Study of Long-term Waterbalance of Lake Naivasha, Kenya.

M'mbui Samuel Gitonga

April, 1999

Study of Long-term Waterbalance of Lake Naivasha, Kenya

By

Mmbui Samuel Gitonga

Thesis submitted to the International Institute for Aerospace Survey and Earth Sciences in partial fulfilment of the requirements for the degree of Master of Science in Water Resources Survey with emphasis in watershed management and conservation.

Degree Assessment Board

Prof. Dr. A.M.J. Meijerink (ITC, Enschede)	-	Chairman
Dr. E. Seyhan (VUA)		External examiner
Drs. R. Becht (ITC, Enschede)		Supervisor 1
Ir. J.A.M. de Brouwer (ITC, Enschede)		Supervisor 2

ITC

INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES
ENSCHEDE, THE NETHERLANDS

To My wife Kagwiria and our sons Muriithi and Muriuki
Without your understanding this would never have happened.

ACKNOWLEDGEMENT

I would like to express my gratitude to the Government of Kenya, through Ministry of Water Resources, for releasing me to pursue this course. My appreciation goes to Water Resources Assessment and Planning Project (WRAP) within Ministry of water Resources, Kenya, for granting me this scholarship.

Thanks to Water Resources Assessment Project (WRAP), Kenya Netherlands Wetlands training program (KNWTP), Kenya Wildlife Services (KWS), Lake Naivasha Riparian Owners Association (LNRA), for their logistics support during our field work in Naivasha, Kenya. In this connection I would like to give special thanks to Dan Arwa, Mack Lidonde and the entire Nakuru WRAP team for their professional support.

My thanks go my course lecturers who greatly opened my mind to the science of water resources survey and management and prepared me for my final M.Sc. project. In this connection Special thanks go to ir A.M van Lieshout my first director of Studies for his guidance and brotherly concern, Ir J.A.M.Hans de Brouwer my second supervisor and my director of studies during my MSc project for his support. Thanks to Prof. A.M.J Merjerink, chairman of Water Resources department, for his patronage. I take this oppurtunity to thank my external examiner Dr. E. Seyhan for finding time for my examination.

Am greatly indebted to Drs R. Becht my first supervisor for always being there for me. From him I learnt a lot about the art of modeling. His enthusiasm and commitment are exemplary.

No words can express my gratefulness to my wife, Kagwiria, for being so understanding and patient in letting me stay away from home for twenty months. To my children Muriithi and muriuki who had to bear with the fact that their father will be away in school for all that long even though they could never understand why “dad” should go to school again
My acknowledgeme won,t be complete without thanking my fellow classmates with whom we have struggled all through. Special thanks go to My friend Kirwa who stood by me during the “trying times”.

ABSTRACT

The observed lake level time series is reconstructed for the period 1900 to 1997 based on the old datum used by ministry of Public works.

The water balance of lake Naivasha, Kenya is modeled on monthly time steps for the period 1932 to 1997 .The model results showed very good correlation between water balance components and the observed lake levels.

Ground water plays a crucial role in the water budget of the lake. There is an exchange of water between the lake and Groundwater. Groundwater outflow from the lake averages 4.6 million cubic meters per month.

Since mid -1980s abstractions from the lake have increased progressively to a current average value of 57 million cubic meters per month. The model predicts that without these abstractions the current lake level would be at least 2 meters higher.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Chapter 1

1.1 Introduction

Growing population density is putting more and more pressures to water resources of Lake Naivasha, and the rivers draining into it. Irrigation fed horticultural farming thrives around the lake while numerous small-scale farmers are abstracting water from the rivers feeding the lake to irrigate their small plots. Though the lake level fluctuates with time and as been on a down ward trend since 1908(John Goldson Associates, 1993), The increased abstraction for irrigation purposes as led to conflicting opinions among the different riparian groups and the authorities concerned with water resources development and conservation. There is mounting fear that increased abstraction will lead to drying up of the lake. On the other hand the big horticultural farmers believe what they abstract could not be the mayor factor in the lowering up of the lake level. There argument is that what they abstract is negligible compared to evaporation losses. According to (edmondson, 1977) as cited by (Ase et al 1986) the lake was almost dry just before 1888. There was hardly any irrigation at that time. The question therefore boils down to the water balance of the lake and the causative factors.

1.2 Importance of the study

Lake Naivasha is the only fresh Water Lake within the East African rift valley. The lake has no surface outflow. The freshness of the lake is maintained by ground water outflow. The lake serves as a water reservoir in an otherwise semi arid region. The inhabitants of Naivasha area depend on the lake for domestic water, fishing, recreation and irrigation water requirements. At the national level the lake is a major source of income through tourism. The lake is among the biggest bird sanctuary in Africa. Hell's gate national park to the south of the lake is the home of many spices of wild animals that depend on the lake for their water requirement and habitant. OlkariaGeothermal power plant located south of the lake generates about 18% of the country's electricity demand. These geothermal wells are recharged by water from the lake. Drying of the lake means loss of a vital source of livelihood for the inhabitants of Naivasha area and a big blow to the Kenyan Economy. Regulation of the water balance is crucial to ensure sustainable exploitation of the natural resource.

1.3 Research Objective.

The main objective of this research is to model the fluctuation of the lake level using long-term Hydro-meteorological time series data and deduce if the fluctuation of the lake level can be explained using hydro-meteorological data. Neo-tectonic activities within the rift valley floor could lead to depletion of the lake water through faults and fissures.

The focus will be on modeling of

- Water inflow and evaporation from the lake.
- Quantify water abstractions from the lake.

- Model Water balance of the lake and the corresponding lake levels

- Compare modeled versus observed water levels

The following questions will be answered,

- Could the fluctuations of lake Naivasha water level be purely a result of hydro-meteorological factors coupled with water abstractions?

- Could neo-tectonic activities within the riftvalley floor be influencing the fluctuation of the lake level

1.4 Methodology

1.4.1 Field work

Field work entailed collection of hydro-meteorological data
River discharge data for rivers Malewa, Gilgil and Karati were obtained from Ministry of Water development, Nairobi, Kenya and ITC DataBase

Precipitation and evaporation data were obtained from the same source above.

1.4.2 Data analysis

1.4.2.1 Filling data gaps

Missing data gaps were filled through

- Correlation and regression analysis between gauging stations

- Rainfall-runoff correlation.

1.4.2.2 Testing data for consistency

Consistency check was done using Spearman's Rank-correlation method and mass curves analysis.

1.4.2.3 Evaporation data

- Evaporation losses from the lake are quantified
- Using pan evaporation data

- Remote sensing technique data (results from my colleagues proposed research)

1.4.2.4 Water Abstractions

Water abstractions from the lake are quantified

- Using field work data
- Data from Ministry of Agriculture, Nakuru, Kenya
- Data from water Resources Assessment and Planning Project, Kenya (WRAP)
- ITC Data Base

1.4.2 Water balance model

Water balance of lake Naivasha is modeled using a water balance model developed on spread sheet. The water balance model uses mass conservation equation for the various water balance components.

1.4.3 Literature review

Lake Naivasha being a fresh water lake within the Kenyan riftvalley with no known outflow has drawn many reaschers interested in different aspects of the lake.

Exploration of the Naivasha area began as early as the 1880's by European explorers. Thompson, of the Royal Geographical Society of England, during a visit at that time, he noted the freshness of the lake's waters, and attributed it to the lake being either of recent origin, or having an underground channel (LNROA, 1993).

Gregory (1922) suggested that the lake's freshness is due to an undiscovered underground outlet. Nilsson (1932) proposed the lake's freshness is a result of water both entering and leaving the lake via underground seepage. In 1936, Sikes made the first statistical attempt to estimate a monthly and annual water budget for the lake, and estimated the magnitude of the proposed underground seepage. It is uncertain which methods he used, but he estimated water was seeping out of the lake at a rate of 43 x 10^6 m^3/yr (Darling et. al, 1990). McCann (1974) estimated that about 34 x 10^6 m^3/yr of water recharges the shallow groundwater aquifers from Lake Naivasha.

Gaudet and Melack (1981), on the basis of rain, river and lake water chemistry concluded that there is a subsurface water outflow from Lake Naivasha. Ase, et al., (1986) worked on the surface hydrology of Lake Naivasha. He calculated the lakes monthly water balance for the period 1972 to 1980 based on mass balance equation. He estimated ground water outflow in the range 45-50 million cubic meters per month. Darling et al. (1990) were able to indirectly determine (using stable isotope analysis and a water mixing model) the directions of subsurface outflow from the lake. They concluded that there is considerable outflow to the south (50-90% of lake outflow) and significantly less outflow to the north. (Their research suggests that the northerly outflow is confined to the area between Eburru and Gilgil, while the southerly outflow is between Olkaria and Longonot.) This concurs with the work of Allen et al. (1989) who previously came to the same conclusion that most of the lake outflow ends up between Olkaria and Longonot.

Ojiambo (1992,1996) discusses the hydrogeologic conditions around the lake. He indicates that the main subsurface outflow is from around the intersection of Oloidien Bay and the main lake with outflow fluxes ranging from 18 x 10^6 to 50 x 10^6 m^3/yr. Table 1.1 below summarizes the results of Water balance studies done previously

	McCann (1974)	Gaudet and Melack (1981)	Ase,Sernbo & Syren (1986)		Ojiambo (1996) (Average)
	a	b	c	d	e
	1957-1967	1973-1975	1972-1974	1978-1980	
INPUT					
Precipitation	132	103(range 7-114)	115(range 84-149)	142(range 127-167)	121
River Discharge	248	185(range 90-260)	187(range 156-263)	254(range 143-383)	212
Surface Runoff	ND	0.6(range0.4-0.7)	ND	ND	0.6
Groundwater Inflow	ND	49(range 41-58)	ND	ND	49
TOTAL INPUT	380	338(range 208-433)	302(range 240-412)	396	382.6
OUTPUT					
Evapotranspiration	346	313(range 289-324)	308(range 294-332)	301(range 272-339)	294
Groundwater outflow	34	44(range 17-78)	ND	ND	39
Irrigation + industrial	ND	12(range 7-15)	ND	ND	12
TOTAL OUTPUT	380	369(range 313-417)	308(range 294-332)	301(range 272-339)	345
Storage change	ND	-31	0.4	95	37.6

Table 1-1Comparison of Lake Naivasha Hydrological balance from different researchers.
Units in million cubic meters per year.[mcm/yr].

Three bathymetric surveys of the Lake bottom have been done. The first survey was done in 1927 by the public Works Department (PWD). The others were surveyed in 1983 by Ase and published in Ase et. al(1986) , and in 1998 by WRAP surveyors respectively The lake shows almost the same morphology in the three surveys Bathymetric map of the Lake taken in 1983 by Ase et. al(1986) show similarities to the one draw by the public Works Department (PWD) in 1927 and reproduced by Thompson and Dodson (1963) except for the depth contours of Oloidien bay. Whereas the 1983 maps show the maximum depth of Oloidien bay as 11.5 meters, the PWD map gives a maximum depth of 4.3 meters despite the fact that the Lake level in 1927 was nearly 3 meters higher than in 1983. Ase, Sernbo and Syren, (1986) contend that this large difference may be due to lack of sufficient depth data taken in 1927. This may be a plausible explanation bearing in mind that echo sounding technlogy was not employed then.

CHAPTER: 2

BACKGROUND INFORMATION

2.1 Location

Lake Naivasha Basin is situated in the kenyan rift valley almost 100km northwest of Nairobi. It is located between latitude $0^o09'$ and $0^o55'$south and longitude 36^o09 and 36^o24, East. Aberdare ranges bound it to the east, to the south by Mt. Logonot, southwest by Mau Escarpments and northwest by the Eburu Mountains. The Nyandarua plateau lies to the North.

2.2 Drainage

Three major rivers drain the Basin namely Malewa, Gilgil and karati. Malewa is the biggest, with a catchment area of about 1600km^{2}and contributing about 80% of the discharge into the lake. Gilgil with a catchment area of 527 km^2 and Karati with a catchment area of about 149 km^{2}contribute the remaining 20% of discharge into the lake. See figure 1.1 .The lake and the surrounding catchment drained by ephemeral streams which disappear underground before reaching the lake have a catchment area of about 1000km^2. This makes the total basin area to be about 3376 km^2.

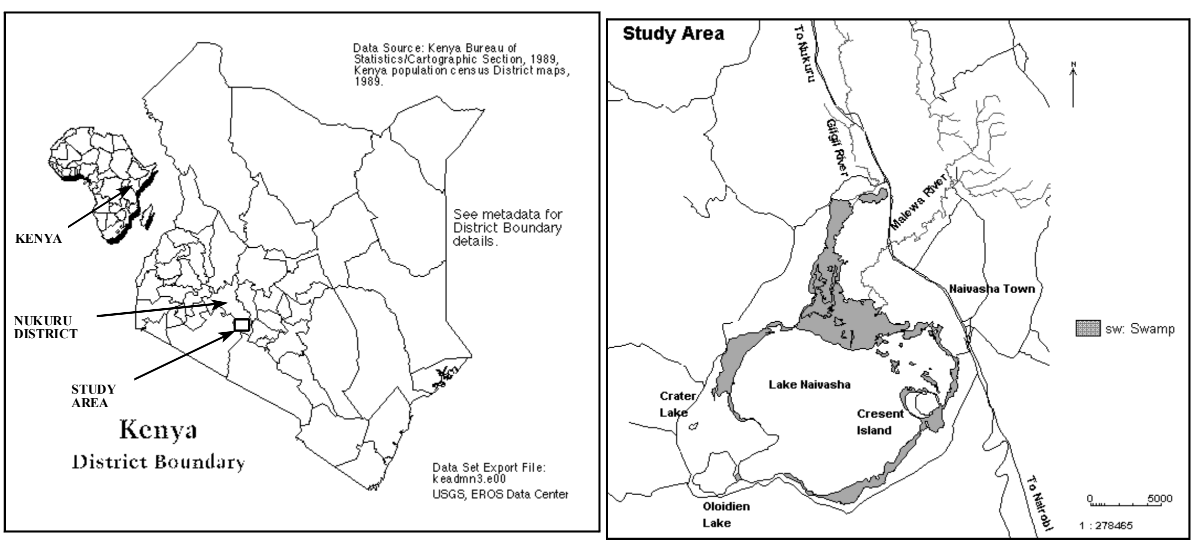

Figure 2. 2. Location Maps of the study area

2.3 The lake

2.3.1 Lake Ecosystem

The lake itself is a shallow freshwater lake at mean altitude of 1887 m above sea level and a mean surface area of 145 km^2. The lake ecosystem consists of a main lake, a smaller, sometimes separate during low lake levels, Oloidien lake located to the southwest of the main lake, and a detached crater lake to the west. Crater lake is the smallest. The lake also as an island to the east called Crescent Island. See figure 2.1. The part of the main lake surrounding Crescent Island is named Crescent Lake.

2.3.2 Lake Morphology

The Lake is shallow with an average depth of 4.4 meters. It as very flat bottom with mayor decrease in depth only close to the shores. The deepest part of the main is located near Hippo Point on the southern western part of the lake. It is 9 meters deep (Ase et al 1986). A WSW-ENE profile of the Lake bottom shows the flatness of the main part of the Lake and the crater like morphology of the two deepest parts of the Lake, the Oloidien bay and Cresent Lake. Ase et. al (1986) state that the flatness may be due to the fact that the basin has filled up with large quantities of sediments that has resulted in the development of an even bottom topography. The two deepest parts of the Lake have typical crater shaped morphology indicating volcanic origin of formation. See figures 2.2 to 2.5 below.

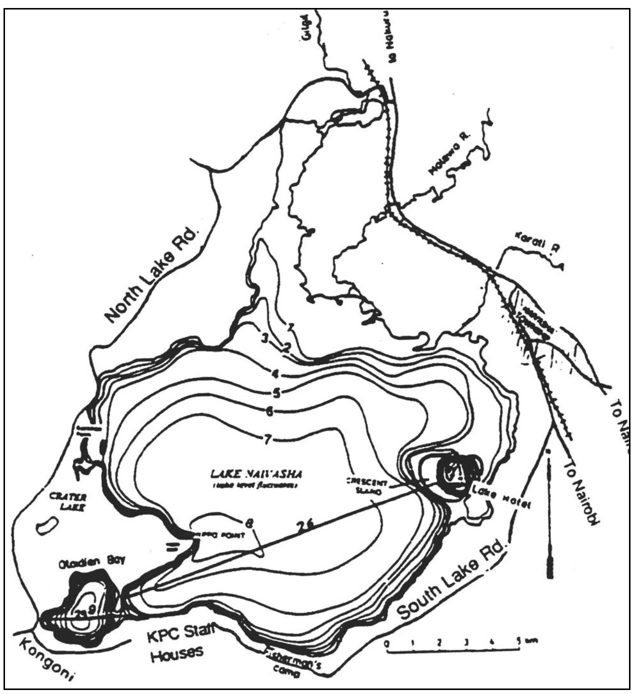

Figure 2-2 Bathymetric map of Lake Naivasha based on October 1983 levels (modified from Ase et. al, 1986).

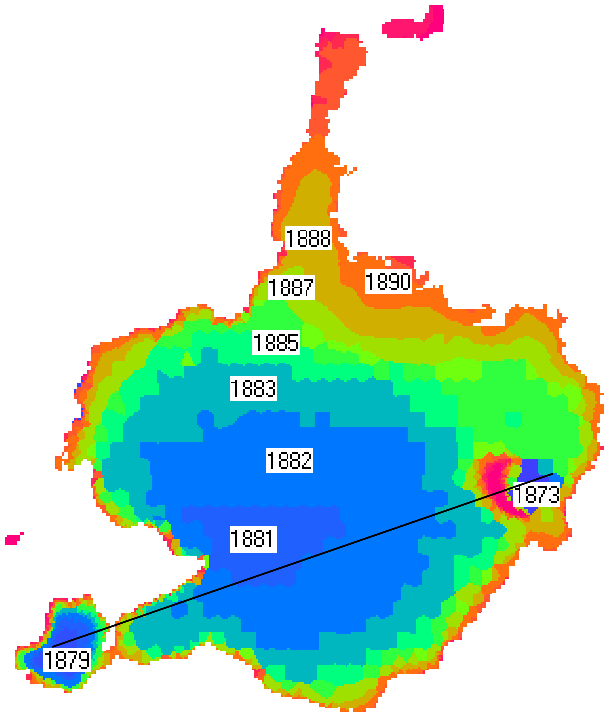

Figure 2-3. Bathymetric map of Lake Naivasha based on November 1998 levels (WRAP).

The cross section shownin figure 2.5 is drawn across the section line shown on the map

Figure 2-4 Bathymetric profile of Lake Naivasha from Oloidien Bay to Crescent Lake, based on soundings 29, 26 and 22 shown in Figure 2.3a (modified from Ase et. al, 1986) d) Bathymetric

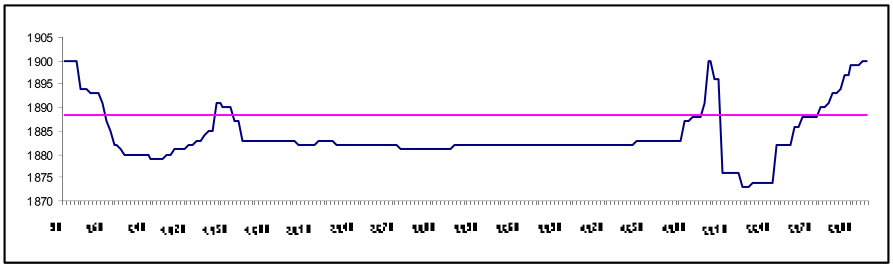

Figure 2-5 profile of Lake Naivasha from Oloidien Bay to Crescent Lake, based on bathymetric survey of WRAP (1998).

2.4 Climate

Climatic conditions in the study area are quit diverse due to considerable differences in the altitude and landforms. Although the lake is located within one degree of the equator and is thus "tropical", it generally experiences relatively cool conditions determined by altitude (Richardson and Richardson). The annual temperature range is approximately from 8^{o}c to 30^{o}c(Kenya government, 1976). The rainfall regime within the lake catchment is influenced by the rainshadow from the surrounding highlands of the Aberdare range to the east and the Mau Escarpment to the west. Two rainy seasons are observed in this region. The "long rains" occurring in March to May and the "short rains" in October and November. Most of the rain is received during the "long rains". Relief controls the rainfall pattern, with much more rainfall in the higher altitudes than the lower altitude.

Naivasha on the Riftvalley floor experienced an average annual rainfall of 640.8 mm, for the period 1932 to 1997,as measured at Naivasha D.O' office. While the wettest slopes of the Nyandarua Mountains receive as much as 1525 mm. The evaporation experienced by Naivasha average 1801mm annually for the period 1959 to 1990, as measured at Naivasha water Development office using a standard class A pan.

2.5 Landuse

Five major landuse units can be identified in the area:

a. Agriculture (horticulture and flower growing)

b. Settlements,

c. Game scantuaries,

d. Rangeland (dairy) and natural vegetation.

e. Forests

Horticulture and flower growing is concentrated around the lake. Vegetable and dairy farming is practiced on large estates mainly in the northeast shores of the lake. Game sanctuaries are mainly present in the west of the study area. However wildlife occupies most of the barren shrub, grass lands. Settlement is mainly concentrated in Naivasha town but scattered homes and villages are present on estates within the study area. The natural vegetation surrounding the lake is mainly papyrus swamp vegetation. Natural vegetation outside of the lake surroundings are shrub, acacia, cactus trees and savannah.

2.6 Hydrogeology

The lake Naivasha sub-catchment is the most important of the Rift valley floor because of its fresh water status and its hydrothermal potential. It is most complex hydrogeologically due to the rift floor geometry and tectonics (Clarke et al. 1990) .

