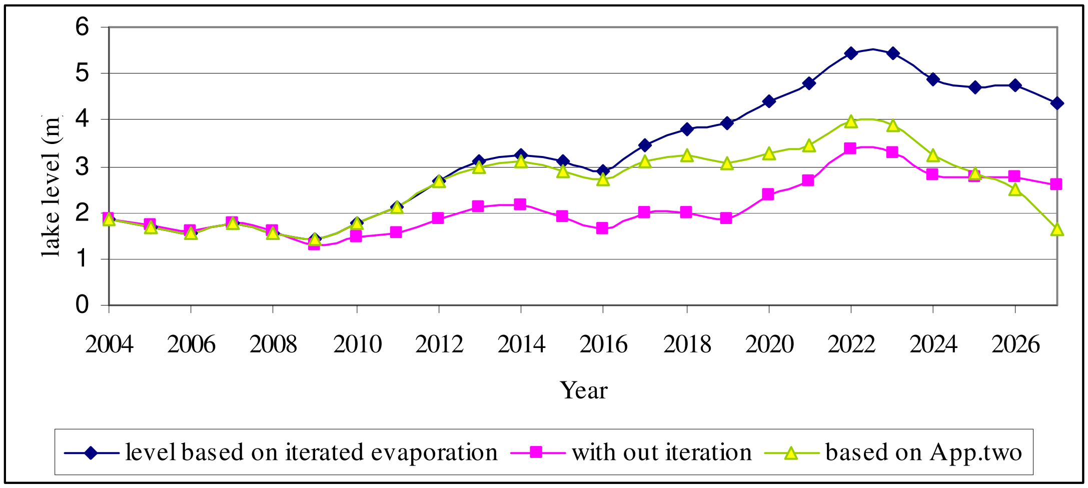

Figure5.8 Lake level fluctuations based on application two with different assumptions (2004-27)

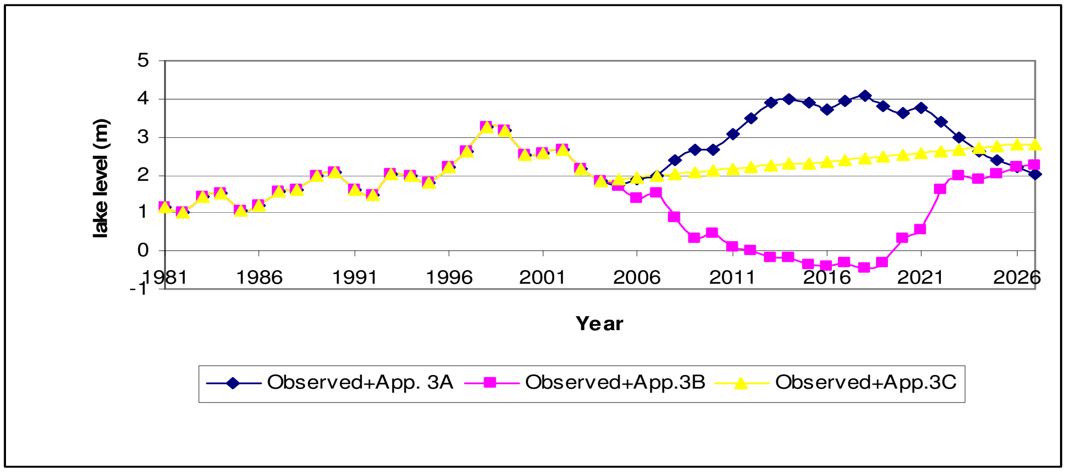

Figure 5.9 the observed and forecasted lake level based on application three (1981-2027)

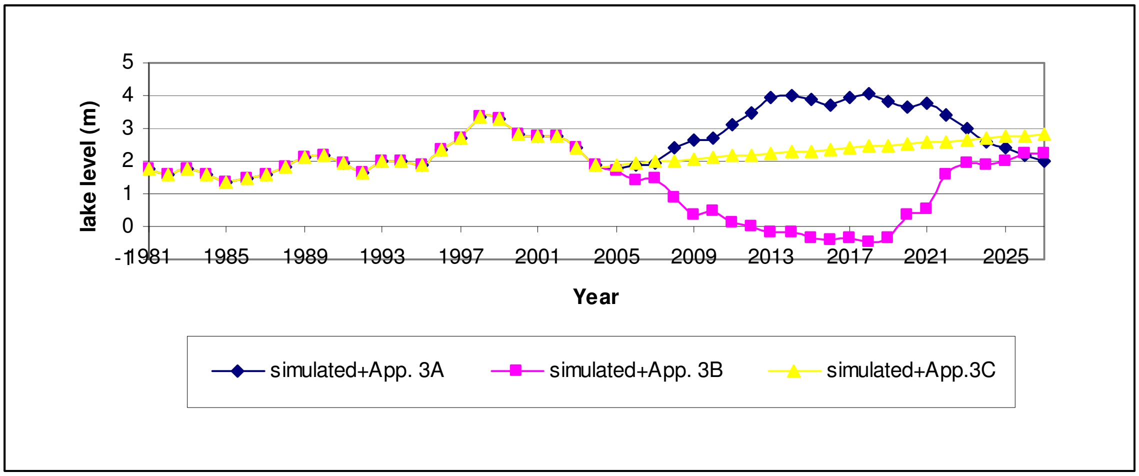

Figure 5.10 the Simulated and forecasted lake level based on application three (1981-2027)

Discussion on application 4: a comparison has been made to see the effect of precipitation on lake level rise between the forecasted lake levels of this application with forecasted levels produced from original precipitation rate, i.e. with out changing the low rain fall years.

The result shows, by the end of 2027, the level will differ by 0.6m on average with those forecasted based on original precipitation values (fig 5.11). This indicates annually a 0.3m rise can happen if the annual rain fall of the catchment is around its base period average.