The main aquifer is the Lacustrine volcanic/ sedimentary series usually occurring as fractured or reworked volcanics, or along the weathered contacts between lithological units. Generally permeability of the rocks in the study area are low.

The floor of the rift valley is covered by young volcanic lake sediments which is a continuous unconfined aquifer with high permeability. It consist of reworked volcanic sediments and forms the major part of the Naivasha area. Estimated hydraulic conductivities averaged 10 m/d and a well yield on average of 3 l/s/m. However Clarke et. al. (1990) indicated from an inventory of boreholes in the lake sediments and volcanics, estimated permeability of 12 - 148 m/d from the NE to the NW of the lake. The lake sediment aquifer constitutes a perched aquifer (ITC-WRAP Phase V, 1996).

The fractured volcanic rocks are often confined or semi-confined with low storage coefficients (Stuttard et al., 1995). Tuffs on the east of the lake are reported to have conductivities of an average 0.8 m/d and the trachytes to the south east and in the west of the study area 1.1 m/d. Average well yield for the tuffs, basalts and trachyte is around 0.2 l/s/m.

CHAPTER 3

3.0 DATA ANALYSIS

Data analysis was done to prepare data for input in the water balance model discussed in chapter Four. Analysis involved preparation of river discharge data, precipitation, Lake Levels and evaporation data. Table1 below gives a summary of available discharge data.

DISCHARGE RECORD SUMMERY OF NAIVASHA BASIN

SL.No.	Name of Station	Code	Data record available	Remarks
1.	MALEWA-GILGIL	2GB1	JULY/31 - AUG/85	* START-97
2.	MALEWA-GILGIL	2GB2	XX	CLOSED
3.	MALEWA	2GB3	SEP/50 - DEC/92	
4.	WANJOHI	2GB4	JAN/61 - JUN/94	*63 - 73 NO RECORD
5.	MALEWAI	2GB5	DEC/58 - JUN/88	
6.	MALEWAI	2GB7	JAN/60 - JUL/94	
7.	TURASHA	2GC4	AUG/50 - DEC/97	
8.	NANDARASI	2GC5	JULY/58 - MAR/94	
9.	TURASHASI	2GC7	SEP/50 - NOV/93	
11.	GILGIL	2GA3	DEC/58 - DEC/94	
12.	GILGIL	2GA5	DEC/59- FEB/88	* CLOSED
13.	LITTLE GILGIL	2GA6	JAN/68 - NOV/92	
15.	KARATIAS	2GD7	JAN/62 - OCT/90	

Table 3.1 Available discharge data.

3.1 Disharge data

Stations $2GB_1$, $2GA_5$, and $2GD_2$ in rivers Malewa, Gilgil and karati respectively were chosen for analysis and consequence use in the water balance model. The decision to use these stations was based on their proximity to Lake Naivasha. This means that the flows as gauged on these stations to a large extent exclude diversions from the rivers. This solves the problem of subtracting water diversions from the gauged flows, which would have been necessary, if gauging stations far upstream were selected.

3.1.1 Station 2GB1

Station 2GB1 had data commencing from 1931 to present. The data was however incomplete due to many data gaps ranging from few days to months within the data. Podder, Msc. Thesis, 1997, worked on the flow series of this station from 1960 to 1990. He infilled all data gaps using linear interpolation, simple and multilinear regression with neighboring stations.

The same technique was used to infill data from 1950 to 1960. Stations 2gc4, 2gb3 and 2gc7, which have data dating back to 1950 were chosen to infill 2GB1 monthly series. Station 2GC4 has the best correlation with station 2GB1 followed by 2GC7 while 2GB4 had the worst correlation and was thus not used. The scatter plots below, figures 3.1to 3.3 show this correlation graphically plus the R^2 coefficient and the regression equations.

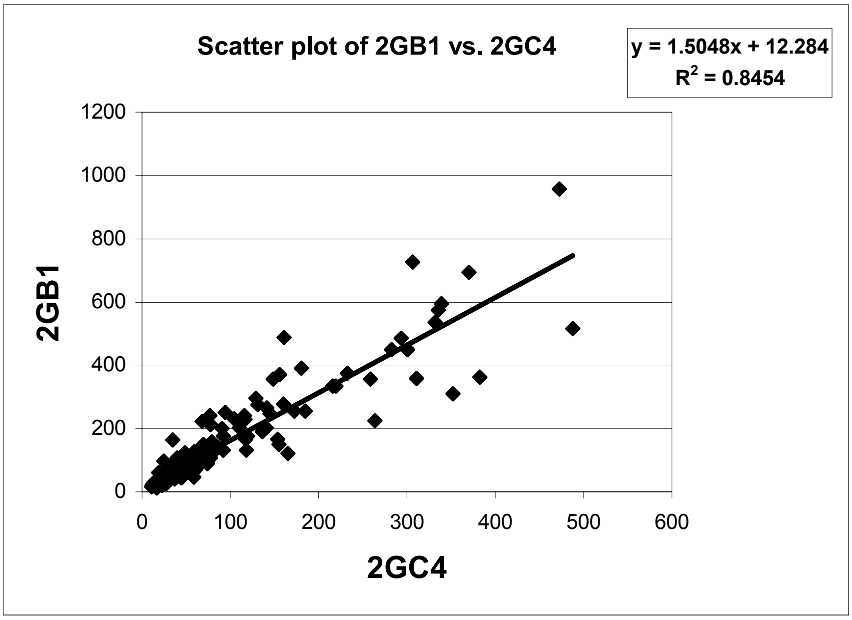

Figure 3-1 Scatter plot of 2Gb1 versus 2gc4 monthly flows. The regression equation and R^2 coefficient are displayed on the graph.

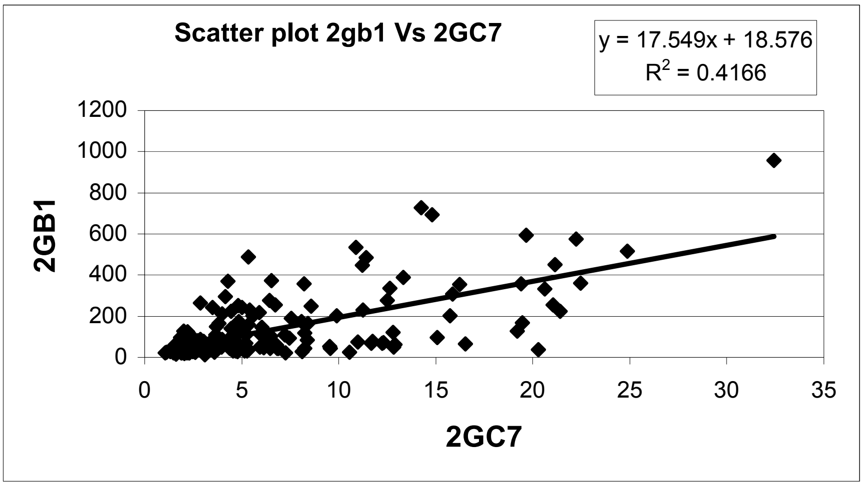

Figure 3-2. Scatter plot of 2Gb1 versus 2gc7 monthly flows. The regression equation and R^2 coefficients are displayed 0n the graph.

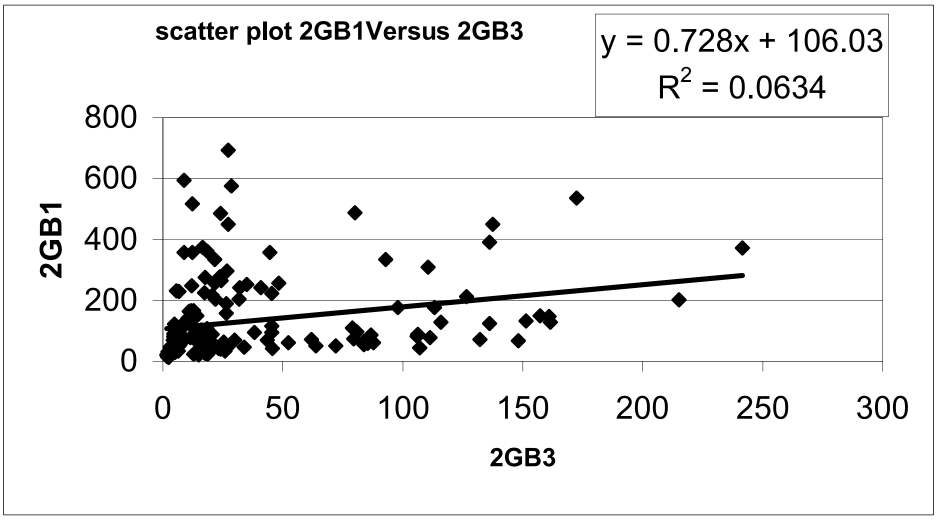

Figure 3-3. Scatter plot of 2GB1 versus 2GB3 monthly flows.

The regression equation and R^2 coefficient are displayed in the graph. The correlation was so poor that the station was not used in data infilling.

Infilling of data gaps for the period 1932 to 1950 was done solely using linear interpolation. This is simply because no neighboring gauging station exists which has data for this period. An attempt to infill data using rainfall- runoff modelling was unsuccessful owing to poor correlation between rainfall and ruoff. The best correlation factor obtained was 0.3 for the month of December. Podder,Msc. Thesis, 1997 and Ase, et al, (1987) both tried rainfall- runoff modeling with the same poor results. Ase,et al, (1987) attributes the poor correlation to poor unrepresentative distribution of rainfall stations and the effect of ground water which seems to have a time lag of about month from the peak rainfall. Attempts to correlate rainfall with runoff by giving the rainfall an early shift of a month and two months respectively were also unfruitful. Even though data for the period 1932 to 1950 were linearly interpolated, on average the data gaps within this period were short averaging six days and thus the errors can not be large. The only problem could be during the rainy months where linear interpolation would lead to under-estimation or over-estimation depending on the magnitude of values in bounding the data gap. But as stated earlier, due to on average short data gaps this error is not major. The two series from 1932 to 1950, are presented in figure 3.4 below.

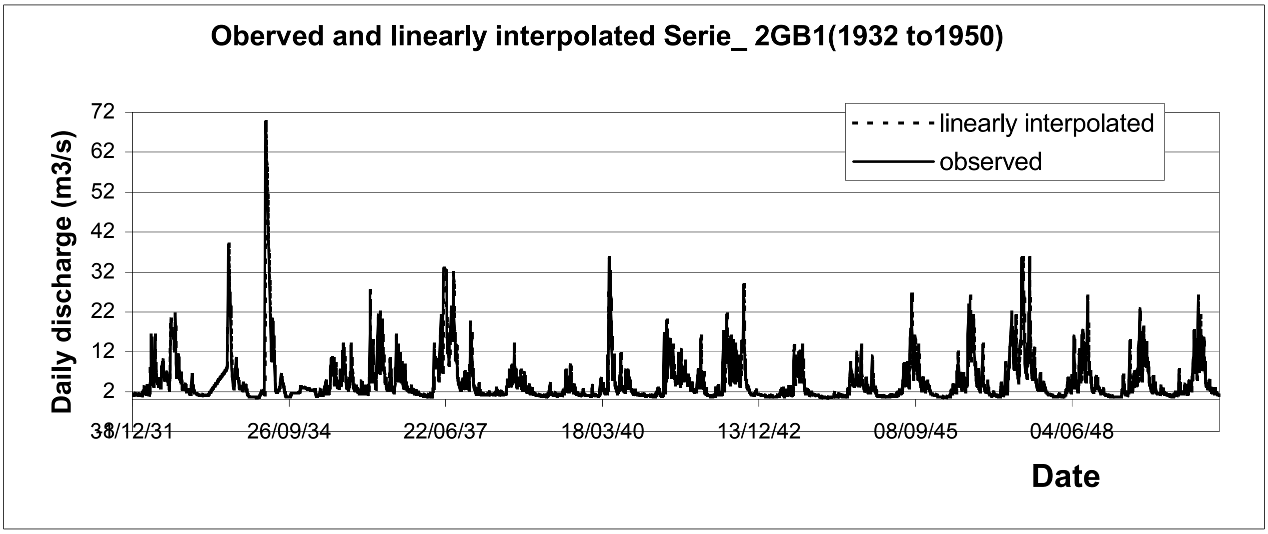

Figure 3-4: GB1 discharge series (1932 to 1950), Data gaps infilled using linear interpolation

The final malewa flow series is represented in figure 3.5 below. The extra-ordinarily high flows measured in 1961- 1963 were as a result of extra ordinary high rains, which were received in Kenya during that period. The peak of the rains was in 1962, which is reflected by the flow peak of November 1962 on figure 3.5 below. See also figure 3.8 for rainfall data. In 1997, again extra-ordinarily high rains were received and once the pick in discharge at the end of the series is evident.

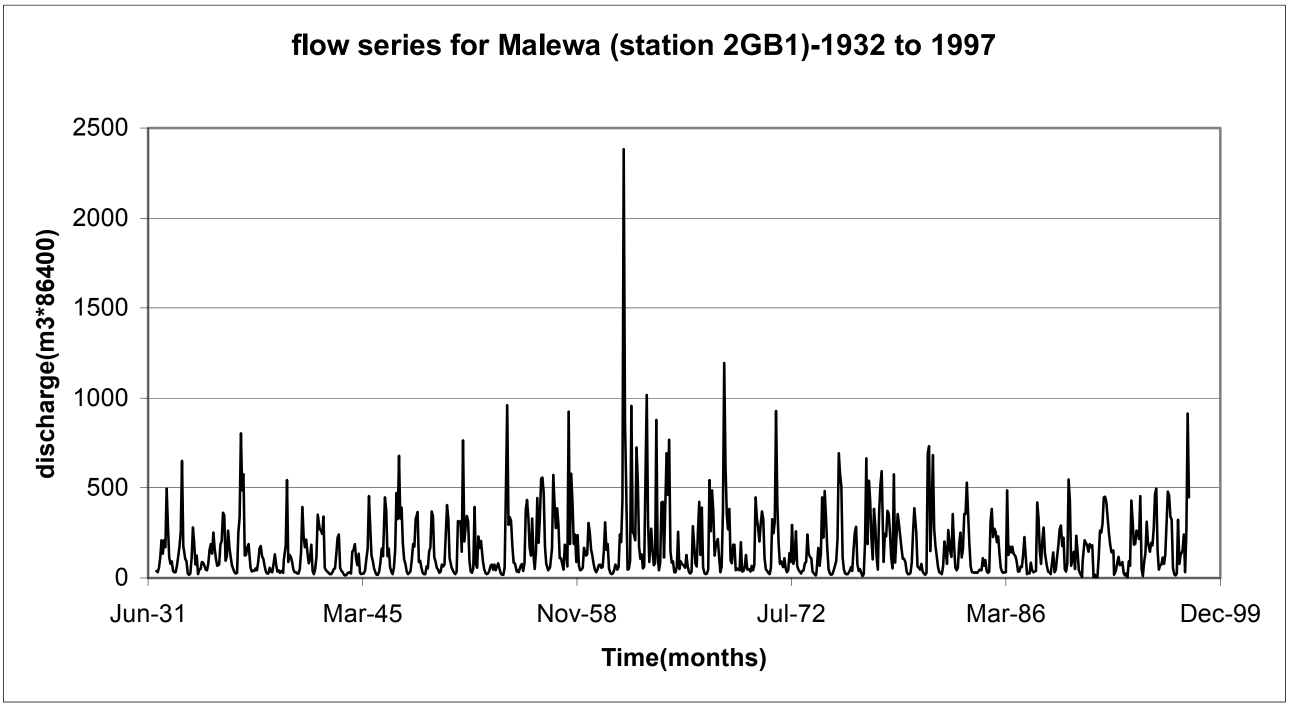

Figure 3-5 : Final infilled flow series of Malewa river. Gauging station 2gb1

3.1.2: Gilgil Flow Series (Station 2GA5).

Gauging station 2GA5 was selected to develop discharge series for Gilgil River. As mentioned earlier the station was selected due to its proximity to Lake Naivasha. It is the last station downstream of Gilgil River. The Station has data commencing from December 1959 to present. The data was incomplete due to missing data gaps. Gaps in this series were filled using stations 2GB1, 2GA3 and 2GA6. The latter two stations are located in Gilgil River upstream of 2GA5. 2GA6 is located on a tributary of Gilgil river known as little Gilgil just before confluence of the two. Inspection of scatter plots of 2GA5 versus any of the other stations revealed elements of heteroscedasticity. This problem was overcome by plotting the logs of the data. An attempt to use rainfall –runoff relationship to infill data gaps was also unsuccessful due to poor correlation at monthly level.

The data series for this station was extended from 1958 to 1932 using regression with station 2GB1. The regression was done using log transformed data to ensure homoscedasticity of variance. According to Ase et al, 1987, this station contributes about 20% of the total discharge into lake Naivasha.

The regression equations used for data infilling are as follows

- Log2GA5 = 1.033*log2GA3-0.263
- Log2GA5 = 1.401*log2GB1-2.291

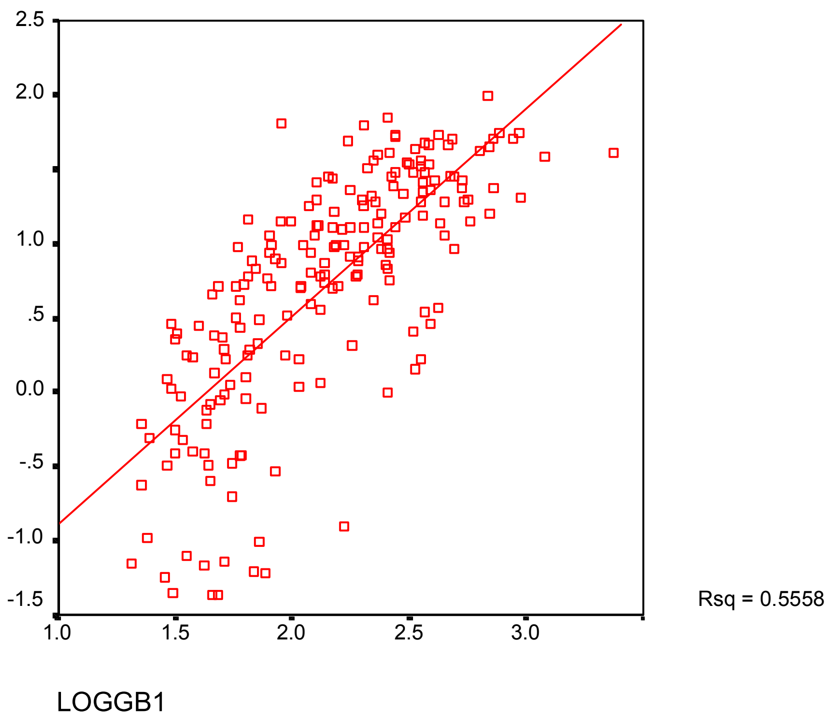

Figure 3-6 Scatter plot of log transformed discharge data for station 2GA5 and 2GB1.

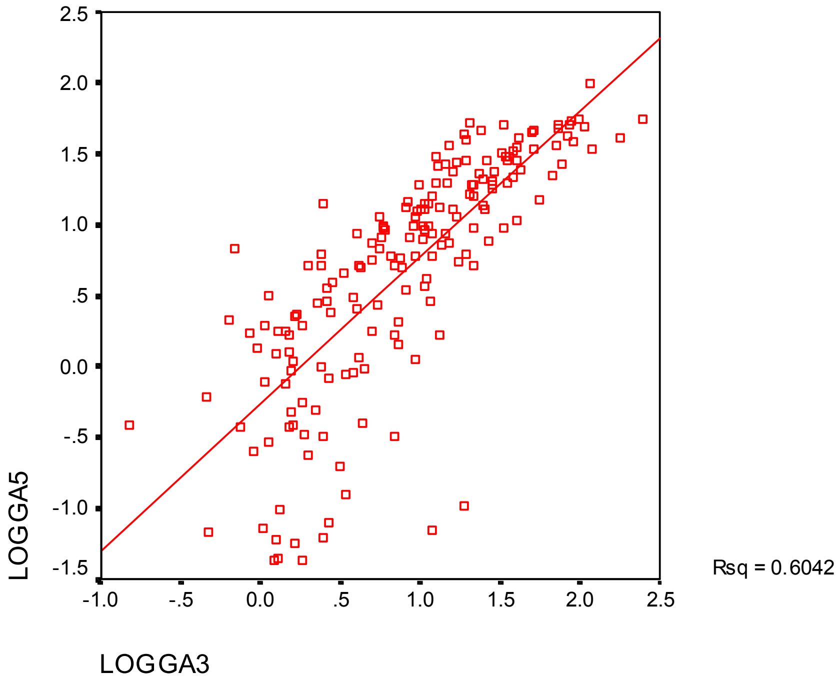

Figure 3-7 : Scatter plot of log transformed discharge data for station 2GA5 and 2GA3.

Correlations

		LOGGA5	LOGGA3	LOGGB1	LOGGA6
LOGGA5	Pearson Correlation	1.000	.777	.746	.280
	Sig. (2-tailed)	.	.000	.000	.007
	N	199	181	199	93

Table 3.2 correlation between stations used to infill data gaps for station 2GA5.

Correlation is significant at the 0.01 level (2-tailed).

3.1.3 Station 2GD2

This station had data commencing from 1952 to 1982. The data was in very poor state in terms of data gaps. The data gaps were infilled using correlation and linear regression with Station 2GB1 and rainfall runoff relationship using Naivasha water development Department Rainfall station. This river drains the smallest catchment among the three mayor rivers and its contribution to Lake Naivasha is negligible.

4.2 Rainfall data

Rainfall data was necessary to compute the direct precipitation into Lake Naivasha. Naivasha Distrct officer (DO) rainfall station data was used for this purpose. The station had data for the duration 1910 to 1997.Data gaps in the series in 1977 was infilled using a neighboring rainfall station, Kenya Meteorological department # 9036179, located at korongo farm on the western shore of the Lake.

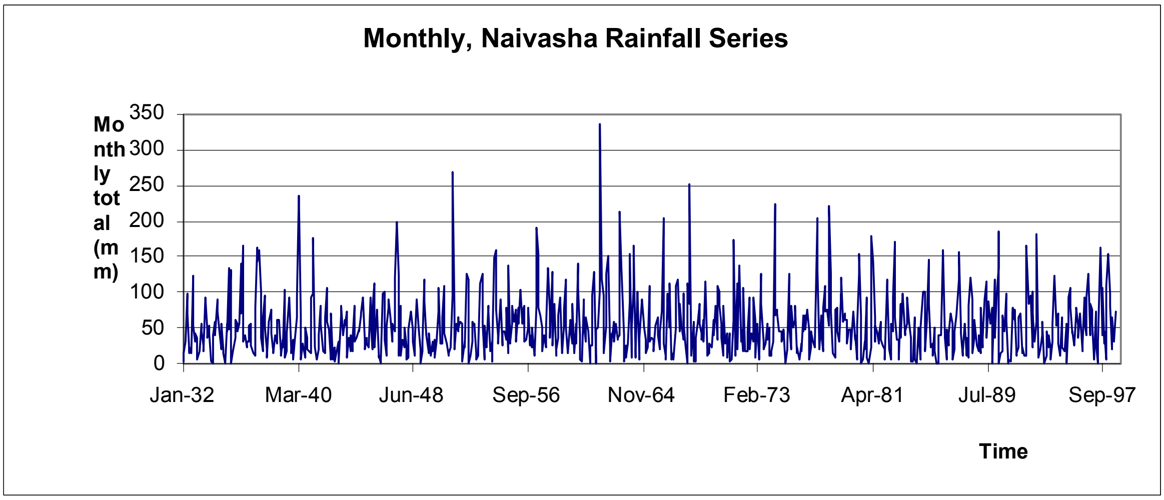

Figure 3-8: monthly rainfall data series as measured at Naivasha Water office. Represents direct precipitation into Lake Naivasha.(1932 to august 1998)

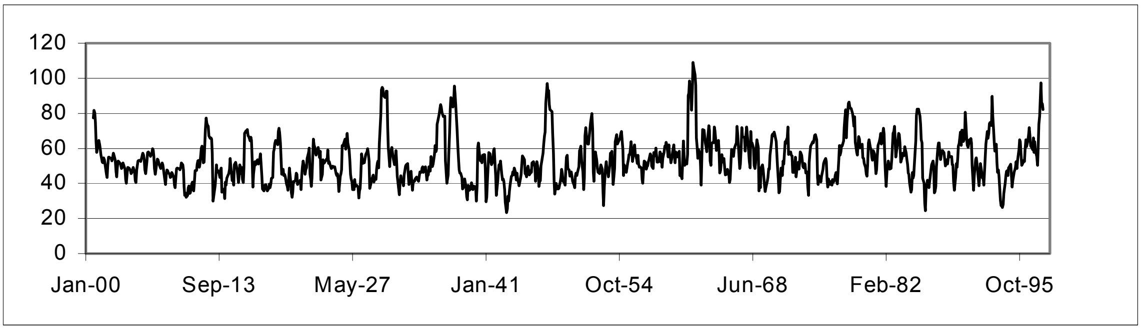

Figure 3.9 10 months moving average Naivasha DO rainfall station.

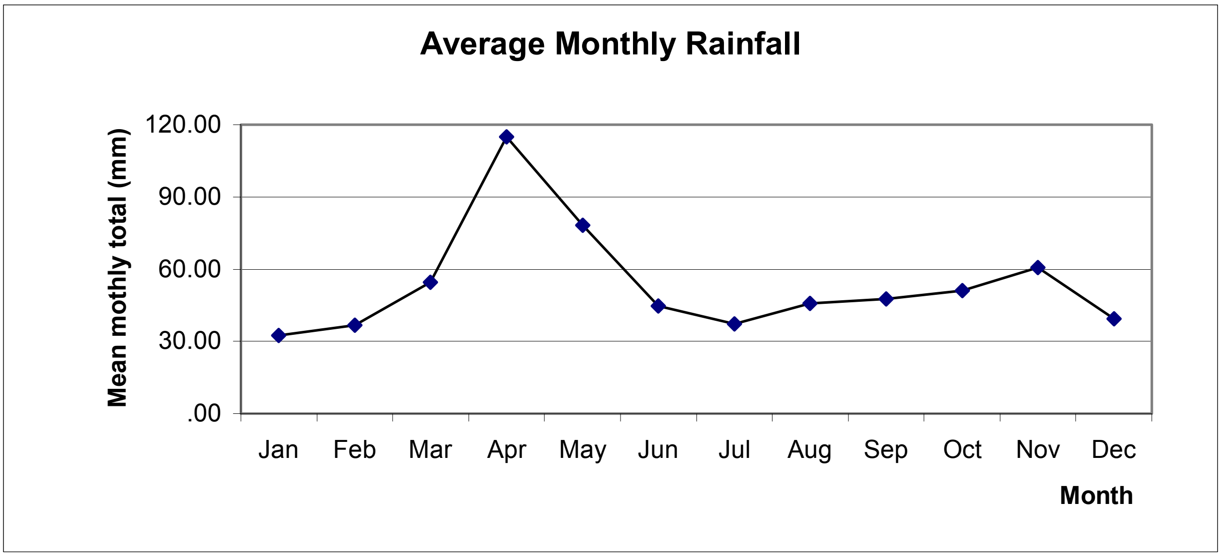

Figure 3-9: monthly Average rainfall as measured at Naivasha District Officer, Kenya. (1932 to 1997)

3.3 Evaporation data

Evaporation data was required to compute the evapotranpiration component of the water balance. Evaporation is very crucial to the lake's water balance. Being a shallow lake within a semi arid climate, the lake is subject to high evaporation loses. Data was obtained from Naivasha Water Development Department. Evaporation Data commenced 1959 and recorded up to 1990. The data was transformed from tabular format to single column format and screened for typing errors and outliers using scatter plots. Apart from 1972, 1978and 1958 which had missing data in the some months, the only other data gaps were consistence two days a week corresponding to Saturday and Sunday. These consistence data gaps were infilled using linear regression. In order to backdate the evaporation data from 1959 to 1932, longterm monthly averages were computed. In this analyses the three years, 1972,1978 and 1958, with missing months of data were excluded. These long-term averages were used to infill months with no recorded data.

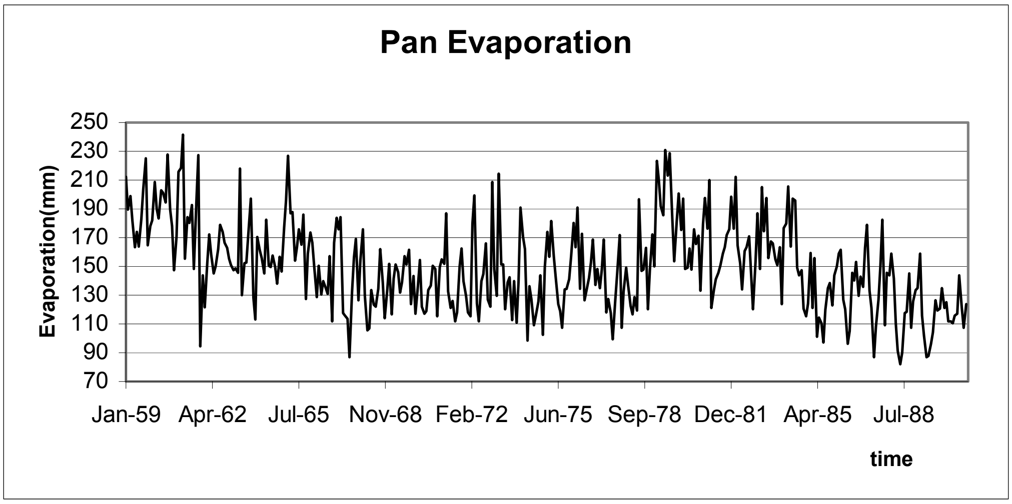

Figure 3-10: Monthly pan evaporation as measured at Naivasha water development office. (1959 to 1990)

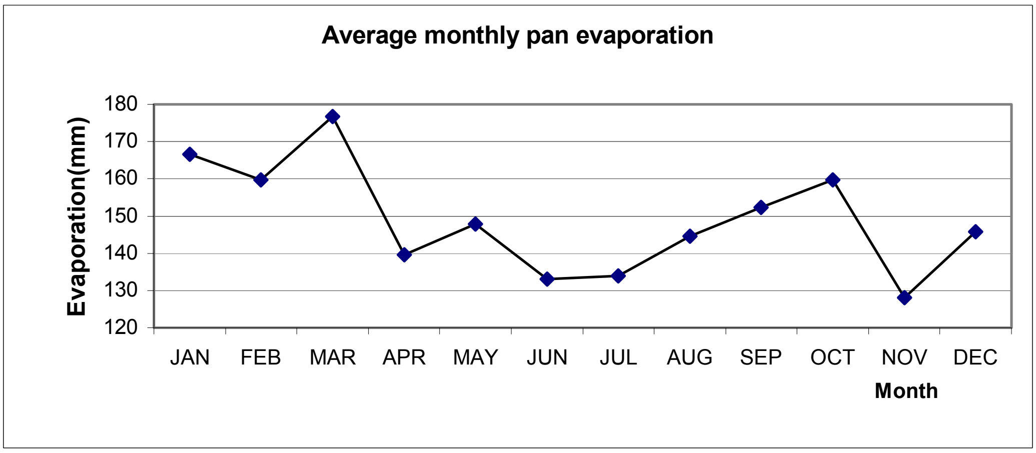

Figure 3-11: Long-term monthly average pan evaporation

as observed at Naivasha Water Development office. The data is used to approximate evaporation from the lake.

3.4 Lake levels

The water levels of Lake Naivasha have been monitored since 1908.Three monitoring station have been operational at various times on the lake. However these stations are located in different locations and have variable record duration. Station 2GD4 is located in Oloidien Lake situated on the southwest of the main lake. During low water levels the two lakes are separated but become one lake at higher lake levels. This station has data from 1959 to 1992. Station 2GD6 located on the Eastern Shore of the main lake has data from 1967 to 1987. Station 2GD1 has data from 1908 to april1982. This station is located on the western shore of Crescent Island located on the eastern part of the lake. The data for this station exists in two formats. One format is water level hydrograph drawn by ministry of Water development, Kenya for the Duration

1908 to 1968 and the other is hard copy tabular data for maximum monthly water levels for the period 1951 to April 1982.This too is from Ministry of Water Development, Kenya. Apart from these monitoring stations, some individual farmers neighboring the lake have monitored the lake levels at various times and kept the data in their farms. Notable among these individual farmers is Sulmac , Vulghan and Menning. Their data is discussed here later.

3.4.1 station 2GD1

Data for this station were converted from hardcopy hydrograph to digital format by digitizing. To digitize the chart, the date axis was converted from date to number format to obtain the minimum and maximum values to use in a co-ordinate system. Digitizing was done for the period 1900 to 1968. Thus 1/1/1900 was converted to number format and used as the minimum X-cordinate and the same done for 29/2/1968 which was used as the maximum X-co- ordinate. The minimum and maximum water levels were used as the minimum and maximum Y co-ordinates respectively. The Lake water level hydrograph was digitized as a segment map. The resultant segment map was converted to a point map using the distance option in ILWIS2.2 with the conversion distance set to 1 meter.1 meter in the X-axis implies one day. Thus the expected results are daily water levels. The resultant point map was opened as a table. The table contained date in number format as the X co-ordinate, and water level as the y co-ordinate of the converted points. The table was then transferred to excel spreadsheet. Here the date column was reconverted to date format and the water levels aggregated to monthly mean water levels.

Figure 3-12: lake water levels digitized from lake level hydrograph published by Ministry of water Development, Kenya. (1900-February1968)

The other series of water levels for 2GD1 existed as hardcopy tabular data. The record duration is from January 1951 to April 1982. The data is a record of maximum, monthly lake levels. This series was keyed into excel spreadsheet and the two series, the digitized data above and tabular data combined to form one series from 1932 to 1982 April.

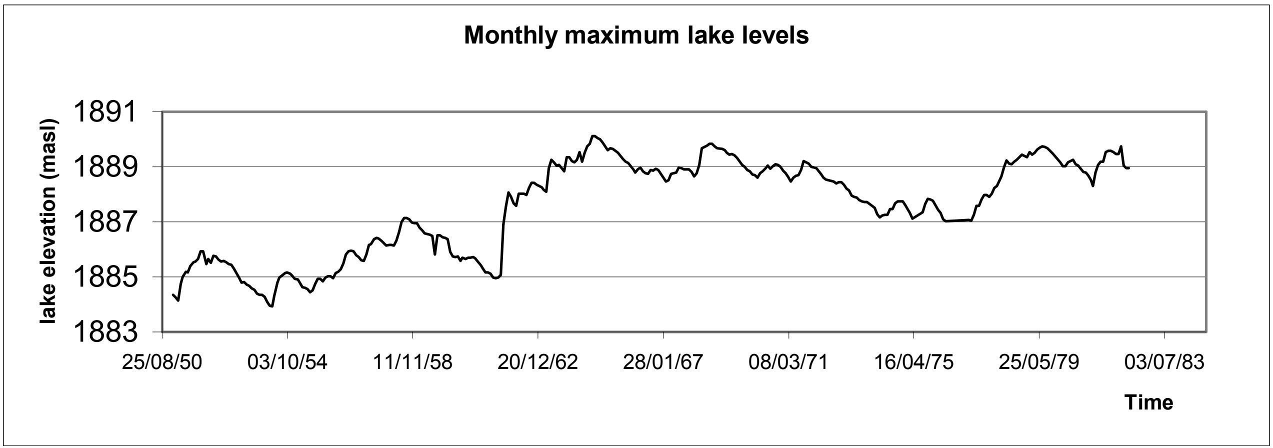

Figure 3-13: Observed maximum monthly lake level. (1951 to April 1982)

3.4.2 Station 2GD6

This station located on the eastern shores of Lake Naivasha has data from 1967 to 1987. Readings were normally done twice a month. The data was screened for typing errors and outliers using time scatter plots. Linear interpolation was done and the data then aggregated to monthly values.

The 2GD6 series was then plotted together with data for station 2GD1 in a times plot. It was evident that the two stations are highly correlated and displayed the same distribution of lake water levels with time where they overlapped. However there was an addative shift of 3.6 meters between the two stations' data. 2GD1 recording the higher values. This shift is attributed to the datum used to change the observed water levels to height above sea level. This datum is controversial in the area and different people have used different values. The shift was removed by adding 3.6 meters to 2GD6 values. The two series were combined extending the observed lake levels from April 1982 to1987. See figure 3.14

3.4.3 Sulmac Lake Level Series

Sulmac is among the oldest horticultural companies which as been practicing irrigated farming using water from Lake Naivasha. The farm is situated in the southern part of lake. Having vested interests in the lake, the company did its own weekly monitoring of the levels. Their weekly data is available from 1984 to 1993. This data series fitted the adjusted 2GD6 data perfectly and was used to extend the water levels to 1993. See figure 3.14

3.4.4Vaughan Series

Vulghan is a riparian of Lake Naivasha. He is a surveyor by profession. Being a surveyor practicing in the area and riparian of Lake, he is an interested party in the welfare of lake. He too as been monitoring the lake levels. His data was plotted against the constructed observed Lake Levels and it fitted the latter perfectly. His data was used to stretch the observed series to 1998. Gaps in his series were filled using data from Ministry of Water Development who started monitoring the lake levels again since 1997 through Water resources Assessment and Planning Project within the Ministry. The combination of these water level series resulted in continuos observed water level data from 932 to 1998, which is the projected water balance modeling duration. See figure 3.14 and 3.15 below.

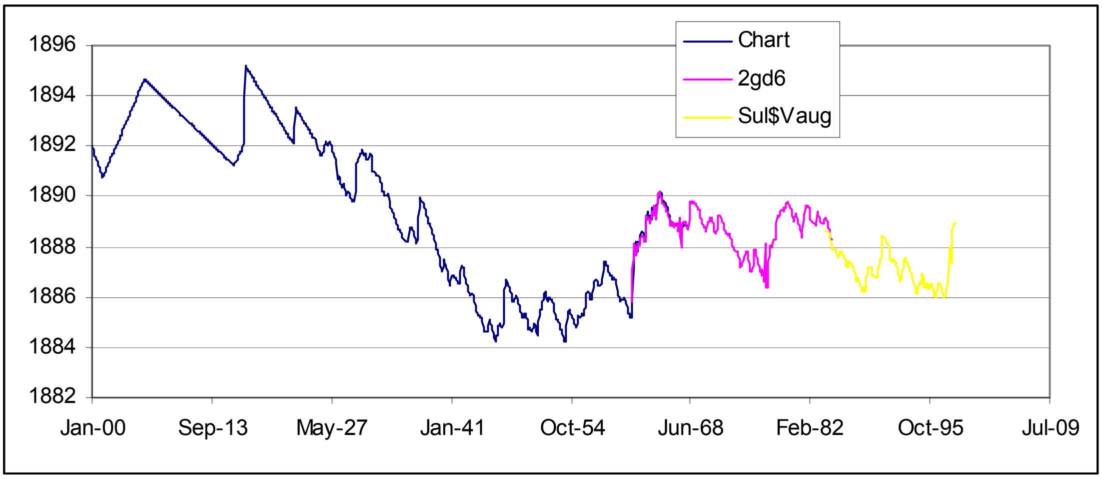

Figure 3-14: The different water level series used in the compilation of the final observed lake levels (1932 to october1998). Chart refers to the digitized ministry levels while Sul$Vaug refer to Sulmac and Vaughan data.

Figure 3-15: Reconstructed observed average monthly lake levels (1900 to October 1998)

CHAPTER 4

4.0 Water Balance Model

The purpose of this water balance model as was mentioned in chapter one, is to find out if the fluctuation of the lake level can be explained fully using hydrometeorological data and human diversions. If this can be achieved then fear of neo-tectonic activities within the riftvalley floor draining the lake would be put to rest. The water balance model is simulated for the period 1932 to 1998 and runs on monthly time steps. Data input for the model was analyzed in chapter four.

The model is based on mass conservation equation formulated below

$$P-ET+R+GWin -Gwout = dS$$

Where;

P = direct precipitation into the lake

ET = Evapotranspiration

R = Surface Runoff into the lake

GW_{in} = ground water inflow into the lake

GW_{out} = ground water out flow from the lake

dS = Change in lake storage.

The water balance model was developed on a Microsoft excel spreadsheet.

4.1 Lake level- Volume- Surface area Relationship

The lake level- volume relationship (rating curve) is very crucial to accurately convert the change in lake's storage into the corresponding lake level. While the water level-surface area rating curve is vital for accurate calculation of direct precipitation into the lake and evapotranspiration from the lake. The latter two are a function of the surface area of the lake.

The rating curves were developed using the latest bathymetric survey of the lake done in October- November by Water Resources assessment and planning project (WRAP) within the ministry of water development, Kenya. The bathymetric survey data was obtained from the latter in digital format through ITC. The bathymetric survey data was augmented with contour map data digitized from Naivasha area map sheet wherever necessary.

Surfer Software was used in the production of data used in the generation of the rating curves. A regular grid of 16 by 17 meters cells was overlaid over the digitized lake area. The bathymetric data was then used to calculate the volume or surface area at different elevations (water levels). This data was then transferred to excel spreadsheet where the respective rating curves were fitted.

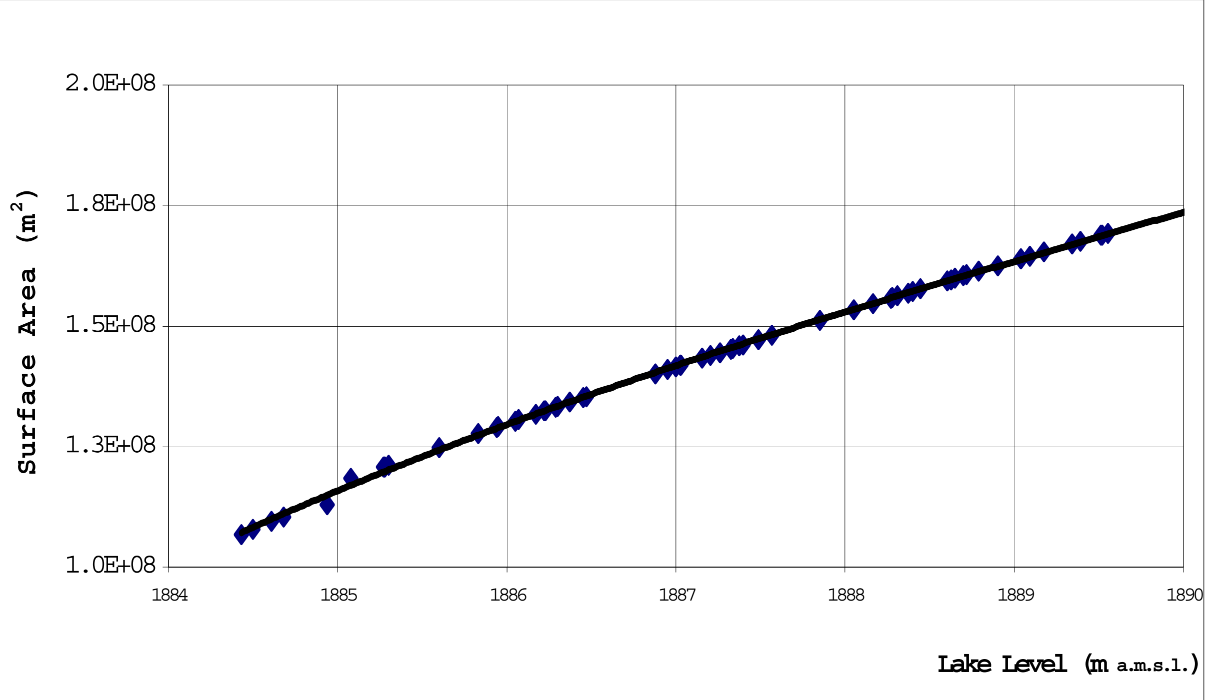

Figure 4-1: Surface area- lake level rating curve. Computed from 1998 bathymetric survey (Water resources assessment and planing project (WRAP), Kenya).