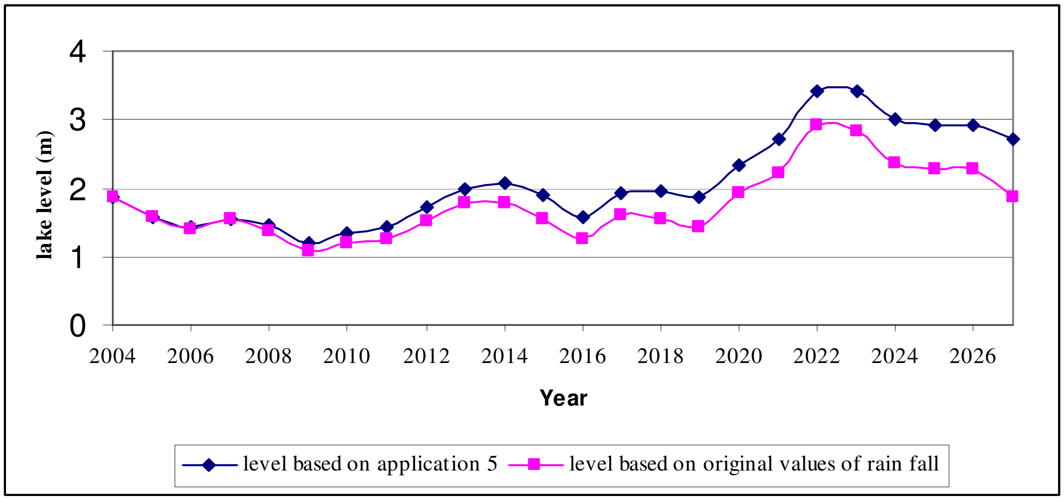

Figure 5.11 Comparison of forecasted lake levels based on application four with those levels based on original precipitation values (2004-2027)

CHAPTER SIX
CONCULUSION AND RECOMMENDATION

The water balance components of lake Awassa, the quantity of runoff, precipitation, evaporation, groundwater and storage changes, and their annual changes over the 1981-2003 period is systematically analyzed and formulated as a Lake level forecast model. The model shows that the average yearly inflow from runoff and precipitation is 167 and 90mcm, while the average outflow from evaporation and groundwater is 148 and 100mcm, respectively.

The formulated model is applied in order to ascertain the effect of these components in the historic and future lake levels based on the sequences of 1981-2003 hydro-climatic conditions with different applications and assumptions. The assumptions are generally aims to test several different values of the observed hydro-climatic for future conditions. Due to the physical reasoning and the closeness of assumptions made to drive the applications, model applications 1A, 1B, 2, and 4 are chosen as a good predicator of Awassa lake level fluctuation. Thus, the following points can be concluded from the models:

- Surface runoff into the lake accounts about 81% in lake level fluctuation. Its effect can also be manifested in short periods when the runoff volume increases. This is mainly the result of land use/cover changes in the catchment. While the evaporation rate accounts about 38% which indicates the significance is low during short periods of lake level fluctuation.
- If the current evaporation trend continues the lake level change will attain a 4.4 meter by the end of 2027 assuming all the rest water balance components are constant. The decreasing trend is mainly due to the decreasing magnitude of wind speed which is the result of land use change in the Awassa town. Thus evaporation rate accounts around 73% in the long term lake level fluctuation.
- Precipitation rate accounts about 45% in the long term lake level fluctuation. This is an indication that the role of climate change, according to this model, is small comparing to land use change in short periods of lake level fluctuation.
- All the applications indicate that the role of groundwater out flow is significant in the water balance of the lake and needs better attention during water balance computation.

These results, however, can be interpreted to indicate that the effect of land use change is higher than the effect of climate change in Awassa lake level fluctuation.

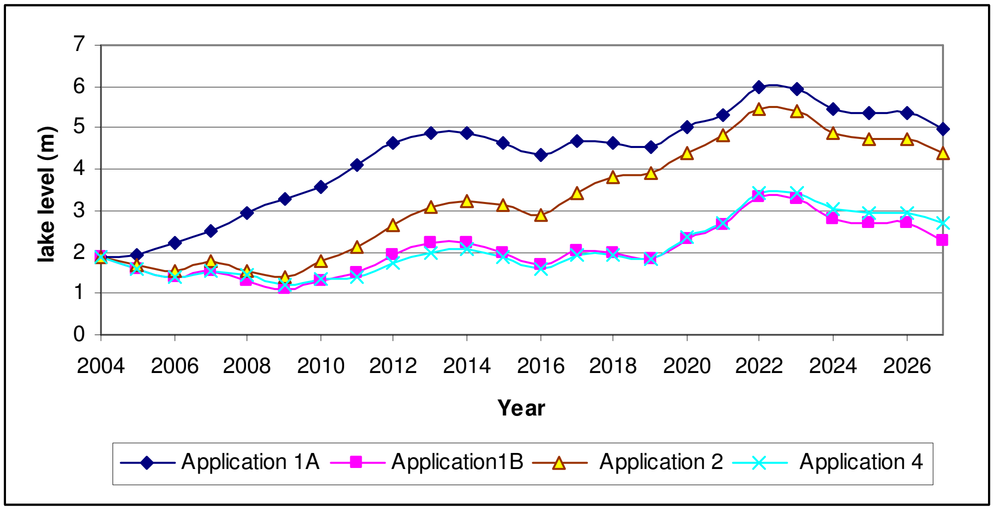

Figure 6.1 Selected model applications

The ability to model the water balance of the lake requires a full and accurate data base of the components. For example we know that evaporation from the Lake is a major component, but our knowledge of the rates of evaporation over time and space is unacceptably limited because of the accuracy and reliability of data. Additional data would substantially improve the accuracy of the component estimates and allow a refinement of component variables into more realistic parameters. For the improvement of the model for future use the following recommendations are found to be appropriate:

- Install/upgrade lake stage recorders on opposite shores to reduce measurement error.
- Develop more detailed bathymetric maps of the lake to improve stage/area/volume relationships
- Monitor evaporation pan, pan water temperature, wind speed, relative humidity to improve estimation of pan coefficients and to determine the spatial variation of evaporation
- Monitor and establish new precipitation stations to improve the accuracy of the data
- Drill and monitor wells around the lake for the purpose of estimating groundwater storage change and getting a visible relationship with lake level changes.

Finally, monitoring the lake level and upgrading all the instruments will provide researchers and policy makers to take alternative actions for sustainable use of the lake.

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Appendix-I Comparison of Error relative to inflow and outflow

YEAR	calculated Storage change, (mcm)	Simulated Storage Change, (mcm))	Difference (over all error) of	Total inflow	Total outflow	Relative error to inflow (%)	Relative error to outflow (%)
1981	-43.861	-10	33.6	226.87	237	14.8	14.22
1982	-12.95	-19.505	-6.56	203.44	222.93	-3.22	-2.94038
1983	40.579	33.407	-7.17	274.8	241.37	-2.61	-2.97137
1984	6.0796667	-18.131	-24.21	141.68	204.62	-17.09	-11.832
1985	-41.014875	-48.804	-7.79	159.03	207.82	-4.90	-3.74802
1986	11.955625	17.343	5.39	276.9	259.56	1.95	2.07558
1987	34.844333	2.351	-32.49	194.38	192.02	-16.72	-16.9218
1988	4.591125	43.104	38.51	237.86	194.74	16.19	19.77656
1989	36.49275	40.02	3.53	225.21	185.18	1.57	1.904768
1990	7.106	6.593	-0.51	246.81	240.21	-0.21	-0.21356
1991	-41.7105	-64.635	-22.92	225.68	276.44	-10.16	-8.29276
1992	-15.207633	-71.546	-56.34	244.96	288.00	-23.00	-19.5619
1993	52.261083	34.79	-17.47	269.65	230.06	-6.48	-7.59414
1994	-2.40975	10.045	12.45	229.41	223.22	5.43	5.579585
1995	-16.134167	37.11	53.24	281.22	244.11	18.93	21.81155
1996	38.274583	103.25	64.98	377.3	274.06	17.22	23.70846
1997	40.84575	73.641	32.80	292.34	218.69	11.22	14.99595
1998	64.766667	144.81	80.04	445.93	301.11	17.95	26.58275
1999	-7.88125	25.985	33.87	319.35	284.30	10.60	11.91215
2000	-61.573917	-67.336	-5.76	237.86	303.35	-2.42	-1.89948
2001	5.5359792	-0.999	-6.53	280.89	267.11	-2.33	-2.44655
2002	5.66525	-10.269	-15.93	292	302.27	-5.46	-5.27153
2003	-23.208482	-45.56	-22.35	253.37	298.93	-8.82	-7.47717

Appendix- II Magnitude of the component error

Appendix-IIA. Magnitude of Tikurwuha River Error

YEAR	Tikurwuha river flow (mcm)	total inflow	Error %	Error amount(mcm)	Relative to inflow %
1981	68.61	226.87	5	3.4305	1.512099
1982	56.88	203.44	5	2.844	1.253581
1983	88.15	274.8	5	4.4075	1.942743
1984	38.87	141.68	5	1.9435	0.856658
1985	40.47	159.03	5	2.0235	0.89192
1986	86.68	276.9	5	4.334	1.910345
1987	54.73	194.38	5	2.7365	1.206197
1988	76.57	237.86	5	3.8285	1.68753
1989	67.78	225.21	5	3.389	1.493807
1990	92.62	246.81	5	4.631	2.041257
1991	77.44	225.68	5	3.872	1.706704
1992	83.32	244.96	5	4.166	1.836294
1993	94.7	269.65	5	4.735	2.087098
1994	79.27	229.41	5	3.9635	1.747036
1995	98.12	281.22	5	4.906	2.162472
1996	137.26	377.3	5	6.863	3.02508
1997	95.25	292.34	5	4.7625	2.09922
1998	172	445.93	5	8.6	3.790717
1999	126.74	319.35	5	6.337	2.79323
2000	84.18	237.86	5	4.209	1.855247
2001	98.42	280.89	5	4.921	2.169084
2002	107.89	292	5	5.3945	2.377793
2003	87.54	253.37	5	4.377	1.929299
Mean	**87.54304**	**258.13**	**5**	**4.377152**	**1.929366**

Appendix-IIB. Magnitude of Unguaged runoff Error

YEAR	Runoff unguaged (mcm)	total inflow	Error %	Error amount(mcm)	Relative to inflow %
1981	62.52	226.87	70	43.764	19.29034
1982	51.9	203.44	70	36.33	16.01358
1983	78.74	274.8	70	55.118	24.29497
1984	35.43	141.68	70	24.801	10.93181
1985	36.52	159.03	70	25.564	11.26813
1986	80.55	276.9	70	56.385	24.85344
1987	50.49	194.38	70	35.343	15.57853
1988	71.33	237.86	70	49.931	22.00864
1989	61.45	225.21	70	43.015	18.9602
1990	83.06	246.81	70	58.142	25.62789
1991	67.62	225.68	70	47.334	20.86393
1992	72.17	244.96	70	50.519	22.26782
1993	86.75	269.65	70	60.725	26.76643
1994	68.3	229.41	70	47.81	21.07374
1995	88.69	281.22	70	62.083	27.36501
1996	125.89	377.3	70	88.123	38.84295
1997	93.79	292.34	70	65.653	28.9386
1998	159.1	445.93	70	111.37	49.08979
1999	111.72	319.35	70	78.204	34.47084
2000	76.46	237.86	70	53.522	23.59148
2001	86.44	280.89	70	60.508	26.67078
2002	96.35	292	70	67.445	29.72848
2003	92.24	253.37	70	64.568	28.46035
Mean	**79.89174**	**258.13**	**70**	**55.92422**	**24.65034**