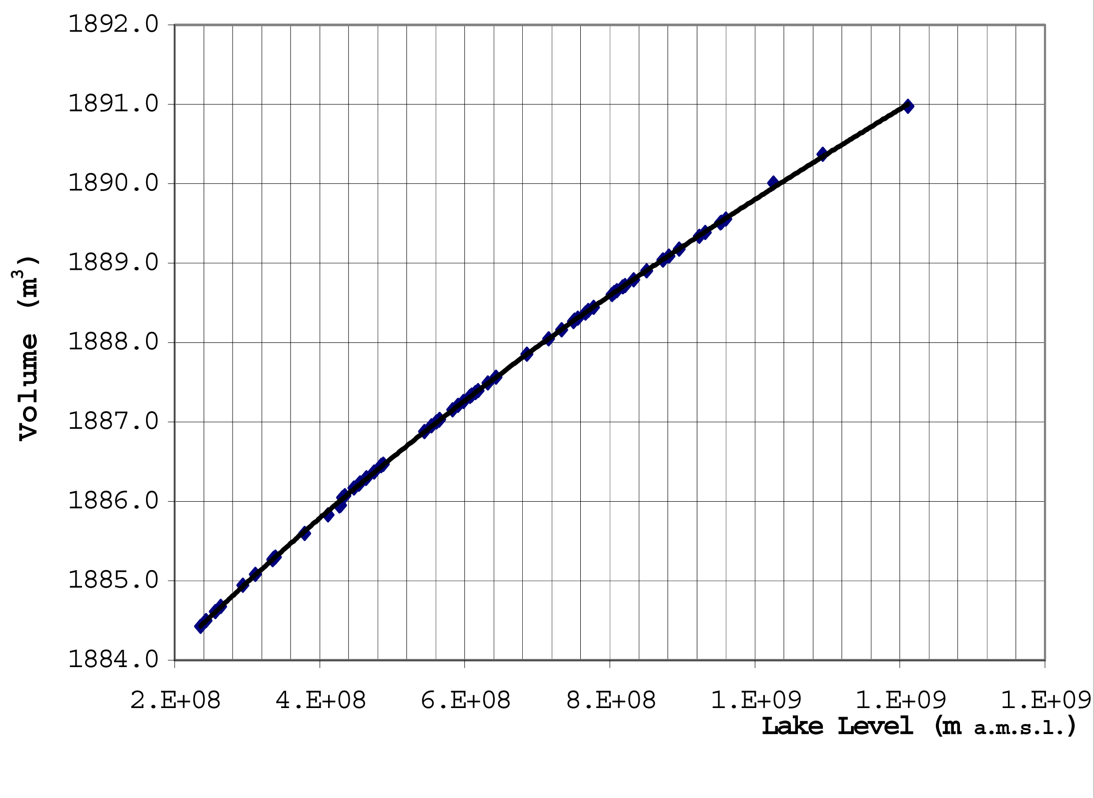

Figure 4-2: Volume - lake level rating curve. Computed from 1998 bathymetric survey (Water resources assessment and planing project (WRAP), Kenya).

4.2: Model Design

The model,as mentioned above, was developed in excel spread sheet. Input data was analysed as discussed in chapter four. Monthly discharge data for rivers Malewa, Gilgil and karati and estimated runoff from the ungauged catchment surrounding the lake were used as surface runoff (R) data. Evapotraspiration and rainfall data were obtained from Naivasha Water Development Office as earlier discussed. Initial ground water inflow and outflow were obtained from literature. See figure 4.3 below for a flow diagram of the model design.

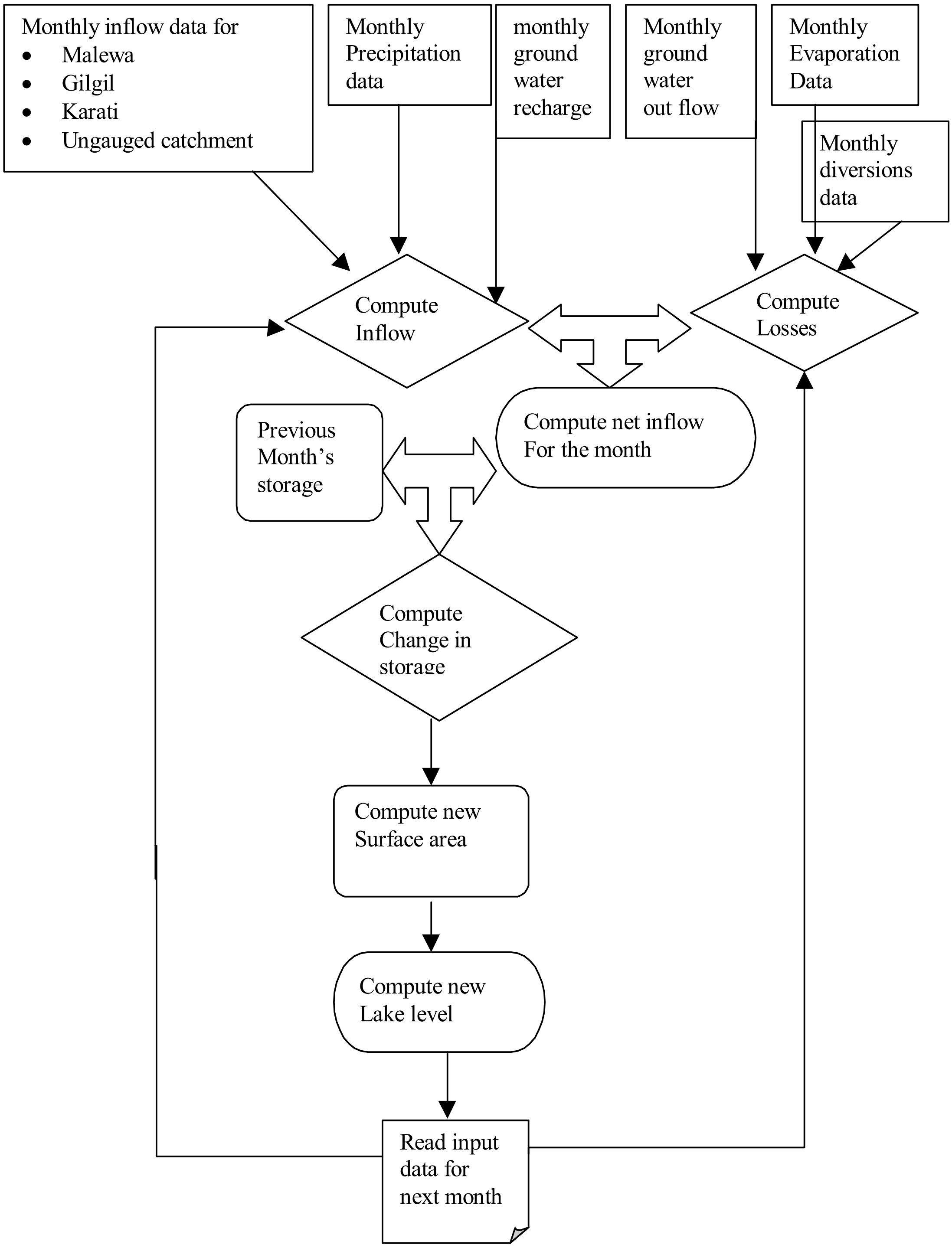

Figure 4-3: Flow diagram of the water balance model

4.3 Running of the Model.

The observed lake level for December 1931 was used as the initial lake level. Using this level and the lake level- volume and lake level - surface area rating equations, the initial volume and surface area of the lake were computed. Using these December 1931 initial values, the model starts running as from January 1932.The model calculates the monthly water balance as flows,

Q2gb1i+Q2ga5i+Q2gd2i +Qungaugedi+Pi-ETi+GWini -Gwouti=Vi

Where,

Q2gb1i = The month i's inflow from malewa river (m3)

Q2ga5i = The month i's inflow from Gilgil river (m3)

Q2gd2i = The month i's inflow from Karati river (m3)

Qungaugedi = The month i's inflow from ungaugedcatchment (m3)

Pi = Direct precipitation into lake Naivasha during month i(m3)

Eti = Total monthly evapotranspiration during month i(m3)

Gwin = Grounwater inflow during month i (m3)

Gwout = Grounwater outflow during month i (m3)

Vi = Net inflow in lake during month i (m3)

The model then calculates the change in storage (S)

$S_i = S_i\text{-}1 + V_i$

Using the change in storage (Si) calculated above, The model then calculates the months water level (Li) using the volume-level rating equation.

The calculated lake level (Li) is then used as input to calculate the month's lake surface area (A_i) using the lake level-surface area rating equation.

This surface area (A_i) is then used to calculate the evapotranspiration and direct precipitation into the lake during the next month (i+1). The computation procedure continues until the last month of input data.

5.4 Verification criteria

A scatter plot of observed and calculated lake levels versus time is plotted. The plot is automatically updated whenever the input data is updated. To check the accuracy of the model, a column is included to compute the sum of square of difference between the calculated and observed lake levels.

Model calibration was done based on the criteria of fit listed below

- Visual inspection of the plot of observed and computed water levels
- Sum of square of differences between observed and calculated water level
- The R^2 value according to Nash and Sutcliffe(1979).

$$R^2 = \frac{\sum\left(\overline{Q}_0 - Q_0\right)^2 - \sum\left(Q_c - Q_0\right)^2}{\sum\left(\overline{Q}_0 - Q_0\right)^2}$$

Where Q_0 = Observed lake level

$\overline{Q}_0$ = Mean of observed lake level

Q_c = Computed lake level

R^2 has a value of 1 if the computed and observed lake levels agree completely, and zero if the model does not perform any better than the mean value of the observed lake levels.

4.5 Model calibration

4.5.1 first run

The first run of the model was done without groundwater components. The calculated water levels followed the same trend as the observed lake levels but were on average higher than the observed. See figure 4.4 below.

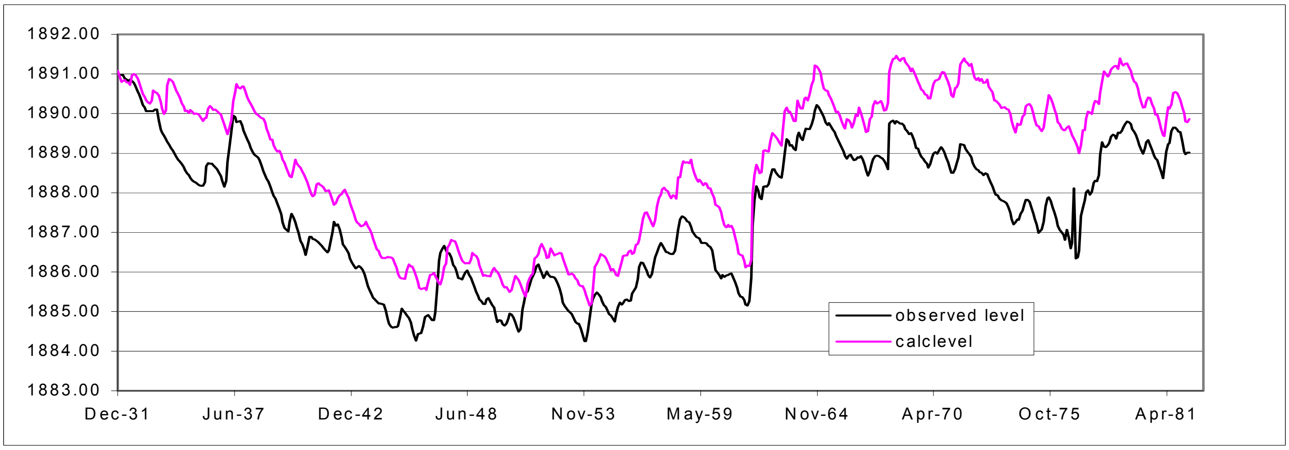

Figure 4-4 results of first run of the water balance model. Note the higher calculated lake levels.

4.5.2 Ground water outflow/ inflow into the lake.

The higher calculated lake levels above imply the total observed lake storage is lower than what is expected if the lake did not have any outlet. Many researchers eg (Ase et al, 1986) and

(Obwire, 1996) estimated ground water outflow from the lake. Ase based his calculations on water balance calculation of the lake using data for the period 1972 to 1980 while Sebastian used hydrogeological approach. Ase gave groundwater outflow in the range of 45- 50 million cubic meters per annum while Obwire gave 18 to 50 million cubic meters.

Ground water flux is calculated in this model using Darcy,s equation. An average lake perimeter of 70km was used.

$$Q = KA\frac{dh}{dx}$$

Where Q = Flow

K = hydraulic conductivity

A = Cross sectional aquifer area

dh = difference between calculated lake and ground water levels

dx = Horizontal distance of the cone of influence. Assumed to be 3 km according to (Damalis, 1998)

5.5.3 Optimization

Model optimization was done to improve the ground water parameters. This was done using the Solver function available in Microsoft excel program. Optimization was done with a view to reducing the sum of square of difference between observed and calculated lake levels. After optimization the groundwater out flow stabilized at 4.6million cubic meters per month. This value is within the range calculated by other researchers as was mentioned in section 4.5.2 above

5.5.4 Abstractions

Agricultural activities in the basin before mid -1980s were negligible. Owing to this reason all water loses from the lake during this period, save for loses due to evapotranspiration, were taken to be due to ground water outflow. The difference between observed and calculated lake levels after mid 1980s were taken to be due to abstractions from the lake for agricultural, industrial and domestic purposes.

4.6 Final modeling results

4.6.1 Lake Levels

The final model gave a very good fit between observed and calculated lake levels. See figure 4.5 below.

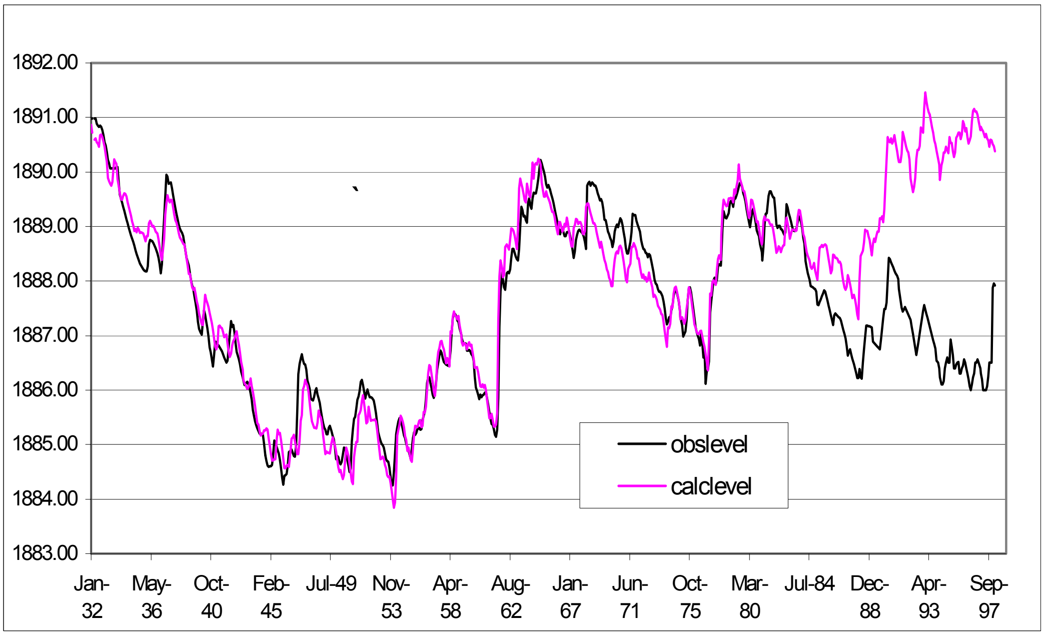

Figure 4-5 Observed and calculated lake levels (1932 to 1997)

From figure 4.5 above it can be seen that the observed and calculated lake levels agree to within acceptable limits up to 1984 after which there is an increasing divergence between observed and calculated lake levels. The differences after 1984 are way off the model noise, which could be attributed to input data inaccuracies. For the 53 years period from 1932 to 1985 the differences lay between negative one (-1) and plus one (+1) meter, while after 1985 the difference increases progressively to a value of 5 meters. Subtracting the long-term one-meter range gives us about four meters deviation. This is attributed to increased horticultural activities around Lake Naivasha. This fact is more clearly illustrated in figure 4.6 below, which is a plot of the temporal distribution of the difference between calculated and observed lake level while figure 4.7 shows the good correlation between the two for the period 1932 to 1984.

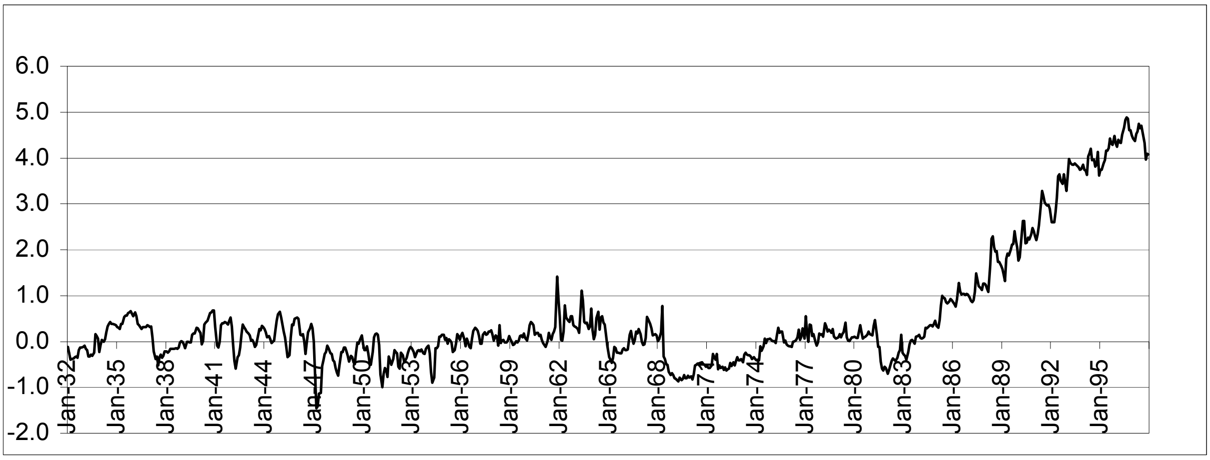

Figure 4-6 Temporal distribution of the differences between calculated and observed lake Levels.

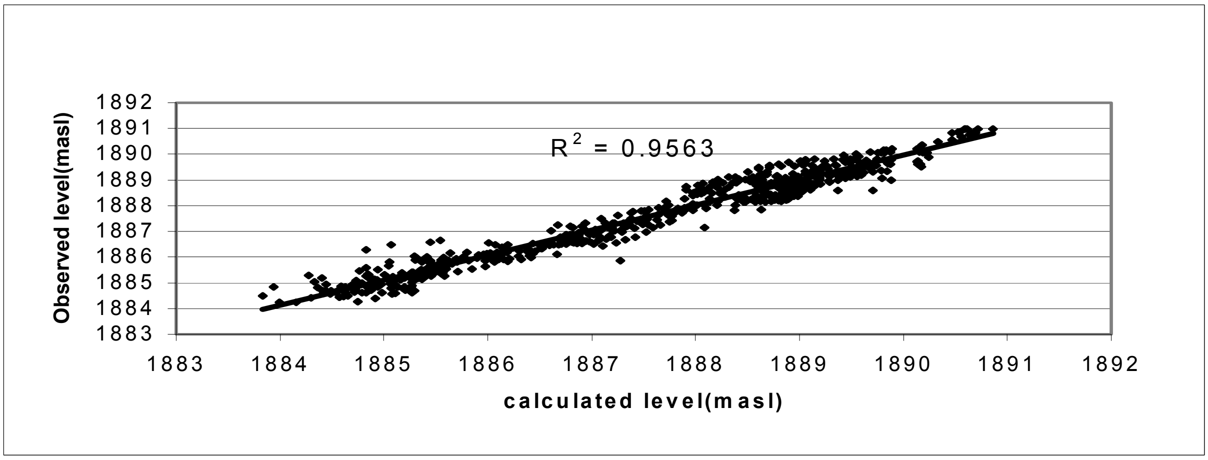

Figure 4-7 scatter plot of obsverved versus calculated lake levels (1932 to 1984)

4.6.2 Lake Storage

The calculated and Observed lake storage values showed the same trend as the lake Levels above. The observed storage was derived from the observed lake levels using the Level-volume rating curve. The divergence commencing mid-1980s is again evident. See figure 4.8 and 4.9 below. Figure 4.10 shows the good correlation between observed and calculated storage for the period 1932 to 1984.