Appendix-IIC. Magnitude of Lake precipitation Error

YEAR	R.F on Lake (mcm)	total inflow	Error %	Error amount(mcm)	Relative to inflow %
1981	95.74	226.87	25	23.935	10.55009
1982	94.66	203.44	25	23.665	11.63242
1983	107.91	274.8	25	26.9775	9.81714
1984	67.38	141.68	25	16.845	11.88947
1985	82.04	159.03	25	20.51	12.89694
1986	109.67	276.9	25	27.4175	9.901589
1987	89.16	194.38	25	22.29	11.46723
1988	89.96	237.86	25	22.49	9.455142
1989	95.98	225.21	25	23.995	10.6545
1990	71.13	246.81	25	17.7825	7.204935
1991	80.62	225.68	25	20.155	8.930787
1992	89.47	244.96	25	22.3675	9.131083
1993	88.2	269.65	25	22.05	8.177267
1994	81.84	229.41	25	20.46	8.91853
1995	94.41	281.22	25	23.6025	8.392895
1996	114.15	377.3	25	28.5375	7.56361
1997	103.3	292.34	25	25.825	8.833892
1998	114.83	445.93	25	28.7075	6.43767
1999	80.89	319.35	25	20.2225	6.332394
2000	77.22	237.86	25	19.305	8.116119
2001	96.03	280.89	25	24.0075	8.54694
2002	87.76	292	25	21.94	7.513699
2003	73.59	253.37	25	18.3975	7.26112
Mean	**90.69304**	**258.13**	**25**	**22.67326**	**9.114151**

Appendix-IID. Magnitude of Groundwater outflow Error

YEAR	**Ground water out flow(mcm)**	**total outflow**	**Error %**	**Error amount(mcm)**	**Relative to outflow %**
1981	89.12	222.93	40	35.648	15.99067
1982	79.56	241.37	40	31.824	13.18474
1983	95.25	204.62	40	38.1	18.61988
1984	19.36	207.82	40	7.744	3.726302
1985	49.21	259.56	40	19.684	7.583603
1986	105	192.02	40	42	21.87272
1987	22.54	194.74	40	9.016	4.629763
1988	25	185.18	40	10	5.400151
1989	26.65	240.21	40	10.66	4.437784
1990	81.35	276.44	40	32.54	11.77109
1991	140	288.00	40	56	19.44444
1992	160	230.06	40	64	27.81883
1993	68	223.22	40	27.2	12.18529
1994	41.23	244.11	40	16.492	6.755971
1995	80	274.06	40	32	11.67628
1996	144.26	218.69	40	57.704	26.38573
1997	76.254	301.11	40	30.5016	10.12972
1998	168.25	284.30	40	67.3	23.67218
1999	149.32	303.35	40	59.728	19.68947
2000	169.12	267.11	40	67.648	25.3259
2001	160	302.27	40	64	21.17312
2002	175.69	298.93	40	70.276	23.50918
2003	169.26	200.67	40	67.704	33.73897
Mean	99.76	246.12	40	28.4	13.12929

Appendix-IIE. Magnitude of Lake Evaporation Error

YEAR	**Lake Evaporation(mcm)**	**total outflow**	**Error %**	**Error amount(mcm)**	**Relative to outflow %**
1981	77.28	148.28	20	15.456	10.42352
1982	143.37	214.37	20	28.674	13.37594
1983	146.12	217.12	20	29.224	13.45984
1984	140.43	256.26	20	37.052	14.45875
1985	158.61	229.61	20	31.722	13.8156
1986	154.56	225.56	20	30.912	13.70456
1987	169.48	240.48	20	33.896	14.09514
1988	169.74	240.74	20	33.948	14.10152
1989	158.53	229.53	20	31.706	13.81344
1990	158.86	229.86	20	31.772	13.82233
1991	150.32	221.32	20	30.064	13.58395
1992	156.5	227.50	20	31.3	13.75824
1993	166.81	237.81	20	33.362	14.02885
1994	181.99	252.99	20	36.398	14.38713
1995	164.11	235.11	20	32.822	13.96027
1996	129.8	200.80	20	25.96	12.92829
1997	142.44	213.44	20	28.488	13.34708
1998	132.86	203.86	20	26.572	13.03444
1999	144.04	215.04	20	28.808	13.39658
2000	136.09	207.09	20	27.218	13.14308
2001	121.88	192.88	20	24.376	12.63791
2002	126.58	197.58	20	25.316	12.81304
2003	129.67	200.67	20	25.934	12.92371
Mean	148.0391	219.04	20	29.60783	13.43536

Appendix - III Summary of initial meteorological data

Appendix-IIIA Mean monthly rain fall at Awassa Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	X	25	199	136	48.3	127	132.9	156	157	52.4	7	X
1982	49.6	46.6	99.9	92.1	70.8	121	166.3	117	72.7	95.9	84.4	12.4
1983	60.5	47.9	56.3	186	239	76.2	102.8	126	154	90.6	14.2	6.4
1984	X	X	36.5	17.4	170	70.7	96.1	92.7	166	27.4	34.5	13.3
1985	9.2	X	75.7	202	93.3	107	146.1	80.7	116	50.2	12.8	8.3
1986	x	34.7	69.6	110	167	193	153.3	194	172	57.3	22.8	18.4
1987	0.1	11.8	151	128	231	58	97.3	108	68.8	100.1	0.4	4.1
1988	25.8	68.5	17.5	80.9	100	111	117.7	139	205	83.9	1.3	6.6
1989	38.8	49.9	62.8	192	95.2	124	78.1	86.4	166	44.7	22.3	50.2
1990	10.5	93.7	121	89.9	85.3	44.4	139.5	39.5	94.1	27.3	7.6	3.8
1991	12.3	90.6	87.4	48	130	117	109.2	90.6	104	21.6	12.2	44.8
1992	23.4	83.2	73	109	60.5	83	92.8	124	74.5	142.3	80.1	16.6
1993	101.6	109.1	22.3	105	165	46.7	54.7	131	47.8	130.8	10.5	3.9
1994	X	4.7	56.8	109	80.8	146	195.7	119	68.9	58.8	19.1	2.9
1995	0.8	21.4	61.8	156	43.6	119	175.7	135	167	22.3	18.3	84.2
1996	78.4	36.9	89.6	114	162	243	121.2	109	145	69.6	19.7	1.4
1997	23.4	1.7	75.1	125	73	111	98.6	114	119	157.1	132	24
1998	92	140	90.8	86.4	88.4	56	172.9	108	110	193.3	10.6	x
1999	19.8	0.4	106	27.1	64.7	99.8	135.1	83.8	115	120.4	20.1	16.8
2000	1.1	X	11	132	145	36.4	80	179	87.6	110.7	29	9.3
2001	1.8	39.9	123	67	234	138	93.5	132	89.7	80.2	2.6	21.3
2002	52.5	2.4	128	120	85.2	118	76.6	190	82.2	37.2	X	51.5
2003	30.4	2	78.2	179	40.4	111	74.5	76.1	85.7	56.4	6.2	51.8

Appendix-IIIB Annual average rain fall at different station (mm)

Meteorological stations

Year	Yirbadbancho	Haisawita	Awassa	Wondgenet	Shashamane
1981	1124.3	1037	1040.6	1159.4	976.4
1982	1253.8	1085.5	1028.9	1207.7	1022
1983	1285.9	1238.3	1160.3	1541	1165.7
1984	813	735.1	724.5	820.9	691.8
1985	1096	979.7	901.5	1159.1	922.4
1986	1174	1084	1192.1	1087.2	1060.4
1987	1585.1	1165.4	958.7	1228.8	1097.2
1988	1258.5	947.4	957	1058.8	988.8
1989	1245	1071.9	1010.3	1241.2	972.3
1990	958.8	966.8	756.7	928.4	793.5
1991	824.9	1020.5	866.9	1164.2	862.8
1992	1064.3	1300.7	962	1307.4	912.6
1993	1194.7	983.6	928.4	1138.1	991.6
1994	990.9	1066.7	861.5	1291.5	742.3
1995	800.5	907.9	1004.4	1024.9	852.6
1996	1213.4	1176.8	1189.1	1253.1	1187.3
1997	1173.8	655.1	1054.1	920.5	1188.4
1998	1099.2	932.5	1148.3	1304.9	1201.3
1999	674.4	848.6	808.9	953.1	717.2
2000	904.7	983.1	821.5	943.5	986
2001	1142.9	1222.3	1021.6	1290.6	852.3
2002	1019.5	851.4	943.7	998	436.5
2003	1105.7	892.8	791.3	754.4	812.8
Mean	**1087.1**	**1006.7**	**962.274**	**1120.7261**	**931.921739**

Appendix-IIIC Monthly Minimum Air temperature at Awassa station(° c)

Year	Jan	Feb	Mar	Ajpr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	10.4	11.5	14.9	14.5	13.6	13.8	14.4	13.7	13.3	10.9	8.7	8.9
1982	12.1	13.1	12.4	14.4	13.7	13.8	13.9	14.4	13.2	11.7	11.9	10.6
1983	10	13.1	14.8	14.3	13.8	15.1	13.1	14.5	13.4	11.8	9.4	8.7
1984	8.3	7.2	10.1	12	13.4	13.4	13.1	12.9	11.6	8.5	9.1	8
1985	8.5	10	11.2	12.5	12.5	12.3	12.7	13.3	12.7	10.5	8.9	7.8
1986	7.5	11.2	10.5	14.8	14.4	13.7	13.5	12.1	12.8	10.8	8.7	9.7
1987	9.9	11.5	14	13.1	14.3	14.5	13.9	13.4	12.7	12.7	9.2	9.5
1988	11.3	13.6	12.2	14.6	13.9	13.9	14.7	14.1	13.9	12.8	6.5	7.9
1989	9.5	10.7	12.7	13.5	12.4	13.1	14.1	13.4	12.9	11.7	9.7	13
1990	9	14.1	12.6	13.7	13.3	12.8	14.2	10.7	12.9	10.5	10.4	9
1991	11.9	12.5	13.4	12.8	14	15.3	14.3	13.7	12.9	9.5	9.4	9.6
1992	12.4	13.6	12.8	14.3	13.5	14	13.9	14.5	12.7	13.1	10.5	11
1993	12.1	12.3	9.7	14.1	14	14.2	13.9	13.7	12.9	13.2	9.3	9.2
1994	9.7	12	13	13.8	14.3	14.5	14.3	14.7	14	10.1	10	8.9
1995	9.8	12.7	13.6	14.9	13.1	13.6	14.2	14.5	13	12.3	8.4	10.6
1996	12.1	10.5	13	14	14.1	14.3	14.5	14.4	13.7	10.9	8.8	9.6
1997	12.4	10	13.3	13.9	13.2	13.6	14.2	14.2	13.2	13.6	13.8	14.4
1998	13.3	14.3	13.9	14.8	15.7	14.7	15.7	15.9	14.5	14.4	8.9	7.8
1999	10.2	9.9	13.8	12.5	13.6	14	14.2	13.7	13.8	14	9.3	9.3
2000	9.6	10.6	11.1	14.1	14	13.7	14.3	14	13.4	14	10.5	9.7
2001	11.5	11.1	13.7	14.4	14.1	15	14.7	15	13.1	13.8	10.3	10.9
2002	12.4	11.8	14	13.5	14.8	14.5	14.4	14.2	13.4	12.8	9.8	13.2
2003	11.8	11.6	13.2	14.3	14.2	14.3	14.5	14.5	14	11.9	11.2	10.4