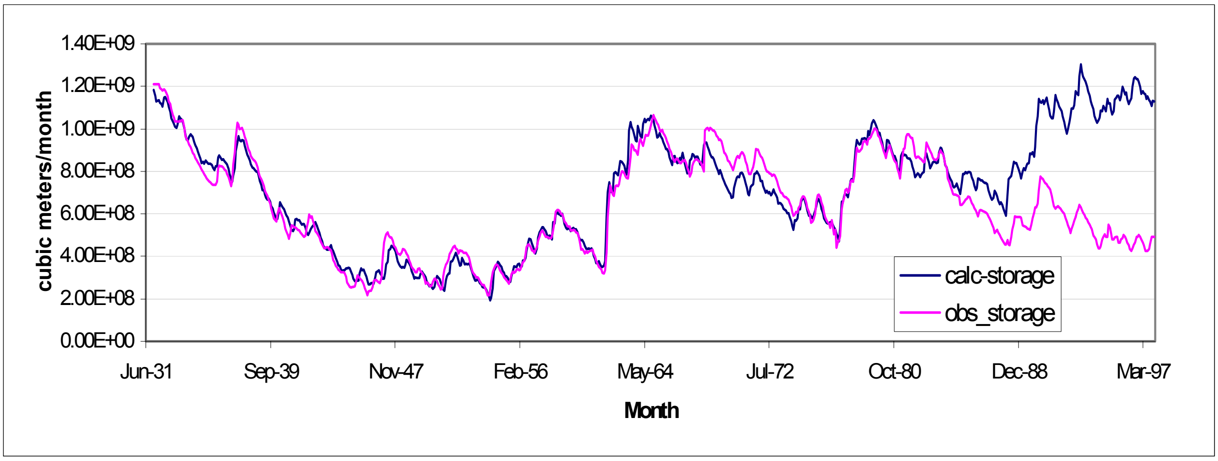

Figure 4-8 plot of temporal distribution of observed and calculated lake storage.

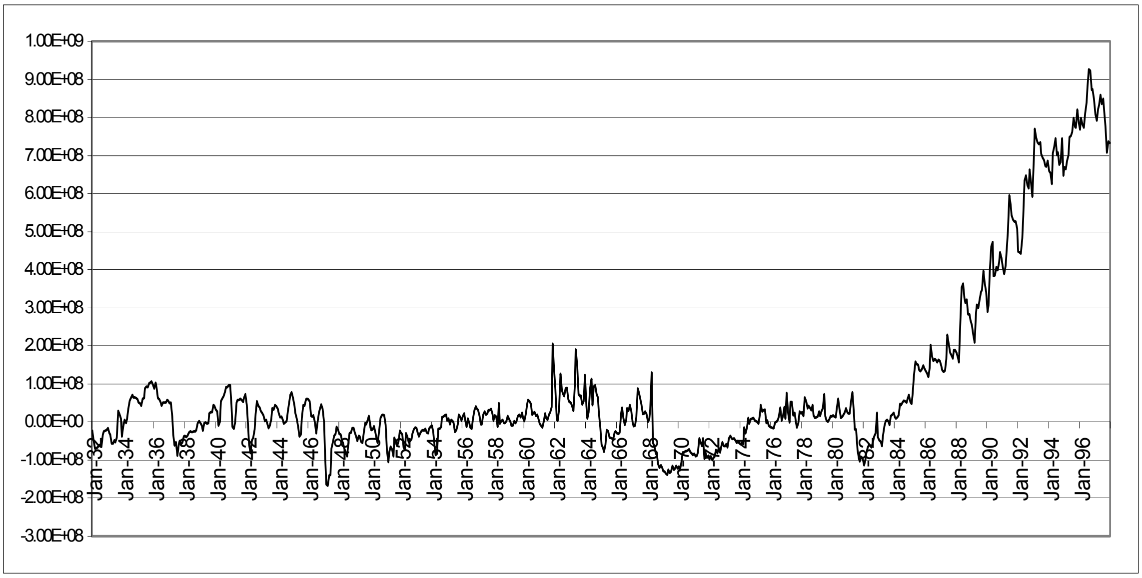

Figure 4-9 Temporal variation of the difference between observed and calculated lake storage.

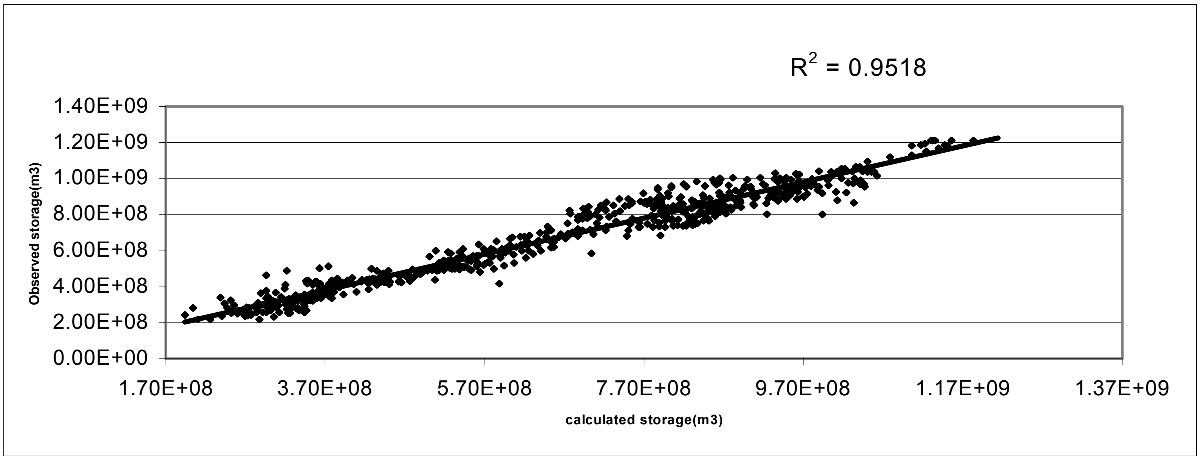

Figure 4.10 Scatter plot of the difference between observed and calclated lake storage.

From these results it can be seen that an increase in water abstraction from the lake as increased progressively to a value of about 800 million cubic meters within a period of 14 years. This gives an average abstraction of about 57 million cubic meters per year.

4.6 The lake water budget

The long-term (1932 to 1997) water balances obtained from the above model are shown in the table 4.1 below. The results are in million cubic meters per month. The last column shows the expected change in the lake levels in meters.

Month	Discharge	Precipitation	Groundwater flow	Groundwater outflow	evaporation	Storage change	Level change
January	11	4.87	0.0948	4.60	25.4	-14.0	-0.097
February	8.03	5.32	0.272	4.60	24.2	-15.0	-0.103
March	9.19	8.12	0.323	4.60	26.5	-14.0	-0.097
April	21.9	1.69	0.300	4.60	20.8	14.0	0.097
May	34.7	1.16	-0.116	4.60	22.2	19.0	0.131
June	20.1	6.81	-0.339	4.60	20.2	1.80	0.012
July	19.8	5.73	-0.139	4.60	20.3	0.420	0.003
August	24.1	6.79	-0.067	4.60	22.0	4.20	0.029
September	22.1	7.15	-0.125	4.60	23.2	1.60	0.11
October	19.3	7.89	-0.0846	4.60	24.5	-1.90	-0.013
November	19.8	9.22	0.0138	4.60	19.6	4.90	0.034
December	13	6.12	-0.0649	4.60	22.3	-7.90	-0.054

Figure 4-10 computation of expected lake storage change using long-term data (1932 to 1997).

All volumes are in million cubic meters per month. The last column is the expected change in lake level in meters. This column was calculated using an average lake area of 145 km^2 (1932-1997). The negative sign in ground water flow column signifies flow from the lake to groundwater.

Summation of the lake storage column does not equal to zero but shows net reduction of lake level by 0.047 meters. This could be due to data errors although generally the lake as been on a downward trend during the modeled period.

4.8 Rainfall runoff modeling

An attempt was done to do rainfall- runoff modeling. The idea behind this was to try and extend the flow series of the three major rivers namely malewa, karati and Gilgil to 1900 with a view to modeling the lake balance to that period. Two types of models were tried. The first was multilinear regression between rainfall and total discharge from the cachment based on the above named three rivers. The second model is a Spreadsheet simplification of the HBV model. The HBV model is a conceptual model for continuous computation of river discharge.

4.8.1 Rainfall-Discharge multilinear regresion

This was done using three staions in the catchment which have long record of data. These are, Naivasha District Officer rainfall station,(1900 to 1998), Kinangop rainfall station (1914 to 1998) and Gilgil Kikwetu rainfall station(1923 to 1998). The correlation between the discharge and the respective rainfall station is shown in table 4.2 below.

	Kinangop	*Naivasha DO*	*Kikwetu*	*discharge*
kinangop	1			
Naivasha DO	0.69	1		
kikwetu	0.72	0.72	1	
discharge	0.73	0.75	0.77	1

Figure 4-11 correlation between annual rainfall and annual discharge (1958 to 1990)

The R^2 coefficient for the regresion is 0.65. Figure 4.11 below show discharge generated using the regresion equation.

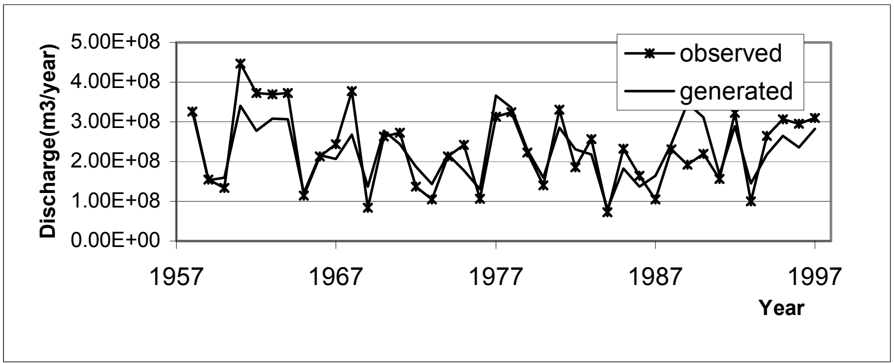

Figure 4-12observed versus generated discharge series.

Using this rainfall-discharge relationship A discharge series was generated for the period 1923 to 1997. The annual series was used to do a lake water balance model based on annual data. The resultant model is shown in figure 4.12 below. The annual groundwater outflow predicted by this model is 45million cubic meters per year which is again within values obtained by (Ase,et al ,1986) and (Obwire,1996) who estimated outflow in the range of 45-50 and 18-50 million cubic meters respectively. The divergence between observed and calculated lake levels commencing mid-1980s is again evident.

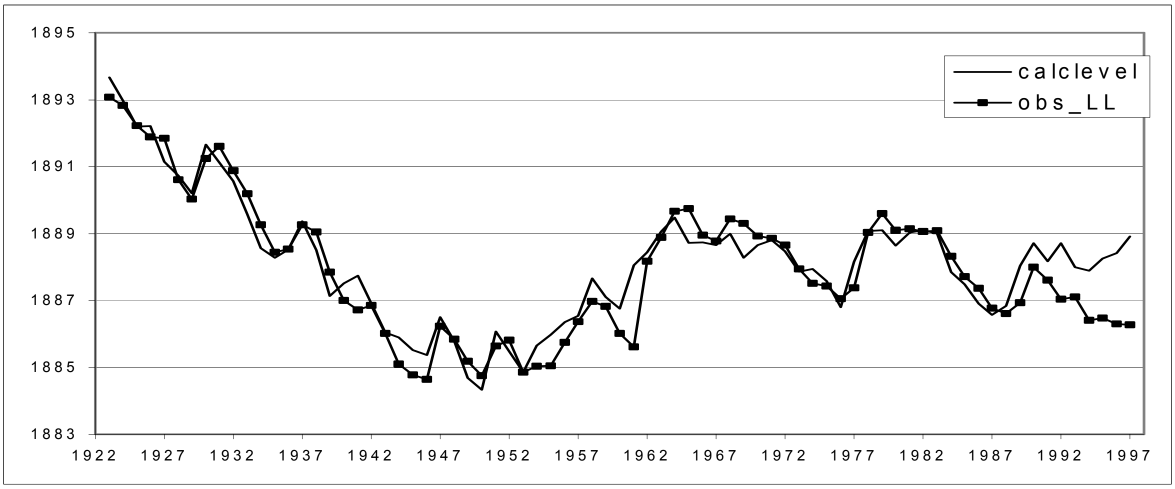

Figure 4-13 Plot of observed and calculated annual water levels.

4.7.2 HBV model

The model is built around two routines for cactments with no snow. A soil moisture routine and response routine. Soil moisture is the main Part controlling runoff formation in this model. The model treats the soil as two linear reservoirs. The upper reservoir contributes to quick flow while the lower reservoir (groundwater) contributes to base flow. Input data are precipitation and long-term means of potential evapotranspiration. Areal values are determined as a weighted mean of observed data from meteorological stations. The model was run on monthly time steps and calculates runoff based on the following equation,

$$\frac{\Delta Q}{\Delta P} = \left(\frac{SM}{FC}\right)^{\beta}$$

Sm = computed soil moisture

FC = Maximum soil moisture storage

ΔQ = Runoff

Δ P =Rainfall

β = Factor controlling contribution to runoff.

Soil moisture is calculated camulatively.The effective precipation received during the month ,that is precipition received during the month less evapotranspiration, recharges the soil moisture,part pecolates to recharge ground water ,while excess water is transformed into runoff.

Evapotranspration is computed as a linear function of the available soil moisture. When the soil is at its maximum storage capacity (FC), actual evapotranspiration is equal to potential evapotraspiration. Otherwise the actual evapotranspiration is less than the potential evapotranspiration and is calculated by the following formula

$$AET = \frac{SM}{FC} * ET_o$$

Where AET = Actual evapotranspiration

ET_o = potential evapotranspiration

SM = calculated soil moisture

FC = maximum soil moisture storage.

The model was calibrated using malewa discharge data and used to generate flow series from 1900 to 1997. Figure 4.14 below shows the mass curve of both observed and modeled discharge.

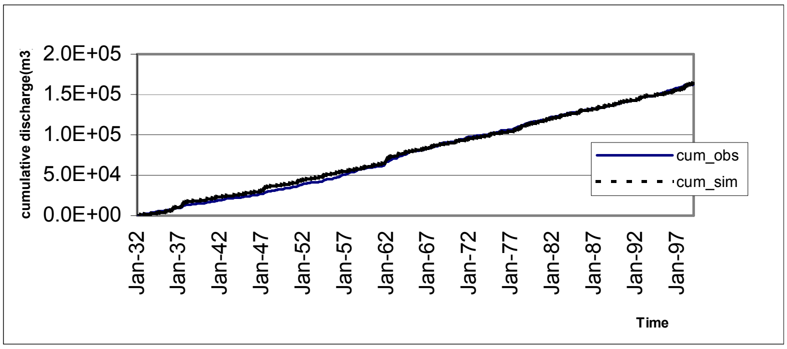

Figure 4-14 cumulative mass curves of observed and modeled

(cum_sim) Flow series

The purpose of this flow simulation as was mentioned earlier was to try and model changes in lake levels which occurred in the early 1990s.The simulation for the whole period was not very successful, especially the period prior to 1918. See figure 4.15 below. Big Lake level fluctuations in the order of three meters between 1900 and 1918 could not be modeled. This could be due to errors in lake level data or poor prediction of discharge data by the model. However a similar attempt using the data generated using the rainfall-discharge regression discussed in section 4.7.1 above encountered the same problem. See figure 4.16 below. This leads to strong suspicion that the problem could be due to errors in either rainfall or lake levels data.

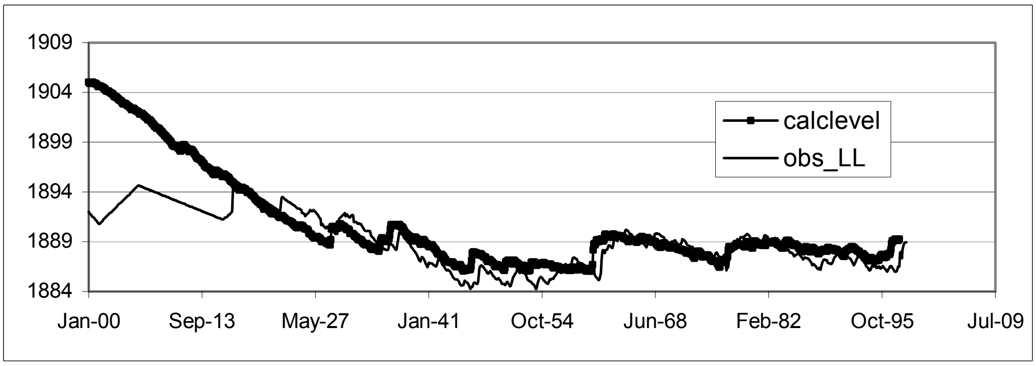

Figure 4-15 times plot of observed (obs_ll) and modeled lake levels (1900to 1997). Lake levels modeled using discharge data generated using HBV model.

Figure 4-16 plot of observed versus modeled lake levels (1900-1997). Lake levels Were modeled using discarge data generated using rainfall-runoff regression.

4.9 Validation of modeled levels using Remote Sensing

Validation of the lake levels using remote sensing was attempted. Draw back in this endeavor was unavailability of satellite images and aerial photos. Available data was a TM satellite image of the area taken in January 1995 and aerial photos taken in 1984.The like perimeter was digitized from the Tm-image. The resultant segment map was converted into a polygon map and a digital elevation model (DEM) of Naivasha area overlain. The Boundary of the polygon map coincided with 1886.7m contour. See figure 4.17 below. This agrees well with observed lake level, which averaged 1886.8 in January 1995.However it deferred with the calculated level due to the divergence evident in figure 4.6 above. A similar process was repeated for the 1984 aerial photos. Again there was agreement between image, observed and modeled levels. The segment map digitized from the aerial photos coincided with the 1889 contour while the observed and modeled levels were in the range 1887.9-1889.1 and 1888.1 –1889.1 respectively in 1984. The exact month the photos were taken could not be ascertained.
The surface area obtained from the polygon map digitized from the TM satellite image compared very well with the surface area computed using lake level-surface area rating curve. Rating curve gave 139 km^2 while polygon map had 138 km^2.

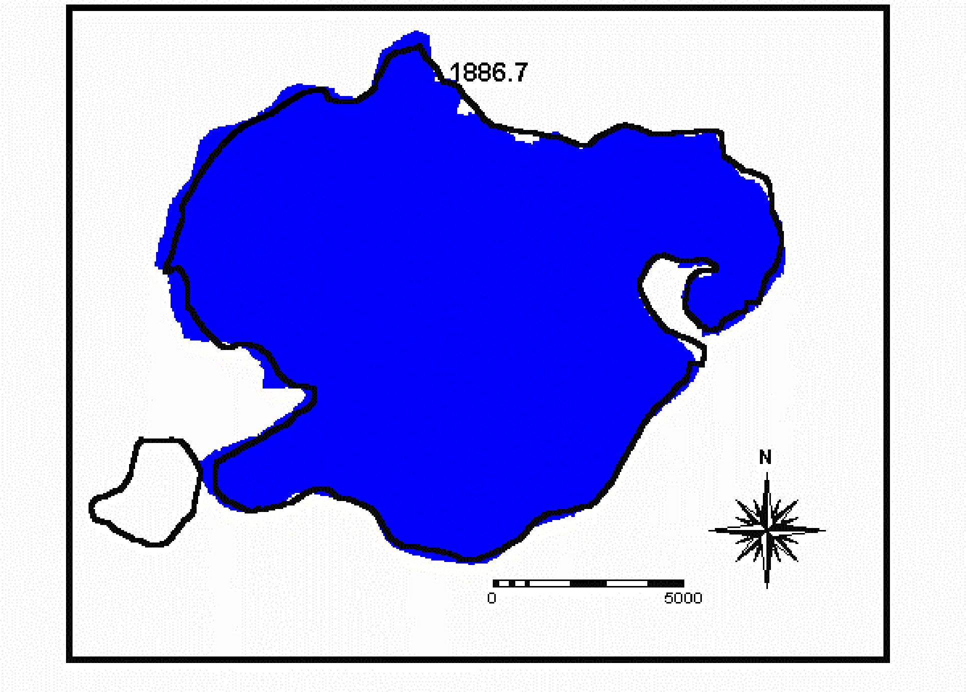

Figure 4-17 Lake area digitized from TM satellite image with 1886.7 m.
Contour from DEM overlain.

CHAPTER 5

CONCLUSIONS

The water balance model of lake naivasha show that there is a very good correlation between the monthly values for river inflow, the average precipitation on lake Naivasha and the potential evapotranspiration.

When the model is run based only on the above parameters there there is a progressive separation between observed and calculated lake levels. The calculated levels implying the lake should accumulate more storage than is actually observed. This separation could not be pinned down to systematic errors in runoff, precipitation and evapotranspiration measurements. It is an indication of subterranean outlet of the lake.

Groundwater flux was found to be a very important component of the lake's water budget. There is a dynamic exchange of water between the lake and groundwater. Ground water outflow was estimated at 4.6 million cubic meters per month.

Abstractions from the lake for agricultural and industrial purposes have increased significantly since the mid-1980s. The model predicts an average abstraction rate of 57 million cubic meters per year. Without these abstractions the lake level would be at least two meters higher than its present value.

Though the rift valley floor is said to experience neo-tectonic activities such as opening up of graven and subsidence of land, there was no indication of such activities having affected the lake levels. There were no sudden changes of lake levels which did not reflect changes in climatic data.

RECOMMENDATIONS

From the foregoing conclusions it is evident that there is good correlation between the various water balance components at monthly time steps. However the accuracy of these results depends on the accuracy of the data used. To enhance this accuracy the following is recommended,

Data for Gilgil and Karati rivers suffer from numerous missing data gaps. Correlation between neighboring stations within these rivers is poor. Thus infilling data introduces big errors. Development of a well-calibrated Rainfall-runoff model for these rivers would increase the accuracy and allow accurate backdating of their discharge series from the 1950s when they commenced to 1900 when the lake levels commenced to be gauged.