Appendix-IIID Monthly Maximum Air temperature at Awassa station (oC)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	29.4	29.3	26.6	25.4	26.5	25.9	23.1	23.5	23.4	26.4	27.3	27.8
1982	27.5	28	29.1	26.2	26.5	25.3	23.3	23.6	25.5	25.5	25.8	26.4
1983	27.4	28.3	30.3	26.9	25.7	25.8	23.8	23.7	24.5	25.6	27.1	27.4
1984	28.5	29.5	30.5	30.5	25.9	25.8	23.4	24.1	24.3	27.7	28.1	27.8
1985	28.9	29.3	30.1	25.7	25.2	24.8	23.1	23.5	24.6	26.2	27.6	28.2
1986	28.8	29.4	28.9	26.3	26.5	23.9	23.5	24.5	25.1	26.7	28.3	28.3
1987	28.5	29.2	27.6	27.4	26.3	25.5	25.2	25.4	26.6	27	29.3	29.3
1988	29.2	29.6	31	28.4	27.5	24.9	22.8	23.8	24.8	25.9	27.9	27.8
1989	27.7	28	28.7	26.2	27.1	23.9	23.3	24.3	24.4	26.4	27.3	27.1
1990	28.6	27.7	27.5	27.8	27.2	26.1	24.4	24.4	25.8	28	29.5	29.2
1991	30.4	29	27.7	29.3	28	26.1	23.3	25.1	26	27.8	29.2	28.1
1992	29.4	28.5	30.5	29.8	27.5	26.3	24.3	23.8	24.9	25.8	27.1	28.5
1993	27.6	26.9	30.8	27	26.9	25.2	24.4	24.8	25.7	26.9	30.1	29.7
1994	30.5	32	30.9	29	26.7	24.7	23.5	25	26.2	28.3	28.3	29.3
1995	30.4	30.7	30	27.3	27.9	27	24.3	24.7	25.9	27.5	29.3	29.3
1996	28.3	30.8	29.4	27.7	26.8	23.8	23.8	24.3	25.2	27	28.1	28.6
1997	28.9	30.3	30.8	26.9	27.5	25.7	23.9	25.5	26.7	26.5	26.4	27.3
1998	27.7	28.7	29	29.7	27.3	26.3	24.3	23.6	25.4	25.3	27.5	28.1
1999	29.1	31.4	28.1	29.1	27.2	26.1	23.6	25	25.6	25	27.2	28
2000	29.5	30.7	31.8	28.8	26.1	25.7	24.7	24.8	25.1	25.6	27.2	28.3
2001	28.7	29.1	28.4	28.4	26.9	24.8	24.4	24.5	25.9	26.7	28.2	28.6
2002	28.2	30.9	28.8	28.6	27.1	25.7	25.6	25.4	26.1	28.3	29.8	28.9
2003	28.4	31.3	30.6	28.1	28.3	25.6	24.2	24.8	25.9	28.2	29.3	27.2

Appendix-IIIE Average Wind speed at Awassa station (m/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	1.4	1.4	1.4	1.4	1.4	1.5	1.3	1.2	0.9	1	1.3	1.3
1982	1.2	1.3	1.5	1.3	1.2	1.8	1.5	1.2	1	1.1	1.2	1.6
1983	1.2	1.4	1.4	1.2	1.2	1.2	1.1	1.1	1	1	1	1
1984	1.4	1.4	1.4	1.3	1.4	1.5	1.4	1.1	1	1	1	1.3
1985	1.5	1.7	1.7	1.4	1.3	1.3	1	1	0.8	0.9	1.1	1.3
1986	1.3	1.4	1.3	1.4	1.3	1.2	1.1	1	1.1	0.9	1	1.2
1987	1.4	1.1	1.2	1.1	1.1	1.1	1	1	0.8	0.9	0.9	1.2
1988	1.3	1.4	1.2	1.4	1.3	1.2	0.9	1.1	1.1	1	1.1	1.3
1989	1.4	1.4	1.4	1.4	1.3	1.4	1.3	1.1	1.1	1	1.1	1.3
1990	1	1.1	0.9	0.9	1	1.4	1.3	1.1	1.1	1	1.1	1.3
1991	1.4	1.4	1.4	1.3	1.3	1.4	1.2	1.1	1	1	1.1	1.3
1992	1.4	1.4	1.4	1.3	1.3	1.4	1.2	1.1	1	1	1.1	1.3
1993	1.4	1.4	1.4	1.3	1.3	1.4	1.2	1.1	0.8	0.5	0.7	0.9
1994	1	1.1	1	0.8	0.8	1.1	0.8	1.4	0.7	0.5	1.2	0.9
1995	0.9	0.9	1	0.8	1.1	1.2	0.9	0.9	0.7	0.6	0.7	0.7
1996	0.8	0.8	0.8	0.8	0.7	1	1	0.7	0.7	0.5	0.6	0.7
1997	0.8	1	0.9	0.7	0.9	0.9	1.1	0.9	0.7	0.5	0.5	0.6
1998	0.6	1	0.6	0.7	0.8	1.1	1	1	0.7	0.5	0.5	0.6
1999	0.9	1	0.6	0.8	1	1.1	1	0.9	0.9	0.5	0.5	0.8
2000	0.9	1	0.8	0.8	0.7	1.2	1.2	0.9	2	0.5	0.7	0.8
2001	0.8	1	0.7	0.7	0.8	0.9	0.9	0.8	0.7	0.6	0.6	0.7
2002	0.7	1	0.6	0.7	1	1.1	1.1	0.8	0.6	0.6	0.6	0.7
2003	0.8	0.8	0.8	0.6	0.8	1	0.9	0.9	0.7	0.6	0.8	0.8