The rating curve for Malewa river gauging station 2GB1 seems to overestimate discharge at high gauge heights. There is need to do more gaugings during high flows to improve the rating curve.

References

1. Amriktar, R.E. and Kumar, p.p, 1995: Interpolation of Missing Data Using Nonlinear and chaotic Systems analysis, journal of Geophysical Research, vol. 100(D2), Pp.3149-3154

2. Apelo C.A.J, Becht, R., Van de Griend A.A. and Spierings T.C.M, : Buildup of discharge along the course of a mountain stream deduced from water- quality routings (EC Routing), instituut Voor Aardwetenschappen,Vrije Unversiteit, 1081 HV Amsterdam, The Netherlands.

3. Brind, W. and Robertson, J.K., 1958: The Hydrology of Lake Naivasha. (Prepared by The section of Hydrology, Ministry of Works, Kenya.) .
4. Clarke M. C. G., Woodhall, D. Allen and Darling G., 1990,: Geological, volcanological and hydrogeological controls on the occurrence of geothermal activity in the area surounding Lake Naivasha, Ministry of Energy, Nairobi, Kenya
5. Dahmen, E.R. and Hall, M.J., 1990: Screening of hydrological data, Tests for stationarity and Relative Consistency, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, PP 58.

6. Donald L. McCann, 1974: Hydrological Investigation of Rift valley Catchments.

7. Dymond J.R. and Christian, R., 1982, Accuracy of Discharge Determined From The Rating Curve, Hydrological-Sciences Journal, Vol.27 (4)pp.493-504.

8. Government of Kenya, Ministry of Energy, Geothermal Section 1988, Kenya - Geological Map of Longonot Volcano, The Greater Olkaria and Eburru Volcanic Complexes, and adjacent areas 1: 100 000
9. Harper, D., 1996, : The Ecology of Lake Naivasha and Hells's Gate National Park, Keny*a*, A collaborative research project between the University of Leicester, the University of Nairobi Zoology Departments and National Museums of Kenya, Field Report for 1996
10. ITC, Water Resources Dept. 1996, Water Resources Assessment Project Phase V, Mission Report, (WRAP): Water Resources Modelling of Rift Valley Lake Basins and Laikiapia (Groundwater Component*),* pp 4-9
11. John Goldson et al, 1993: A Three Phase Environmental Impact Study Of Recent Developments Around Lake Naivasha.

12. Lars-Erik Ase, Kreister Sernbo Per Syren, 1986, Studies of Lake Naivasha, Kenya, and its drainage area*,* Stockholms Universitet Naturgeografiska Institutionen 106 91 Stockholm, ISSN 0 346-7406, STOU-NG 63, UPPLAGA: 400 MARS 1986
13. LNROA - Lake Naivasha Riparian Owners Association, : Lake Naivasha Management Plan 1996, (Incorporating Amendment List No.1), Naivasha, Kenya
14. Methods for water balancecomputations. An international guide for research and practice. Published by unesco Press Paris, 1974.

15. Norusis Marija J. / SPSS Inc., [2] SPSS fo*r* Window*s*™ Bas*e* Syatem User's Guide Release *6.0* 1994, Printed in the USA
16. Norusis Marija J. / SPSS Inc., [1] SPSS Professional Statistics ™ *6.1,* 1994, Printed in the USA
17. Ojiambo B. S., 1992,: Hydrological, Hydrogeochemical and Stable Isotopic Study of possible Interactions Between Lake Naivasha, shallow Subsurface and Olkaria Geothermal, M.Sc. Thesis, Unversity of Nevada, Reno.
18. Ojiambo B. S., 1996,: Characterization of Subsurface Outflow From a closed Freshwater Tropical Lake, Rift valley, Kenya. Ph.D. Thesis, Unversity of Nevada, Reno.
19. Podder, A .H., 1998: Estimation of longterm Inflow into Lake Naivasha From the Malewa Catchment, Kenya,M.Sc. Thesis, International Institute for aerospce Survey and Earth Sciences (ITC), Enschede, The Netherlands.
20. Sikes, H.L., 1936: Notes on the Hydrology of Lake Naivasha, journal of the East Africa and Uganda Natural History Society.
21. Stuttard, M., Hayball, J., Narciso G., Carizi, G., Suppo, M., Catani, R., Isavwa, L., Baraza, J., and Oroda, A., 1995, Final Report: Monitoring Lakes in Kenya: An Environmental Analysis Methodology for developing Countries*,* Document No. MLK-EOS-FR-001, CEC DG XII STD-3 programme
22. Thompson, A.O., and Dodson, R.G., 1958,: Geology of the Naivasha Area , Explanation of degree sheet 43 S.W.
23. Walton, H.L, Filling in missing data in unvariate coastal data, Journal of applied Statistics, Vol.23 (1), pp.31-39
24. Yuretich R. F., 1982*,* Possible influence upon Lake developement in the Eastern Rift Valleys, Department of Geology and Geography, University of Massachusetts, Amerst, Mass. 01003, Journal of Geology 1982 vol.90 , p 329 – 337
25. VIAK, (1975): Naivasha Water supply Project, Prepared for the Ministry of Agriculture Water Department, VIAK EA Ltd., Consulting Engineering and Mapping Services.

APPENDICES

Appendix_A: Monthly rainfall

Table A-1Naivaha DO monthly rainfall(1910-1998) (units = mm*10)

Naivasha districs office														
ID	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTA L
9036002	1910	229	25	234	516	94	490	836	561	112	384	691	155	4327
9036002	1911	28	234	668	1087		925	312	394	307	320	942	356	5573
9036002	1912	305	516	828	2814	942	112	206	221	427	191	351	424	7337
9036002	1913	25	94	147	452	660	963	43	269	160	213	434	224	3684
9036002	1914	79	490	826	381	1021	69	566	399	503	470	693	48	5545
9036002	1915	18	836	290	1252	630	465	107	196	203	447	660	300	5404
9036002	1916	658	561	450	1339	2037	335	114	632	297	241	419	765	7848
9036002	1917		112											9398
9036002	1918	56	384	64	353	658	470	460	254	488	544	318	135	4184
9036002	1919		691	673	1956	607	574	671	465	140	909	447	442	7575
9036002	1920	117	155	859	617	297	526	58		312	231	630	917	4719
9036002	1921	81	28	0	787	686	427	422	615	569	318	213	99	4245
9036002	1922	51	234	1501	899	780	254	175	625	272	627	381	498	6297
9036002	1923	0	668	318	739	2410	295	135	277	295	699	216	371	6423
9036002	1924	33	1087	770	648	978	30	343	780	373	292	602	312	6248
9036002	1925	894	200	729	61	460	742	340	338	196	198	1006	157	5321
9036002	1926	48	925	607	945	1758	277							7112
9036002	1927	229	312	978	0	203	0	437	1095	196	467	211	203	4331
9036002	1928	368	394	356	688	1722	526	353	343	427	470	528	584	6759
9036002	1929	30	307	145	724	671	490	541	64	668	605	615	650	5510
9036002	1930	262	320	2045	2126	1966	226	597	196	513	663	620	305	9839
9036002	1931	43	942	871	1072	655	358	231	373	236	508	635	302	6226
9036002	1932	36	356	305	991	711	163	226	140	1240	544	328	429	5469
9036002	1933	386	305	178	569	447	262	180	930	470	389	526	432	5074
9036002	1934	25	516	391	587	401	904	729	447	193	572	216	140	5121
9036002	1935	15	828	447	1359	472	1303	0	178	381	620	564	465	6632
9036002	1936	554	2814	719	1654	323	396	246	302	318	531	554	254	8665
9036002	1937	163	942	777	1618	1427	1615	1011	368	168	658	960	516	10223
9036002	1938	206	112	602	757	429	188	163	404	290	622	620	191	4584
9036002	1939	124	206	244	1041	91	175	419	942	244	150	348	56	4040
9036002	1940	363	221	937	2362	676	104	84	279	89	518	376	216	6225
9036002	1941	185	427	927	983	1765	226	74	71	201	396	803	551	6609
9036002	1942	168	191	643	1074	589	470	79	704	71	203	234	46	4472
9036002	1943	173	351	10	671	831	414	627	533	747	109	368	191	5025
9036002	1944	404	424	368	828	312	386	490	445	676	719	937	361	6350
9036002	1945	193	25	282	234	932	620	201	787	1118	229	757	94	5472
9036002	1946	132	94	76	978	1003	340	117	544	798	917	650	310	5959
9036002	1947	569	1478	1201	1996	1242	132	813	112	345	244	518	257	8907
9036002	1948	61	452	472	737	470	323	132	307	912	505	513	213	5097
9036002	1949	18	660	330	1184	881	409	142	427	137	315	175	361	5039
9036002	1950	89	963	742	1067	310	297	295	645	1090	432	287	114	6331
9036002	1951	147	43	958	2692	770	211	566	450	648	523	602	577	8187
9036002	1952	48	269	226	1257	1191	10	132	312	602	528	559	142	5276
9036002	1953	79	160	213	1125	1250	582	71	526	239	818	734	180	5977

9036002	1954	320	213	244	1494	1598	762	414	277	914	254	447	450	7387
9036002	1955	353	434	160	1374	274	300	572	826	607	770	323	780	6773
9036002	1956	572	224	556	732	808	302	343	500	792	269	404	246	5748
9036002	1957	498	79											6233
9036002	1958	505	490	744	368	1280	267	861	119	198	368	668	932	6800
9036002	1959	160	826	541	759	1179	498	157	620	508	277	841	147	6513
9036002	1960	554	381	1400	1062	396	79	38	897	561	305	655	455	6783
9036002	1961	0	1021	262	965	1300	86	0	495	505	1026	3345	1173	10178
9036002	1962	945	69	544	1270	1519	246	36	432	386	612	335	554	6948
9036002	1963	338	566	394	2126	1318	396	25	251	104	290	874	1527	8209
9036002	1964	91	399	1059	1659	109	185	1013	81	376	894	551	538	6955
9036002	1965	348	503	241	1106	560	321	366	340	181	542	660	395	5563
9036002	1966	205	470	736	2062	282	128	56	988	879	511	1129	54	7500
9036002	1967	146	693	506	1089	1194	461	844	521	344	991	570	249	7608
9036002	1968	18	48	855	2514	138	591	36	25	389	555	841	554	6564
9036002	1969	428	18	617	304	1151	199	130	165	295	234	626	390	4557
9036002	1970	835	836	1109	1001	835	586	374	120	831	274	418	96	7315
9036002	1971	417	290	63	640	1738	117	393	1128	218	1377	327	494	7202
9036002	1972	186	1252	176	186	463	923	207	423	321	925	639	101	5802
9036002	1973	572	630	80	1271	842	335	205	299	559	350	521	136	5800
9036002	1974	134	465	321	2231	670	750	703	445	460	302	408	494	7383
9036002	1975	17	107	258	1272	548	204	803	506	618	814	157	245	5549
9036002	1976	78	196	169	690	461	678	484	758	476	75	232	460	4757
9036002	1977	309	203	306	2050	1306	201	671	418	188	785	1095	726	8258
9036002	1978	763	447	2224	1251	737	150	109	771	794	446	325	982	8999
9036002	1979	777	660	588	707	632	634	282	496	476	211	746	354	6563
9036002	1980	391	300	536	1256	1558	675	22	79	322	200	934	97	6370
9036002	1981	3	658	1787	1420	657	315	548	448	296	413	595	356	7496
9036002	1982	247	561	62	1183	1113	207	82	574	459	926	1707	651	7772
9036002	1983	355	450	83	843	382	997	396	462	584	920	593	389	6454
9036002	1984	32	1339	30	642	83	0	511	421	69	520	1003	1019	5669
9036002	1985	178	2037	667	1471	848	224	291	112	510	166	0	0	6504
9036002	1986	408	335	406	1610	401	367	76	486	270	419	700	558	6036
9036002	1987	82	114	458	678	1182	1588	546	420	115	184	578	114	6059
9036002	1988	387	632	806	1214	906	160	379	623	270	172	396	155	6100
9036002	1989	778	297	389	910	1166	375	801	864	554	794	0	1194	8122
9036002	1990	389	241	1355	1853	0	145	190	675	466	992	635	0	6941
9036002	1991	72	419	798	682	627	762	112	158	222	652	706	157	5367
9036002	1992	233	765	132	1644	854	890	945	224	1014	706	301	592	8300
9036002	1993	182		102	201	393	606	1	137	446	231	411	225	2935
9036002	1994	79	112	561	1240	600	536	708	278	119	658	227	184	5302
9036002	1995	0		937	1074	801	420	462	254	714	801	527	387	6377
9036002	1996	176		930	592	395	926	1263	407	847	760	571	67	6934
9036002	1997	282		306	1619	398	1054	294	457	74	1104	1557	989	8134
9036002	1998	218		315	745									

Table A-2 Gilgil kikwetu monthly rainfall (1923-1998) units in (mm*10)

Gil Gil Kweto farm														
ID	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
9036029	1923	10	498	650	3457	2784	935	1077	881	1138	724	1303	450	13907
9036029	1924	64	196	658	1692	947	64	1026	1344	683	249	1176	241	8340
9036029	1925	884	274	757	381	1062	447	648	950	396	475	1862	556	8692
9036029	1926	404	401	665	1991	691	521	833	1836	1336	1143	886	155	10862
9036029	1927	681	297	1267	1049	1420	333	371	1694	488	147	439	310	8496
9036029	1928	117	84	318	1227	1638	1382	1171	752	216	942	1461	241	9549
9036029	1929	18	36	58	1577	2228	663	1687	988	594	579	648	1107	10183
9036029	1930	780	622	1923	3155	1646	1410	869	993	1067	876	1003	711	15055
9036029	1931	272	335	572	1918	833	886	1054	1179	721	640	726	361	9497
9036029	1932	282	399	1039	904	1415	899	1064	775	1184	970	785	257	9973
9036029	1933	130	71	5	386	287	782	1392	2070	1326	343	406	516	7714
9036029	1934	0	3	170	490	838	658	1458	1415	345	533	592	236	6738
9036029	1935	25	216	114	881	1110	1864	528	856	442	993	701	325	8055
9036029	1936	589	904	1430	1024	729	739	366	930	615	742	1615	445	10128
9036029	1937	224	168	805	2352	1872	1405	866	1687	452	551	737	328	11447
9036029	1938	142	58	498	632	1189	645	577	612	729	744	803	599	7228
9036029	1939	272	20	264	1339	749	902	729	1234	292	18	688	122	6629
9036029	1940	582	782	2131	1062	1085	617	1425	1181	198	551	653	107	10374
9036029	1941	302	772	516	3320	1681	681	841	800	284	770	1194	259	11420
9036029	1942	5	132	1313	1364	1572	1519	432	1176	470	274	556	97	8910
9036029	1943	99	18	46	907	925	655	1057	930	1427	505	564	678	7811
9036029	1944	23	0	678	1105	417	523	1438	1090	869	1196	1097	617	9053
9036029	1945	203	25	160	173	1072	1113	1321	1300	709	1059	859	193	8187
9036029	1946	5	0	30	1801	1402	1273	554	1189	635	953	457	218	8517
9036029	1947	295	272	1318	1745	1910	521	1905	787	1057	371	500	363	11044
9036029	1948	61	168	452	1440	1417	1379	963	373	719	493	538	185	8188
9036029	1949	3	71	3	691	1229	1148	963	673	848	427	358	330	6744
9036029	1950	107	38	450	1590	1072	1092	584	930	516	465	930	69	7843
9036029	1951	81	13	686	2578	759	638	511	1801	538	1257	1212	2400	12474
9036029	1952	28	282	30	1074	1930	188	803	1382	442	759	1008	43	7969
9036029	1953	0	56	284	1453	640	1260	577	1001	450	810	744	366	7641
9036029	1954	56	0	142	2116	1969	1687	871	671	1184	963	475	772	10906
9036029	1955	64	582	152	1895	1181	549	1064	1572	899	696	561	516	9731
9036029	1956	1232	528	711	1135	1400	709	1214	1786	716	775	213	132	10551
9036029	1957	607	127	859	2210	1615	947	810	1356	429	305	1054	551	10870
9036029	1958	625	1565	782	1143	2951	1435	1427	810	295	803	1077	808	13721
9036029	1959	551	114	498	1466	1080	488	843	1207	1105	815	671	244	9082
9036029	1960	178	0	620	1110	500	610	526	1105	881	772	968	124	7394
9036029	1961	41	56	241	861	973	312	295	2022	671	1163	3142	1407	11184
9036029	1962	655	127	881	1748	1615	754	445	1341	1900	752	546	518	11282
9036029	1963	396	363	399	2860	1316	645	541	1242	89	843	1534	2022	12250
9036029	1964	51	132	1087	2860	1176	1156	2042	744	1552	1684	864	381	13729
9036029	1965	259	79	186	1163	567	255	1011	970	101	941	532	119	6183
9036029	1966	60	267	407	1527	685	514	771	1955	567	511	1363	81	8708
9036029	1967	8	3	339	1678	2075	947	752	405	464	1224	1037	239	9171
9036029	1968	70	832	1392	2216	1499	873	811	1205	267	1001	1059	767	11992
9036029	1969	508	1331	719	410	2142	591	1006	509	1204	639	854	158	10071
9036029	1970	1397	38	1479	2329	1289	727	389	1244	1162	843	827	128	11852
9036029	1971	510	32	170	935	1240	885	1955	3093	775	322	634	1247	11798
9036029	1972	818	911	293	482	1756	2048	426	1153	192	956	764	199	9998
9036029	1973	624	445	2	639	1661	829	515	1148	1289	433	696	94	8375
9036029	1974	12	12	1416	914	1146	778	1572	973	1024	1038	536	235	9656
9036029	1975	127	150	116	1192	1276	929	1153	1745	1657	1072	383	148	9948
9036029	1976	74	176	85	822	903	635	1487	1677	407	321	476	445	7508
9036029	1977	425	360	286	2589	1866	1144	1864	739	615	859	1885	709	13341
9036029	1978	534	1375	1767	1154	841	740	566	1391	1703	1198	398	535	12202
9036029	1979	1348	1159	394	1208	863	1571	1354	572	406	279	1016	143	10313
9036029	1980	334	189	201	1250	1980	900	542	545	190	636	803	75	7645
9036029	1981	18	213	1424	1715	1415	976	1762	1461	800	1296	412	288	11780
9036029	1982	85	33	5	1763	1197	203	956	1097	935	1230	1611	1227	10342
9036029	1983	72	295	92	1046	1074	1261	774	994	1012	1221	868	914	9623
9036029	1984	103	13	30	904	343	342	1290	1025	294	849	483	444	6120
9036029	1985	41	303	905	1895	1056	1242	1117	1263	682	278	520	176	9478
9036029	1986	18	89	137	1657	884	554	1160	725	932	627	355	449	7587
9036029	1987	97	190	607	1035	893	1517	300	942	611	601	1757	160	8710

9036029	1988	561	190	349	2542	750	1748	1370	1475	1003	958	1034	317	12297
9036029	1989	608	574	613	1235	1011	321	2053	1350	1216	2135	1041	1633	13790
9036029	1990	647	421	2719	2943	441	696	884	1225	297	1162	1018	562	13015
9036029	1991	353	124	1034	1401	959	1842	725	1280	692	643	610	533	10196
9036029	1992	81	65	126	1815	1344	1772	1442	1284	1119	1202	1087	830	12167
9036029	1993	1483	1654	104	916	1190	1378	518	514	570	485	801	499	10112
9036029	1994	3	445	732	1946	503	1224	468	1504	637	689	1645	210	10006
9036029	1995	18	580	1307	1963	590	1235	583	726	859	2298	1384	542	12085
9036029	1996	162	361	734	1355	1213	1038	1193	1779	1329	961	1201	124	11450
9036029	1997	66	0	209	3406	733	1030	735	660	89	1604	2198	1328	12058
9036029	1998	755	643	585	1522									
(1923-97)	Mean	302	316	614	1523	1223	922	969	1164	747	809	919	479	9986

Table A-3 North Kinangop monthly rainfall(1914-1998) units in (mm*10)