Appendix-IIIF Average Relative humidity at Awassa station (%)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	8.6	8.9	5.8	5.6	7.6	7.9	4.6	5.5	4.6	7.8	9.6	9.5
1982	8.5	7.1	8.5	6.5	6.6	7	5	5	5.9	7.3	7.3	8.6
1983	9.2	8.2	8.1	6.3	6.6	7.2	5	3.7	5.3	8	8.7	8.6
1984	9.4	9.6	8.2	x	6.4	6.2	6	6.3	5.5	8.9	8.9	9.2
1985	9.3	8.6	8.2	7.5	6.9	7.7	4.8	5.3	5.7	7.1	8.6	9.5
1986	9.5	7.6	7.8	5.7	7.5	5.3	5.4	7	6.6	7.8	9.1	9.3
1987	x	8	x	5.5	6.3	7.2	7.1	6.6	6.2	x	9.7	10
1988	8.8	7.6	8.3	7.3	8.2	6.5	2.9	4.6	5.2	7.1	9.9	8
1989	8.5	8.4	7	5.8	7.9	7.1	3.8	5.9	5.2	x	8.5	7.6
1990	8.8	6	7.3	5.9	6.5	7.3	5.1	4.5	5.5	8	8.1	9.4
1991	8.4	7.3	7.1	6.5	7.4	6.5	3.7	4.1	5.8	7.6	8.2	8.2
1992	7.8	7.5	8.5	7.5	8.1	7.2	5.5	4.5	5.4	6.8	8.7	8.7
1993	7.7	7.2	9.2	8.2	6.9	6	4.3	5.4	x	x	x	x
1994	9.6	8.9	7.4	6.4	6.6	5.7	4	5.1	5.2	8.5	8.4	9.4
1995	9.7	7.6	7.3	6.3	7.9	7.7	4.1	4.8	6.4	2.9	9.5	8.5
1996	8.3	8.9	7.1	5.9	7.1	4.8	1.6	4.5	5.4	8	9.3	10.1
1997	8.8	10.4	8.3	2.7	6	6.8	5.5	6.6	7.1	7.1	6.8	8.6
1998	7.2	7.9	7.8	7.8	6.8	6.3	4.4	4.4	5.3	3.8	9.4	10
1999	9.4	9.7	6.7	6.9	7.5	7.1	4.6	5.9	6	5.1	8.6	9.9
2000	9.8	9.8	8.9	7	11.3	6.6	5.6	5.3	5.4	6.2	9.1	9.7
2001	8.8	9.1	6.5	6.9	7.5	5.8	5.5	5.2	5.8	6.8	9.1	9.7
2002	9	9.6	7.8	7.6	7.1	6.4	7.1	6.3	7.1	6.9	9.7	8.1
2003	9	9.5	8.3	6.8	7.8	4.5	7.3	5.3	x	x	x	x

Appendix-IIIG Class A pan evaporation at Awassa Station (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	0.00	0.00	0.00	0.00	0.00	120.00	64.00	139.00	112.50	172.50	221.00	221.00
1982	198.70	198.70	228.00	157.50	161.50	157.50	116.00	116.00	146.00	157.70	168.70	142.00
1983	206.00	187.50	229.00	136.00	127.00	168.70	142.00	116.00	131.00	139.00	172.00	210.00
1984	232.00	285.00	255.00	247.00	187.00	165.00	161.00	161.00	131.00	221.00	217.00	228.00
1985	247.00	251.00	276.00	120.00	161.00	176.00	109.00	131.00	142.00	161.00	191.00	214.00
1986	230.50	211.70	240.90	176.60	113.20	140.20	124.40	146.90	162.60	172.40	192.50	188.10
1987	239.80	200.10	179.90	179.90	190.70	173.80	173.50	172.20	154.50	175.10	208.00	230.50
1988	212.90	203.30	243.20	192.10	206.30	171.40	110.20	146.60	140.20	164.50	273.50	193.00
1989	196.40	126.30	227.60	155.40	219.60	183.50	129.40	153.70	166.60	179.70	189.10	158.60
1990	180.50	143.60	167.20	173.90	187.00	187.70	149.70	143.20	158.40	198.60	198.50	224.20
1991	222.30	191.00	178.10	154.60	153.00	159.10	120.60	142.10	149.40	183.60	178.50	188.10
1992	152.50	120.90	254.40	216.20	182.00	185.60	178.40	160.70	135.30	155.50	177.60	184.40
1993	182.70	163.60	237.10	170.00	200.10	161.50	153.20	161.70	148.20	169.70	212.30	234.80
1994	250.10	242.90	235.30	195.10	179.70	179.70	121.60	141.50	162.40	206.10	231.30	248.90
1995	267.20	242.50	240.00	182.00	202.90	198.80	122.60	107.50	118.50	139.20	158.50	202.60
1996	148.10	183.00	159.10	140.30	129.40	109.40	108.30	118.00	103.20	149.90	164.80	176.54
1997	169.60	211.90	203.10	126.60	169.00	143.90	146.30	153.90	114.30	128.10	110.20	139.90
1998	207.60	129.80	149.30	152.50	143.50	141.20	113.80	103.80	110.70	93.40	144.90	170.30
1999	177.80	196.80	150.30	162.00	160.10	152.40	128.90	133.50	109.80	103.30	153.80	171.80
2000	201.50	201.80	205.20	158.20	131.20	142.40	127.60	117.10	113.00	113.90	139.00	158.80
2001	156.40	172.70	137.90	144.20	130.30	105.30	104.70	114.10	109.50	120.90	154.50	170.30
2002	153.80	164.20	149.60	144.70	136.50	131.50	147.30	103.80	111.50	136.40	183.60	138.50
2003	160.30	174.00	149.30	109.90	145.40	130.20	96.80	117.50	129.50	156.60	190.40	183.00

Appendix-IV Summary of initial hydrological data

Appendix-IVA Monthly flow of Tikurwuha River at Dato Village (Mcm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	2	0.8	0.65	3.02	3.4	2.23	3.29	10.2	16.3	16.1	9.22	1.28
1982	0.57	0.50	0.48	0.91	2.32	2.3	7.62	7.44	10.9	13.2	6.02	4.55
1983	2.2	0.91	0.71	1.04	9.47	13.6	6.45	9.09	13.6	15.8	10.0	5.12
1984	3.22	1.93	1.34	1.02	1.23	2.8	4.12	6.07	8.07	6.57	1.6	0.89
1985	0.56	0.33	0.17	0.04	2.17	4.46	2.14	4.3	12.0	11.4	2.04	0.78
1986	2	0.38	0.53	0.82	2.66	14.0	13	13.9	10.2	13.5	9.22	6.31
1987	1.02	0.50	0.91	2.84	9.33	11.1	5.29	3.72	7.11	6.85	3.9	2.11
1988	1.37	0.99	1.14	1.13	1.59	2.96	7.18	14.3	16.6	15.0	9.34	4.87
1989	3.68	2.67	2.6	2.72	3.73	7.39	5.99	6.31	9.48	11.9	6.71	4.45
1990	3.9	3.28	7.77	13.7	9.39	4.96	4.95	7.04	7.43	15.8	11.2	3.03
1991	2.26	1.46	1.21	3.17	9.43	3.45	6.70	9.91	11.7	13.8	8.91	5.27
1992	2.08	0.76	0.62	0.82	3.05	4.26	5.79	7.95	16.8	21.5	14.5	4.99
1993	2.91	1.85	1.35	1.09	3.79	9.4	11.9	11.5	13.0	15.8	11.7	10.2
1994	5.82	1.6	0.9	1.62	2.69	4.35	7.54	14.8	15.8	10.8	7.34	5.92
1995	4.67	3.48	1.1	2.48	4.4	6.38	7.58	9.72	11.5	12.8	15.6	18.3
1996	4.5	3.2	3	4.42	10	14.8	15.8	15.7	16.1	20.5	16.2	12.8
1997	8.8	6.24	5.76	4.46	5.9	6.11	5.43	6.17	6.59	10.5	13.0	16.1
1998	18.4	16	10.7	4.5	9.4	18.4	18.8	15.3	15.5	21.5	13.9	9.6
1999	11.8	9.74	10.6	10.2	10.2	9.17	10.5	11.0	11	12.0	10.8	9.4
2000	8.24	7.22	3.67	0.01	3.64	7.16	8.47	9.98	10.2	9.99	7.97	7.54
2001	7.55	5.07	5.05	6.47	8.32	9.33	8.69	8.46	8.65	10.2	10.6	9.81
2002	9.08	7.35	7.78	7.95	9.04	9.69	9.08	8.46	8.65	10.2	10.6	9.81

Appendix-IVB Awassa Lake level (m.a.m.s.l)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	1679.74	1679.48	1679.51	1679.59	1679.58	1679.52	1679.51	1679.63	1679.82	1680.03	1679.99	1679.83
1982	1679.71	1679.6	1679.52	1679.45	1679.41	1679.36	1679.42	1679.5	1679.55	1679.65	1679.74	1679.74
1983	1679.64	1679.57	1679.46	1679.39	1679.52	1679.85	1679.95	1680.07	1680.37	1680.66	1680.73	1680.69
1984	1680.54	1680.34	1680.23	1680.03	1679.95	1679.97	1679.95	1679.96	1680.01	1680.04	1679.95	1679.79
1985	1679.58	1679.45	1679.28	1679.31	1679.44	1679.49	1679.53	1679.66	1679.75	1679.86	1680.01	1679.95
1986	1679.66	1679.48	1679.39	1679.34	1679.32	1679.46	1679.65	1679.84	1680.02	1680.26	1680.3	1680.16
1987	1679.96	1679.79	1679.74	1679.73	1679.81	1680.18	1680.28	1680.31	1680.37	1680.45	1680.44	1680.29
1988	1680.13	1679.98	1679.88	1679.72	1679.74	1679.73	1679.78	1680.03	1680.42	1680.79	1680.92	1680.75
1989	1680.62	1680.52	1680.41	1680.39	1680.38	1680.49	1680.51	1680.52	1680.58	1680.73	1680.72	1680.67
1990	1680.58	1680.52	1680.54	1680.63	1680.68	1680.66	1680.64	1680.67	1680.67	1680.74	1680.66	1680.48
1991	1680.33	1680.21	1680.16	1680.12	1680.13	1680.13	1680.14	1680.18	1680.23	1680.26	1680.16	1680.02
1992	1679.88	1679.78	1679.74	1679.66	1679.64	1679.62	1679.69	1679.8	1680.04	1680.36	1680.57	1680.56
1993	1680.48	1680.49	1680.39	1680.3	1680.37	1680.48	1680.53	1680.58	1680.66	1680.78	1680.9	1680.79
1994	1680.62	1680.45	1680.32	1680.23	1680.26	1680.25	1680.34	1680.64	1680.86	1680.93	1680.86	1680.7
1995	1680.51	1680.37	1680.28	1680.27	1680.28	1680.23	1680.24	1680.29	1680.5	1680.58	1680.44	1680.37
1996	1680.28	1680.14	1680.04	1680.05	1680.16	1680.47	1680.83	1681.1	1681.38	1681.62	1681.61	1681.46
1997	1681.38	1681.14	1680.97	1680.94	1680.92	1680.92	1681.02	1681.13	1681.18	1681.31	1681.57	1681.69
1998	1681.66	1681.64	1681.68	1681.61	1681.62	1681.63	1681.65	1681.77	1681.88	1682.17	1682.36	1682.23
1999	1682.09	1681.92	1681.83	1681.73	1681.64	1681.57	1681.55	1681.61	1681.61	1681.78	1681.85	1681.73
2000	x	x	x	x	1681.14	1681.03	1680.96	1680.94	1681	1681.18	1681.27	x
2001	x	x	x	1680.78	1680.82	1680.96	1681.08	1681.21	1681.41	1681.58	1681.65	1681.57
2002	1681.44	1681.27	1681.2	1681.19	1681.16	1681.15	1681.11	1681.19	1681.3	1681.29	1681.17	1681.02
2003	1680.91	1680.77	1680.65	1680.6	1680.68	x	x	x	x	x	x	x