Nort Kinangpot forest station														
ID	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
9036025	1914	597	478	1173	701	1910	312		889	1237	234	1417	277	
9036025	1915	48	310	701	2621	1123	1537	274	556	602	930	445	411	9558
9036025	1916	630	663	587	2019	1382	1481	358	963	1595	721	302	615	11316
9036025	1917	732	2167	1430	2301	1732	1582	1273	1593	1839	2383	376	79	17487
9036025	1918	272	107	605	643	1557	427	610	434	259	772	630	218	6534
9036025	1919	15	1247	1224	3084	1991	1196	716	975	986	668	521	56	12679
9036025	1920	292	239	1143	1928	660	2090	592	462	864	439	1562	1212	11483
9036025	1921	478	376	351	1257	1397	1628	683	417	691	1361	536	178	9353
9036025	1922	140	744	1285	1433	635	1514	607	1814	1153	1260	1163	610	12358
9036025	1923	135	1146	810	3467	3637	1184	1059	683	965	1382	607	345	15420
9036025	1924	89	478	1019	1105	1661	526	912	1509	1227	1852	1775	239	12392
9036025	1925	742	135	1491	320	749	861	775	673	94	434	1549	655	8478
9036025	1926	165	650	564	1786	1326	1008	1041	1349	1908	1351	1367	526	13041
9036025	1927	251	445	1143	396	1717	310	546	1054	732	599	1156	236	8585
9036025	1928	257	127	505	1113	1930	1516	729	645	561	653	528	203	8767
9036025	1929	0	76	711	516	1577	716	876	947	1024	909	945	1059	9356
9036025	1930	1201	775	2758	4313	2004	1367	1102	559	1768	1090	1072	638	18647
9036025	1931	912	411	945	1318	932	953	424	1176	1262	610	663	963	10569
9036025	1932	114	795	1283	1212	1389	876	747	513	970	1326	711	279	10215
9036025	1933	1001	76	137	246	1715	442	615	1356	1618	777	658	551	9192
9036025	1934	112	81	452	1288	874	843	846	640	533	975	986	328	7958
9036025	1935	117	1034	826	1151	1455	1814	310	744	714	1867	691	648	11371
9036025	1936	709	1544	1255	2797	1125	1039	483	892	800	1100	429	239	12412
9036025	1937	213	94	1638	2586	1521	1715	996	790	452	1415	1671	747	13838
9036025	1938	330	239	899	1242	841	1107	1173	561	991	1288	752	899	10322
9036025	1939	312	554	561	1064	297	579	1052	713	630	190	881	277	7110
9036025	1940	1641	1237	1638	2410	2301	688	919	1024	493	452	1019	262	14084
9036025	1941	554	919	610	1915	1466	1349	953	726	975	691	1643	818	12619
9036025	1942	79	130	1278	1908	1473	2228	244	742	592	414	688	267	10043
9036025	1943	43	71	307	947	1913	1176	1021	671	1044	714	592	191	8690
9036025	1944	99	48	932	1115	965	1308	869	1001	1603	686	1059	457	10142
9036025	1945	472	262	455	521	1369	1943	671	1687	770	480	1062	284	9976
9036025	1946	0	0	221	1651	1577	1530	782	1956	1262	1153	681	551	11364
9036025	1947	757	363	1397	3546	1659	1349	1524	330	1267	1029	1024	358	14603
9036025	1948	160	152	498	1394	1847	1260	541	765	1918	836	1151	445	10967
9036025	1949	109	140	97	2228	1006	818	627	1072	838	886	632	615	9068
9036025	1950	218	25	1026	1255	838	866	1537	1478	556	714	709	282	9504
9036025	1951	348	173	1402	3708	1255	1334	935	919	1250	871	899	1618	14712
9036025	1952	127	241	378	2027	2682	157	823	1158	1257	960	391	173	10374
9036025	1953	239	66	297	1034	785	1572	323	716	663	1250	348	368	7661
9036025	1954	183	8	99	3053	2344	1755	592	1024	874	884	363	693	11872
9036025	1955	69	1153	617	932	960	561	1102	1468	762	986	655	1509	10774
9036025	1956	1674	978	1082	1717	1923	658	643	615	1722	343	953	392	12700
9036025	1957	749	704	648	1897	1920	1407	523	511	1250	927	442	699	11677
9036025	1958	711	1763	1372	1321	2151	1361	1397	551	823	762	986	1290	14488
9036025	1959	246	282	775	683	1610	617	518	650	1158	541	973	351	8404
9036025	1960	823	234	879	1466	734	511	643	605	1745	607	1298	318	9863
9036025	1961	43	307	587	1481	1958	556	102	1488	1308	1829	3419	1948	15026
9036025	1962	978	150	602	1532	2629	945	569	1214	2220	1509	856	983	14187
9036025	1963	503	879	800	2009	2377	638	409	861	488	691	1293	2540	13488
9036025	1964	130	1697	1364	1539	2563	1547	513	518	881	1280	599	503	13134
9036025	1965	640	156	762	1631	2207	622	1060	772	774	858	1114	676	11272
9036025	1966	322	385	1205	2282	1093	322	267	1189	1444	997	1744	99	11349
9036025	1967	81	165	452	1437	2862	975	926	500	745	765	1453	474	10835
9036025	1968	114	1550	1734	2535	823	472	168	683	662	796	729	534	10800
9036025	1969	937	484	498	385	1350	325	390	1045	640	679	636	238	7607
9036025	1970	2604	386	1789	1184	1973	892	733	792	1700	663	762	317	13795
9036025	1971	429	210	122	1491	1967	728	1312	1661	423	761	543	804	10451

9036025	1972	67	1240	222	663	1151	1700	842	1211	576	1348	1349	449	10818
9036025	1973	585	738	68	1306	1487	1107	402	677	1221	715	415	55	8776
9036025	1974	159	335	1136	1517	693	1501	1274	563	1697	1036	850	215	10976
9036025	1975	124	182	363	945	1170	656	795	1392	1189	1867	440	779	9902
9036025	1976	230	245	688	1163	1066	1401	1398	1596	885	833	926	583	11014
9036025	1977	959	523	114	4093	2410	744	1265	960	670	1141	2125	1628	16632
9036025	1978	1120	840	1921	2237	1647	493	466	988	1896	1015	313	765	13701
9036025	1979	1051	1428	925	1250	1172	1561	595	630	855	714	745	70	10996
9036025	1980	480	845	441	1422	2409	1312	215	429	540	1182	1162	225	10662
9036025	1981	125	404	2331	1925	2342	1507	1130	956	684	630	961	1137	14132
9036025	1982	272	231	153	1858	1450	855	768	710	824	1196	1495	593	10405
9036025	1983	188	316	621	1644	744	940	865	1116	1061	2858	1151	1113	12617
9036025	1984	250	112	170	1215	259	282	1910	1390	406	1301	1230	823	9348
9036025	1985	105	717	1232	1946	1550	1398	1072	562	1080	1200	1305	177	12344
9036025	1986	96	165	799	2516	932	587	165	786	570	426	885	751	8678
9036025	1987	310	27	495	894	1482	1429	178	866	1266	322	2127	73	9469
9036025	1988	469	200	918	3786	1706	488	532	1379	1387	498	1113	389	12865
9036025	1989	821	555	483	1888	1164	667	1032	1872	1501	1576	1409	1702	14670
9036025	1990	902	569	1997	2391	1719	998	534	920	1009	860	1008	331	13238
9036025	1991	216	400	1323	1156	1280	1634	346	505	973	1503	458	295	10089
9036025	1992	0	224	264	2257	1574	1291	1353	1433	1071	1682	752	656	12557
9036025	1993	1246	832	338	772	1090	963	405	726	482	513	811	320	8498
9036025	1994	0	1087	851	2257	2012	1672	386	558	1666	1252	1865	293	13899
9036025	1995	0	675	2009	528	1100	1400	935	556	1208	1797	1230	587	12025
9036025	1996	38	848	713	510	600	1376	800	1385	1375	883	961	125	9614
9036025	1997	131	0	527	1709	297	1280	642	1301	432	1705	1920	1168	11112
9036025	1998	1978	1197	512	2256									
(1915-97)	Mean	445	518	851	1700	1523	1067	759	938	1015	985	959	587	11346.3

APPENDIX_B: VISUAL BASIC MACROS

Macro B-1

```
'This macro fill months with no recorded data with the long-term monthly average for
the respective month.

Sub fillgap()

Worksheets("nav_do").Select
For i = 2 To 1069
If Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "jan" Then
Cells(i, 5).Value = 29.15
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "feb" Then
Cells(i, 5).Value = 49.32
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "mar" Then
Cells(i, 5).Value = 58.1
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "apr" Then
Cells(i, 5).Value = 110.67
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "may" Then
Cells(i, 5).Value = 81.72
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "jun" Then
Cells(i, 5).Value = 43.87
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "jul" Then
Cells(i, 5).Value = 35.87
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "aug" Then
Cells(i, 5).Value = 43.96
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "sep" Then
Cells(i, 5).Value = 43.53
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "oct" Then
Cells(i, 5).Value = 51.08
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "nov" Then
Cells(i, 5).Value = 59.79
ElseIf Cells(i, 3).Value = 9999 And Cells(i, 2).Value = "dec" Then
Cells(i, 5).Value = 38.83
Else
Cells(i, 5).Value = Cells(i, 3).Value
End If
Next I
End Sub
```

' **Macro B-2**

```
This macro computes and writes   monthly total averages
'Whenever there is a gap in a month the macro ignores the computed
'total and inserts 9999
Sub Monthlytotal()
Worksheets("Sheet2").Select
Cells(1, 4).Value = " Year "
Cells(1, 5).Value = " Month "
Cells(1, 6).Value = " Monthtotal"
k = 2
Found9999 = False
monthTotal = 0
For i = 2 To 19722
    currentmonth = Month(Worksheets("sheet2").Cells(i, 1).Value)
  While Month(Worksheets("sheet2").Cells(i, 1).Value) = currentmonth
   If Worksheets("sheet2").Cells(i, 2).Value = 9999 Then
      Found9999 = True
   End If
   monthTotal = monthTotal + Worksheets("sheet2").Cells(i, 2).Value

     i = i + 1
Wend

   Cells(k, 4).Value = Year(Worksheets("sheet2").Cells(i - 1, 1).Value)
   Cells(k, 5).Value = currentmonth
      If Found9999 = True Then
            Cells(k, 6).Value = 9999
            Else
            Cells(k, 6).Value = monthTotal
   End If

   Found9999 = False
    k = k + 1

   monthTotal = 0


   currentmonth = Month(Worksheets("sheet2").Cells(i, 1).Value)
  i = i - 1

    Next i

End Sub
```

Macro B-3

'This macro checks for gaps in date in a time series.Fills the date gaps and prints 9999 for date gaps data value.

```
Sub DataGaps2()
Worksheets("sheet2").Select
Cells(1, 1).Value = "Date"
Cells(1, 2).Value = "Discharge"
k = 2
For i = 2 To 11324
   DateGap = (Worksheets("sheet1").Cells(i + 1, 1).Value) -
(Worksheets("sheet1").Cells(i, 1).Value)
   CurrentDate = (Worksheets("sheet1").Cells(i, 1).Value)
If DateGap > 1 Then
   Cells(k, 1).Value = (Worksheets("sheet1").Cells(i, 1).Value)
   Cells(k, 2).Value = (Worksheets("sheet1").Cells(i, 2).Value)
   k = k + 1
    For j = 1 To CInt(DateGap - 1)
      Cells(k, 1).Value = CurrentDate + j
      Cells(k, 2).Value = 9999
      k = k + 1
   Next j
Else
   Cells(k, 1).Value = CurrentDate
   Cells(k, 2).Value = (Worksheets("sheet1").Cells(i, 2).Value)
      k = k + 1
End If

Next i
End Sub
```

Macro B-4

```
'This macro converts data from tabular format and writes the data in a single
column.It returns 9999 for days with no recorded data.
Sub columndata()
Worksheets("st65").Select
k = 2
For i = 261 To 312
For J = 3 To 14


If Worksheets("sheet1").Cells(i, J).Value = "" Then
Cells(k, 2).Value = "9999"

k = k + 1

Else
Cells(k, 2).Value = Worksheets("sheet1").Cells(i, J).Value
'Cells(k, 4).Value = Worksheets("sheet1").Cells(i, J + 1).Value
k = k + 1

End If
Next J
Next i

End Sub
```

APPENDIX_C: OBSERVED LAKE LEVELS (1900-1998)

Table C_1 :Observed lake levels(1900-1998)

Jan-00	1892.03	Mar-04	1893.17	May-08	1893.88	Jul-12	1892.47	Sep-16	1891.52
Feb-00	1891.91	Apr-04	1893.24	Jun-08	1893.84	Aug-12	1892.44	Oct-16	1891.59
Mar-00	1891.82	May-04	1893.30	Jul-08	1893.80	Sep-12	1892.42	Nov-16	1891.67
Apr-00	1891.74	Jun-04	1893.37	Aug-08	1893.78	Oct-12	1892.39	Dec-16	1891.72
May-00	1891.66	Jul-04	1893.43	Sep-08	1893.75	Nov-12	1892.36	Jan-17	1891.77
Jun-00	1891.58	Aug-04	1893.50	Oct-08	1893.72	Dec-12	1892.34	Feb-17	1891.82
Jul-00	1891.50	Sep-04	1893.56	Nov-08	1893.70	Jan-13	1892.31	Mar-17	1891.87
Aug-00	1891.42	Oct-04	1893.63	Dec-08	1893.67	Feb-13	1892.28	Apr-17	1891.93
Sep-00	1891.34	Nov-04	1893.69	Jan-09	1893.64	Mar-13	1892.26	May-17	1892.10
Oct-00	1891.26	Dec-04	1893.76	Feb-09	1893.62	Apr-13	1892.23	Jun-17	1893.91
Nov-00	1891.18	Jan-05	1893.86	Mar-09	1893.59	May-13	1892.20	Jul-17	1895.21
Dec-00	1891.10	Feb-05	1893.96	Apr-09	1893.56	Jun-13	1892.18	Aug-17	1895.16
Jan-01	1891.02	Mar-05	1894.02	May-09	1893.54	Jul-13	1892.14	Sep-17	1895.12
Feb-01	1890.94	Apr-05	1894.09	Jun-09	1893.51	Aug-13	1892.10	Oct-17	1895.07
Mar-01	1890.86	May-05	1894.15	Jul-09	1893.48	Sep-13	1892.07	Nov-17	1895.03
Apr-01	1890.78	Jun-05	1894.22	Aug-09	1893.46	Oct-13	1892.04	Dec-17	1894.98
May-01	1890.82	Jul-05	1894.28	Sep-09	1893.43	Nov-13	1892.02	Jan-18	1894.94
Jun-01	1890.89	Aug-05	1894.35	Oct-09	1893.40	Dec-13	1891.99	Feb-18	1894.89
Jul-01	1890.95	Sep-05	1894.41	Nov-09	1893.38	Jan-14	1891.96	Mar-18	1894.85
Aug-01	1891.02	Oct-05	1894.48	Dec-09	1893.35	Feb-14	1891.94	Apr-18	1894.80
Sep-01	1891.12	Nov-05	1894.54	Jan-10	1893.31	Mar-14	1891.91	May-18	1894.76
Oct-01	1891.21	Dec-05	1894.61	Feb-10	1893.27	Apr-14	1891.88	Jun-18	1894.71
Nov-01	1891.28	Jan-06	1894.66	Mar-10	1893.24	May-14	1891.86	Jul-18	1894.65
Dec-01	1891.34	Feb-06	1894.63	Apr-10	1893.22	Jun-14	1891.83	Aug-18	1894.58
Jan-02	1891.41	Mar-06	1894.61	May-10	1893.19	Jul-14	1891.80	Sep-18	1894.53
Feb-02	1891.47	Apr-06	1894.58	Jun-10	1893.16	Aug-14	1891.78	Oct-18	1894.49
Mar-02	1891.54	May-06	1894.55	Jul-10	1893.14	Sep-14	1891.75	Nov-18	1894.44
Apr-02	1891.61	Jun-06	1894.53	Aug-10	1893.11	Oct-14	1891.72	Dec-18	1894.40
May-02	1891.67	Jul-06	1894.50	Sep-10	1893.08	Nov-14	1891.70	Jan-19	1894.35
Jun-02	1891.74	Aug-06	1894.47	Oct-10	1893.06	Dec-14	1891.67	Feb-19	1894.31
Jul-02	1891.80	Sep-06	1894.45	Nov-10	1893.03	Jan-15	1891.64	Mar-19	1894.26
Aug-02	1891.87	Oct-06	1894.41	Dec-10	1893.00	Feb-15	1891.62	Apr-19	1894.22
Sep-02	1891.93	Nov-06	1894.37	Jan-11	1892.98	Mar-15	1891.58	May-19	1894.17
Oct-02	1892.00	Dec-06	1894.34	Feb-11	1892.95	Apr-15	1891.54	Jun-19	1894.13
Nov-02	1892.06	Jan-07	1894.31	Mar-11	1892.92	May-15	1891.51	Jul-19	1894.08
Dec-02	1892.13	Feb-07	1894.29	Apr-11	1892.90	Jun-15	1891.48	Aug-19	1894.04
Jan-03	1892.19	Mar-07	1894.26	May-11	1892.87	Jul-15	1891.46	Sep-19	1893.99
Feb-03	1892.26	Apr-07	1894.23	Jun-11	1892.84	Aug-15	1891.43	Oct-19	1893.95
Mar-03	1892.32	May-07	1894.21	Jul-11	1892.82	Sep-15	1891.40	Nov-19	1893.90
Apr-03	1892.39	Jun-07	1894.18	Aug-11	1892.79	Oct-15	1891.38	Dec-19	1893.86
May-03	1892.45	Jul-07	1894.15	Sep-11	1892.76	Nov-15	1891.35	Jan-20	1893.81
Jun-03	1892.55	Aug-07	1894.13	Oct-11	1892.72	Dec-15	1891.32	Feb-20	1893.77
Jul-03	1892.65	Sep-07	1894.10	Nov-11	1892.68	Jan-16	1891.29	Mar-20	1893.70
Aug-03	1892.72	Oct-07	1894.07	Dec-11	1892.66	Feb-16	1891.27	Apr-20	1893.63
Sep-03	1892.78	Nov-07	1894.04	Jan-12	1892.63	Mar-16	1891.24	May-20	1893.59
Oct-03	1892.85	Dec-07	1894.02	Feb-12	1892.60	Apr-16	1891.26	Jun-20	1893.54
Nov-03	1892.91	Jan-08	1893.99	Mar-12	1892.58	May-16	1891.31	Jul-20	1893.50
Dec-03	1892.98	Feb-08	1893.96	Apr-12	1892.55	Jun-16	1891.36	Aug-20	1893.45
Jan-04	1893.04	Mar-08	1893.94	May-12	1892.52	Jul-16	1891.41	Sep-20	1893.41
Feb-04	1893.11	Apr-08	1893.91	Jun-12	1892.50	Aug-16	1891.47	Oct-20	1893.36

Table C_1 :Observed lake levels(1900-1998)

Nov-20	1893.32	Mar-25	1892.38	Jul-29	1890.06	Nov-33	1890.10	Mar-38	1889.34
Dec-20	1893.27	Apr-25	1892.35	Aug-29	1889.94	Dec-33	1890.10	Apr-38	1889.24
Jan-21	1893.23	May-25	1892.35	Sep-29	1889.88	Jan-34	1889.82	May-38	1889.14
Feb-21	1893.18	Jun-25	1892.32	Oct-29	1889.76	Feb-34	1889.59	Jun-38	1889.04
Mar-21	1893.14	Jul-25	1892.29	Nov-29	1889.85	Mar-34	1889.52	Jul-38	1888.96
Apr-21	1893.09	Aug-25	1892.20	Dec-29	1889.91	Apr-34	1889.44	Aug-38	1888.92
May-21	1893.05	Sep-25	1892.20	Jan-30	1889.76	May-34	1889.36	Sep-38	1888.88
Jun-21	1893.00	Oct-25	1891.89	Feb-30	1890.22	Jun-34	1889.29	Oct-38	1888.82
Jul-21	1892.96	Nov-25	1891.86	Mar-30	1890.67	Jul-34	1889.21	Nov-38	1888.69
Aug-21	1892.91	Dec-25	1891.86	Apr-30	1891.28	Aug-34	1889.13	Dec-38	1888.55
Sep-21	1892.87	Jan-26	1891.80	May-30	1891.38	Sep-34	1889.06	Jan-39	1888.43
Oct-21	1892.80	Feb-26	1891.74	Jun-30	1891.44	Oct-34	1888.98	Feb-39	1888.35
Nov-21	1892.73	Mar-26	1891.59	Jul-30	1891.50	Nov-34	1888.91	Mar-39	1888.28
Dec-21	1892.69	Apr-26	1891.65	Aug-30	1891.59	Dec-34	1888.84	Apr-39	1888.15
Jan-22	1892.64	May-26	1891.74	Sep-30	1891.68	Jan-35	1888.78	May-39	1888.01
Feb-22	1892.60	Jun-26	1891.80	Oct-30	1891.71	Feb-35	1888.72	Jun-39	1887.92
Mar-22	1892.55	Jul-26	1891.89	Nov-30	1891.80	Mar-35	1888.65	Jul-39	1887.85
Apr-22	1892.51	Aug-26	1892.02	Dec-30	1891.89	Apr-35	1888.57	Aug-39	1887.72
May-22	1892.46	Sep-26	1892.11	Jan-31	1891.59	May-35	1888.5	Sep-39	1887.6
Jun-22	1892.42	Oct-26	1892.20	Feb-31	1891.65	Jun-35	1888.44	Oct-39	1887.45
Jul-22	1892.37	Nov-26	1892.11	Mar-31	1891.74	Jul-35	1888.38	Nov-39	1887.25
Aug-22	1892.33	Dec-26	1892.05	Apr-31	1891.68	Aug-35	1888.32	Dec-39	1887.12
Sep-22	1892.28	Jan-27	1892.05	May-31	1891.59	Sep-35	1888.28	Jan-40	1887.06
Oct-22	1892.24	Feb-27	1892.11	Jun-31	1891.50	Oct-35	1888.25	Feb-40	1887.02
Nov-22	1892.19	Mar-27	1892.20	Jul-31	1891.44	Nov-35	1888.21	Mar-40	1887.26
Dec-22	1892.15	Apr-27	1892.11	Aug-31	1891.47	Dec-35	1888.19	Apr-40	1887.47
Jan-23	1892.10	May-27	1892.05	Sep-31	1891.59	Jan-36	1888.18	May-40	1887.38
Feb-23	1892.15	Jun-27	1891.99	Oct-31	1891.71	Feb-36	1888.18	Jun-40	1887.25
Mar-23	1892.75	Jul-27	1891.80	Nov-31	1891.68	Mar-36	1888.27	Jul-40	1887.14
Apr-23	1893.35	Aug-27	1891.74	Dec-31	1891.65	Apr-36	1888.67	Aug-40	1886.99
May-23	1893.52	Sep-27	1891.68	Jan-32	1890.98	May-36	1888.75	Sep-40	1886.79
Jun-23	1893.47	Oct-27	1891.59	Feb-32	1890.98	Jun-36	1888.74	Oct-40	1886.69
Jul-23	1893.40	Nov-27	1891.47	Mar-32	1890.98	Jul-36	1888.73	Nov-40	1886.56
Aug-23	1893.33	Dec-27	1891.38	Apr-32	1890.98	Aug-36	1888.69	Dec-40	1886.43
Sep-23	1893.28	Jan-28	1891.28	May-32	1890.98	Sep-36	1888.65	Jan-41	1886.64
Oct-23	1893.24	Feb-28	1890.67	Jun-32	1890.89	Oct-36	1888.6	Feb-41	1886.89
Nov-23	1893.19	Mar-28	1890.83	Jul-32	1890.86	Nov-36	1888.51	Mar-41	1886.88
Dec-23	1893.14	Apr-28	1890.77	Aug-32	1890.83	Dec-36	1888.42	Apr-41	1886.83
Jan-24	1893.10	May-28	1890.64	Sep-32	1890.86	Jan-37	1888.31	May-41	1886.82
Feb-24	1893.05	Jun-28	1890.52	Oct-32	1890.83	Feb-37	1888.15	Jun-41	1886.79
Mar-24	1893.00	Jul-28	1890.46	Nov-32	1890.77	Mar-37	1888.31	Jul-41	1886.75
Apr-24	1892.95	Aug-28	1890.37	Dec-32	1890.67	Apr-37	1888.79	Aug-41	1886.71
May-24	1892.91	Sep-28	1890.46	Jan-33	1890.55	May-37	1889.15	Sep-41	1886.66
Jun-24	1892.86	Oct-28	1890.49	Feb-33	1890.49	Jun-37	1889.55	Oct-41	1886.6
Jul-24	1892.81	Nov-28	1890.52	Mar-33	1890.37	Jul-37	1889.95	Nov-41	1886.55
Aug-24	1892.77	Dec-28	1890.37	Apr-33	1890.22	Aug-37	1889.91	Dec-41	1886.5
Sep-24	1892.72	Jan-29	1890.22	May-33	1890.16	Sep-37	1889.78	Jan-42	1886.54
Oct-24	1892.67	Feb-29	1890.06	Jun-33	1890.06	Oct-37	1889.8	Feb-42	1886.78
Nov-24	1892.63	Mar-29	1890.16	Jul-33	1890.06	Nov-37	1889.81	Mar-42	1887.03
Dec-24	1892.58	Apr-29	1890.22	Aug-33	1890.06	Dec-37	1889.7	Apr-42	1887.26
Jan-25	1892.50	May-29	1890.19	Sep-33	1890.06	Jan-38	1889.57	May-42	1887.16

Feb-25	1892.47	Jun-29	1890.13	Oct-33	1890.06	Feb-38	1889.46	Jun-42	1887.2
Jul-42	1887.07	Feb-47	1885.58	Sep-51	1885.99	Apr-56	1885.45	Nov-60	1885.95
Aug-42	1886.87	Mar-47	1886.29	Oct-51	1886.15	May-56	1885.53	Dec-60	1885.96
Sep-42	1886.7	Apr-47	1886.48	Nov-51	1886.19	Jun-56	1885.61	Jan-61	1885.85
Oct-42	1886.63	May-47	1886.58	Dec-51	1886.09	Jul-56	1885.82	Feb-61	1885.73
Nov-42	1886.56	Jun-47	1886.66	Jan-52	1885.98	Aug-56	1886.13	Mar-61	1885.6
Dec-42	1886.47	Jul-47	1886.55	Feb-52	1885.85	Sep-56	1886.24	Apr-61	1885.47
Jan-43	1886.34	Aug-47	1886.48	Mar-52	1885.94	Oct-56	1886.23	May-61	1885.38
Feb-43	1886.24	Sep-47	1886.47	Apr-52	1886.01	Nov-56	1886.13	Jun-61	1885.37
Mar-43	1886.17	Oct-47	1886.37	May-52	1885.93	Dec-56	1886.03	Jul-61	1885.29
Apr-43	1886.09	Nov-47	1886.18	Jun-52	1885.87	Jan-57	1885.92	Aug-61	1885.18
May-43	1886.12	Dec-47	1886.11	Jul-52	1885.87	Feb-57	1885.86	Sep-61	1885.15
Jun-43	1886.15	Jan-48	1886.02	Aug-52	1885.86	Mar-57	1885.95	Oct-61	1885.27
Jul-43	1886.12	Feb-48	1885.85	Sep-52	1885.81	Apr-57	1886.13	Nov-61	1885.86
Aug-43	1886.05	Mar-48	1885.83	Oct-52	1885.71	May-57	1886.37	Dec-61	1887.16
Sep-43	1885.94	Apr-48	1885.81	Nov-52	1885.58	Jun-57	1886.5	Jan-62	1887.82
Oct-43	1885.82	May-48	1885.88	Dec-52	1885.4	Jul-57	1886.63	Feb-62	1888.17
Nov-43	1885.64	Jun-48	1885.99	Jan-53	1885.23	Aug-57	1886.73	Mar-62	1888.05
Dec-43	1885.53	Jul-48	1886.04	Feb-53	1885.14	Sep-57	1886.68	Apr-62	1887.89
Jan-44	1885.43	Aug-48	1885.92	Mar-53	1885.08	Oct-57	1886.59	May-62	1887.84
Feb-44	1885.35	Sep-48	1885.85	Apr-53	1885.01	Nov-57	1886.51	Jun-62	1888.15
Mar-44	1885.3	Oct-48	1885.76	May-53	1884.99	Dec-57	1886.49	Jul-62	1888.17
Apr-44	1885.25	Nov-48	1885.63	Jun-53	1884.94	Jan-58	1886.47	Aug-62	1888.15
May-44	1885.2	Dec-48	1885.5	Jul-53	1884.84	Feb-58	1886.46	Sep-62	1888.21
Jun-44	1885.2	Jan-49	1885.39	Aug-53	1884.74	Mar-58	1886.45	Oct-62	1888.42
Jul-44	1885.19	Feb-49	1885.31	Sep-53	1884.7	Apr-58	1886.53	Nov-62	1888.59
Aug-44	1885.18	Mar-49	1885.27	Oct-53	1884.69	May-58	1886.73	Dec-62	1888.59
Sep-44	1885.02	Apr-49	1885.19	Nov-53	1884.58	Jun-58	1887.07	Jan-63	1888.52
Oct-44	1884.81	May-49	1885.19	Dec-53	1884.42	Jul-58	1887.33	Feb-63	1888.45
Nov-44	1884.7	Jun-49	1885.31	Jan-54	1884.25	Aug-58	1887.4	Mar-63	1888.4
Dec-44	1884.62	Jul-49	1885.34	Feb-54	1884.25	Sep-58	1887.39	Apr-63	1888.38
Jan-45	1884.59	Aug-49	1885.25	Mar-54	1884.5	Oct-58	1887.36	May-63	1888.59
Feb-45	1884.61	Sep-49	1885.16	Apr-54	1884.83	Nov-58	1887.28	Jun-63	1889
Mar-45	1884.61	Oct-49	1885.1	May-54	1885.19	Dec-58	1887.25	Jul-63	1889.36
Apr-45	1884.63	Nov-49	1884.94	Jun-54	1885.32	Jan-59	1887.14	Aug-63	1889.31
May-45	1884.83	Dec-49	1884.74	Jul-54	1885.42	Feb-59	1887.02	Sep-63	1889.19
Jun-45	1885.07	Jan-50	1884.79	Aug-54	1885.48	Mar-59	1886.95	Oct-63	1889.2
Jul-45	1885.03	Feb-50	1884.77	Sep-54	1885.43	Apr-59	1886.88	Nov-63	1889.12
Aug-45	1884.97	Mar-50	1884.68	Oct-54	1885.37	May-59	1886.86	Dec-63	1889.07
Sep-45	1884.9	Apr-50	1884.64	Nov-54	1885.27	Jun-59	1886.85	Jan-64	1889.43
Oct-45	1884.84	May-50	1884.69	Dec-54	1885.17	Jul-59	1886.73	Feb-64	1889.52
Nov-45	1884.72	Jun-50	1884.82	Jan-55	1885.12	Aug-59	1886.73	Mar-64	1889.39
Dec-45	1884.57	Jul-50	1884.95	Feb-55	1885.01	Sep-59	1886.74	Apr-64	1889.33
Jan-46	1884.39	Aug-50	1884.93	Mar-55	1884.94	Oct-59	1886.72	May-64	1889.52
Feb-46	1884.26	Sep-50	1884.85	Apr-55	1884.9	Nov-59	1886.66	Jun-64	1889.62
Mar-46	1884.43	Oct-50	1884.72	May-55	1884.82	Dec-59	1886.63	Jul-64	1889.61
Apr-46	1884.44	Nov-50	1884.62	Jun-55	1884.75	Jan-60	1886.55	Aug-64	1889.61
May-46	1884.46	Dec-50	1884.5	Jul-55	1884.92	Feb-60	1886.25	Sep-64	1889.72
Jun-46	1884.62	Jan-51	1884.56	Aug-55	1885.12	Mar-60	1886.05	Oct-64	1889.88
Jul-46	1884.86	Feb-51	1885.05	Sep-55	1885.23	Apr-60	1885.99	Nov-64	1890.07
Aug-46	1884.89	Mar-51	1885.28	Oct-55	1885.18	May-60	1885.92	Dec-64	1890.22
Sep-46	1884.91	Apr-51	1885.47	Nov-55	1885.21	Jun-60	1885.84	Jan-65	1890.16
Oct-46	1884.85	May-51	1885.51	Dec-55	1885.29	Jul-60	1885.92	Feb-65	1890.08

Nov-46	1884.79	Jun-51	1885.66	Jan-56	1885.31	Aug-60	1885.87	Mar-65	1890.01
Dec-46	1884.78	Jul-51	1885.82	Feb-56	1885.27	Sep-60	1885.91	Apr-65	1889.91
Jan-47	1884.97	Aug-51	1885.88	Mar-56	1885.28	Oct-60	1885.92	May-65	1889.77

Jun-65	1889.71	Jan-70	1888.79	Aug-74	1887.55	Mar-79	1889.51	Oct-83	1889.079
Jul-65	1889.76	Feb-70	1888.74	Sep-74	1887.72	Apr-79	1889.57	Nov-83	1889.191
Aug-65	1889.68	Mar-70	1888.63	Oct-74	1887.82	May-79	1889.64	Dec-83	1889.149
Sep-65	1889.6	Apr-70	1888.72	Nov-74	1887.83	Jun-79	1889.73	Jan-84	1889.086
Oct-65	1889.53	May-70	1888.90	Dec-74	1887.78	Jul-79	1889.79	Feb-84	1888.967
Nov-65	1889.44	Jun-70	1888.99	Jan-75	1887.62	Aug-79	1889.79	Mar-84	1888.791
Dec-65	1889.34	Jul-70	1889.03	Feb-75	1887.47	Sep-79	1889.73	Apr-84	1888.687
Jan-66	1889.24	Aug-70	1888.99	Mar-75	1887.34	Oct-79	1889.61	May-84	1888.371
Feb-66	1889.14	Sep-70	1889.07	Apr-75	1887.20	Nov-79	1889.55	Jun-84	1888.255
Mar-66	1889.04	Oct-70	1889.15	May-75	1886.99	Dec-79	1889.46	Jul-84	1888.14
Apr-66	1888.94	Nov-70	1889.12	Jun-75	1887.03	Jan-80	1889.32	Aug-84	1888.024
May-66	1888.86	Dec-70	1889.03	Jul-75	1887.08	Feb-80	1889.20	Sep-84	1887.909
Jun-66	1888.94	Jan-71	1888.89	Aug-75	1887.27	Mar-80	1889.09	Oct-84	1887.896
Jul-66	1888.96	Feb-71	1888.78	Sep-75	1887.66	Apr-80	1888.98	Nov-84	1887.882
Aug-66	1888.9	Mar-71	1888.61	Oct-75	1887.86	May-80	1889.13	Dec-84	1887.869
Sep-66	1888.82	Apr-71	1888.50	Nov-75	1887.89	Jun-80	1889.28	Jan-85	1887.855
Oct-66	1888.83	May-71	1888.50	Dec-75	1887.79	Jul-80	1889.33	Feb-85	1887.807
Nov-66	1888.9	Jun-71	1888.61	Jan-76	1887.64	Aug-80	1889.20	Mar-85	1887.568
Dec-66	1888.89	Jul-71	1888.72	Feb-76	1887.49	Sep-80	1889.08	Apr-85	1887.557
Jan-67	1888.92	Aug-71	1888.89	Mar-76	1887.32	Oct-80	1888.93	May-85	1887.612
Feb-67	1888.83	Sep-71	1889.23	Apr-76	1887.16	Nov-80	1888.88	Jun-85	1887.666
Mar-67	1888.7	Oct-71	1889.21	May-76	1887.06	Dec-80	1888.82	Jul-85	1887.72
Apr-67	1888.57	Nov-71	1889.21	Jun-76	1887.00	Jan-81	1888.67	Aug-85	1887.775
May-67	1888.43	Dec-71	1889.11	Jul-76	1886.93	Feb-81	1888.53	Sep-85	1887.829
Jun-67	1888.54	Jan-72	1889.04	Aug-76	1886.82	Mar-81	1888.37	Oct-85	1887.809
Jul-67	1888.75	Feb-72	1888.98	Sep-76	1887.06	Apr-81	1888.63	Nov-85	1887.722
Aug-67	1888.85	Mar-72	1888.90	Oct-76	1886.87	May-81	1889.04	Dec-85	1887.635
Sep-67	1888.92	Apr-72	1888.75	Nov-76	1886.60	Jun-81	1889.23	Jan-86	1887.548
Oct-67	1888.94	May-72	1888.66	Dec-76	1886.73	Jul-81	1889.25	Feb-86	1887.461
Nov-67	1888.92	Jun-72	1888.59	Jan-77	1886.11	Aug-81	1889.56	Mar-86	1887.375
Dec-67	1888.89	Jul-72	1888.57	Feb-77	1886.34	Sep-81	1889.64	Apr-86	1887.288
Jan-68	1888.87	Aug-72	1888.52	Mar-77	1886.37	Oct-81	1889.65	May-86	1887.201
Feb-68	1888.81	Sep-72	1888.51	Apr-77	1886.53	Nov-81	1889.59	Jun-86	1887.376
Mar-68	1888.7191	Oct-72	1888.44	May-77	1887.41	Dec-81	1889.54	Jul-86	1887.401
Apr-68	1888.59	Nov-72	1888.50	Jun-77	1887.62	Jan-82	1889.53	Aug-86	1887.38
May-68	1889.75	Dec-72	1888.47	Jul-77	1887.81	Feb-82	1889.3086	Sep-86	1887.36
Jun-68	1889.80	Jan-73	1888.38	Aug-77	1888.02	Mar-82	1889.0398	Oct-86	1887.34
Jul-68	1889.82	Feb-73	1888.27	Sep-77	1888.06	Apr-82	1888.975	Nov-86	1887.32
Aug-68	1889.75	Mar-73	1888.16	Oct-77	1887.95	May-82	1889.0082	Dec-86	1887.277
Sep-68	1889.81	Apr-73	1888.03	Nov-77	1888.03	Jun-82	1889.009	Jan-87	1887.194
Oct-68	1889.79	May-73	1887.95	Dec-77	1888.26	Jul-82	1888.949	Feb-87	1887.111
Nov-68	1889.75	Jun-73	1887.93	Jan-78	1888.31	Aug-82	1888.9452	Mar-87	1887.027
Dec-68	1889.75	Jul-73	1887.85	Feb-78	1888.29	Sep-82	1888.8906	Apr-87	1886.944
Jan-69	1889.69	Aug-73	1887.80	Mar-78	1888.45	Oct-82	1888.8454	May-87	1886.808
Feb-69	1889.61	Sep-73	1887.80	Apr-78	1888.96	Nov-82	1888.8895	Jun-87	1886.631
Mar-69	1889.56	Oct-73	1887.77	May-78	1889.28	Dec-82	1889.4054	Jul-87	1886.7
Apr-69	1889.48	Nov-73	1887.73	Jun-78	1889.16	Jan-83	1889.3459	Aug-87	1886.746
May-69	1889.50	Dec-73	1887.63	Jul-78	1889.15	Feb-83	1889.2489	Sep-87	1886.659

Jun-69	1889.45	Jan-74	1887.50	Aug-78	1889.20	Mar-83	1889.1767	Oct-87	1886.573
Jul-69	1889.32	Feb-74	1887.33	Sep-78	1889.25	Apr-83	1889.0882	Nov-87	1886.486
Aug-69	1889.12	Mar-74	1887.21	Oct-78	1889.42	May-83	1888.9997	Dec-87	1886.399
Sep-69	1889.11	Apr-74	1887.25	Nov-78	1889.47	Jun-83	1888.9312	Jan-88	1886.313
Oct-69	1889.01	May-74	1887.33	Dec-78	1889.44	Jul-83	1888.9157	Feb-88	1886.226
Nov-69	1888.91	Jun-74	1887.32	Jan-79	1889.36	Aug-83	1888.9196	Mar-88	1886.22
Dec-69	1888.86	Jul-74	1887.47	Feb-79	1889.52	Sep-83	1888.9725	Apr-88	1886.383

May-88	1886.2321	Jan-92	1887.2834	Sep-95	1886.3
Jun-88	1886.2112	Feb-92	1887.1553	Oct-95	1886.4
Jul-88	1886.5006	Mar-92	1887.0272	Nov-95	1886.45
Aug-88	1886.7528	Apr-92	1886.8991	Dec-95	1886.56
Sep-88	1886.9676	May-92	1886.771	Jan-96	1886.5
Oct-88	1887.1856	Jun-92	1886.6429	Feb-96	1886.4
Nov-88	1887.1793	Jul-92	1886.77	Mar-96	1886.3
Dec-88	1887.1731	Aug-92	1886.9064	Apr-96	1886.2
Jan-89	1887.1668	Sep-92	1887.0428	May-96	1886.07
Feb-89	1887.1605	Oct-92	1887.1792	Jun-96	1886
Mar-89	1887.1542	Nov-92	1887.3156	Jul-96	1886.1
Apr-89	1886.8879	Dec-92	1887.4504	Aug-96	1886.24
May-89	1886.8649	Jan-93	1887.5588	Sep-96	1886.3
Jun-89	1886.842	Feb-93	1887.4788	Oct-96	1886.5
Jul-89	1886.819	Mar-93	1887.3988	Nov-96	1886.5
Aug-89	1886.7961	Apr-93	1887.3188	Dec-96	1886.56
Sep-89	1886.7732	May-93	1887.2388	Jan-97	1886.5
Oct-89	1886.7502	Jun-93	1887.1588	Feb-97	1886.4
Nov-89	1886.927	Jul-93	1887.0788	Mar-97	1886.3
Dec-89	1887.1252	Aug-93	1886.9988	Apr-97	1886.2
Jan-90	1887.3234	Sep-93	1886.9188	May-97	1886
Feb-90	1887.4832	Oct-93	1886.8388	Jun-97	1886
Mar-90	1887.4889	Nov-93	1886.7588	Jul-97	1886
Apr-90	1887.6009	Dec-93	1886.54	Aug-97	1886.07
May-90	1888.0158	Jan-94	1886.5	Sep-97	1886.25
Jun-90	1888.4307	Feb-94	1886.4	Oct-97	1886.5
Jul-90	1888.3974	Mar-94	1886.23	Nov-97	1886.5
Aug-90	1888.3466	Apr-94	1886.1	Dec-97	1886.5
Sep-90	1888.2958	May-94	1886.1	Jan-98	1887.87
Oct-90	1888.245	Jun-94	1886.16	Feb-98	1887.9543
Nov-90	1888.1942	Jul-94	1886.4	Mar-98	1887.9219
Dec-90	1888.1434	Aug-94	1886.5	Apr-98	1887.36
Jan-91	1888.0926	Sep-94	1886.6	May-98	1888.25
Feb-91	1888.0418	Oct-94	1886.5	Jun-98	1888.72
Mar-91	1887.851	Nov-94	1886.5	Jul-98	1888.85
Apr-91	1887.6574	Dec-94	1886.92	Aug-98	1888.92
May-91	1887.5156	Jan-95	1886.8	Sep-98	1888.92
Jun-91	1887.4411	Feb-95	1886.64	Oct-98	1888.93
Jul-91	1887.4769	Mar-95	1886.4	Nov-98	
Aug-91	1887.5252	Apr-95	1886.4	Dec-98	
Sep-91	1887.4784	May-95	1886.47		
Oct-91	1887.4316	Jun-95	1886.5		
Nov-91	1887.3848	Jul-95	1886.51		
Dec-91	1887.3381	Aug-95	1886.3		

APPENDIX_D: DATA FILE NAMES

Folder	subfolder	files
Naivasha	Orignal	Contains all availagble original discharge data
	Naiv _flow	Contains processed discharge data
	Naiv-rain	Contains all original rainfall data
	Rain-90s	Contains processed rainfall data
	Naiv_evap	Contains original evaporation data
		Contains processed evaporation data
	Lake_levs -	Contains lake level data
Model		Contains all modeling files
Thesis		Contains my thesis

All files are named after the respective stations being analyzed.
Model file named 1900f =model for period 1900to 1997 based on discharge data modeled from rainfall
Model file name flowfile5 = model for period 1932 to 1997 based on gauged infilled and extrapolated discharge data
Model file name flowtur = model for period 1932 to 1997 based on Turasha discharge
Model file name Hyd_mod2=model for period 1900to 1997 based on HBV model generated discharge data
Model file name annmod 3= annual model based on rainfall- runoff model