WATER BALANCE OF THE SOUTHERN KENYA RIFT VALLEY LAKES

Muno Fred Armstrong
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By

Muno Fred Armstrong

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Degree Assessment Board
Prof.Dr.A.M.J.Meijerink, Chairman (Head, WRS Division)
External Examiner: Dr. J.C.Gehrels, TNO, Delft
Supervisor:Drs. Robert Becht (Lecturer, ITC, Enschede)
Member: Dr. M.W.Lubczcnsky

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATIONS, ITC
ENSCHEDE, THE NETHERLANDS

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DEDICATED TO:

My Mother, Imat Bency Nywalowok

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Last but not least, I believe everything has been made possible by God.

So May God Almighty bless you all!

ABSTRACT

For any proper management of a waterbody water balance is an essential prerequisite. Previous studies carried out suggest that Lake Naivasha discharges about 50 mcm/yr to groundwater system and nobody knows for certain where it disappears. Researchers have often speculated the possible discharge areas to be Lake Elementeita to the north and Magadi to the south. It is for this reason that the study was initiated to cast on more light on the groundwater flow north and south of Naivasha.

Describing groundwater regime in the rift valley is one of the most difficult tasks in hydrogeology due to complex geology tied to the area dynamic evolution and its volcanic systems. Consequently, there is no single method that can provide all the necessary data sufficient to explain groundwater flow and that is why there is need for an integrated approach.

Before this can be done various components of hydrological system have to be analysed basing on the conceptual groundwater model of the region providing the backbone for quantification of the fluxes. The quantification of the hydrological system is derived by matching results from groundwater model for the whole study area and simple model describing the waterbalance components of the lakes.

Water balance approach was used to provide an indirect evaluation of groundwater components from known components. Using excel spreadsheet modeling, simulating historical lake levels, it was possible to determine groundwater recharge to the lakes. Somehow, a method had to be devised to approximate evaporation flux and groundwater recharge of the trona covered Lake Magadi.

The study showed that precipitation and streamflow to lakes Elementeita and Nakuru are not sufficient to maintain the lake levels, and thus groundwater recharge estimated at 15 and 26 mcm/yr respectively were obtained. The evaporation estimate for Lake Magadi obtained is about 135 mcm/yr from which groundwater estimate of 64mcm/yr is derived.

The results of the water balances indicate that the surrounding lakes gain groundwater inflow in their water balances and more interestingly, amounts to the groundwater loss from Lake Naivasha. If this water bodies share the same reservoir then it is plausible to say that they gain from contribution from Lake Naivasha. Although it is not implicitly conclusive that groundwater gained are products of Lake Naivasha, piezometric levels and isotopic evidence point in this direction.

If our observation is correct, it implies therefore that the basins in the southern Rift valley are hydrologicaly connected by regional flow systems perhaps through yet little well understood basal aquifer.

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REPORT LAYOUT

Chapter 1 deals with the general background and relevance of the study.

Chapter 2 discusses the study area, location and climate.

Chapter 3 and 4 handles the geologic and hydrogeological framework that was essential for defining the conceptual model.

Chapter 5 deals with the analyses of the fieldwork and all the achieved hydrological and meteorological data necessary for the modeling and water budgets.

Chapter 6 deals with isotope geochemistry into the origin of the springs feeding Lakes Magadi and Elementeita

Chapter 7 and 8 analyse the lakes and catchments water budgets results and relate it to groundwater flow regimes.

Chapter 9 discusses the results and the results pertinent with the water budgets modeling and all the preceding data handling processes and therefrom draws a number of conclusions with some recommendations.

Chapter 1 Introduction

1.1 BACKGROUND

The study aimed to integrate data and assess water budgets on the four lakes in the southern Kenya Rift Valley (Naivasha, Elementeita, Nakuru and Magadi). Lake level fluctuation is a common feature of all lakes in the Rift Valley. Evidence for this is provided by both historical records and casual observations which indicate that the lakes at one time came close to completely drying up. This phenomena, suggests that the water balance and the flow systems in the area, over time, have been altered. Changing water levels on these particular lakes have indirect impact on socio-economy of Kenya as they could affect fisheries, tourism and agriculture. In the case of Elementeita and Nakuru the environmental impact would be severe on the unique ecology of fauna and flora that thrives in the unusual alkaline aquatic lake environment. Naivasha owing to its freshness experiences heavy demands on its water for agricultural purposes. The Olkaria geothermal power project (generating about 18% of the electricity) to the south of Lake Naivasha,a major electricity-producing enterprise in Kenya, indirectly derives its waters by recharge from the lake. There is thus a big strain on the availability of water of suitable quality and adequate quantity to meet the diverse and conflicting demands. Lake Magadi is an important soda producing lake and it has the second largest trona concentration in the world after Salton Sea in California. In recent years the efficiency of soda production has diminished because of greater rainfall and decreased evaporation.

It is thus important to make a quantitative evaluation of water resources of these hydrological reservoirs and their response to the changes in climate and human activities, and for that purpose hydrological water balance is becoming critically important.

The modeling approach can be used for evaluating the sensitivity of a lake to different controlling factors, to infer past fluctuations in precipitation from past fluctuations in lake water level, or to predict the consequences of climate and artificial changes in the regime of streams, lakes, and groundwater basins. Above all, water balance study can provide an indirect evaluation of unknown water balance component from the difference between the known components.

Previous studies around Lake Naivasha have indicated that over 50 million cubic meters of water annually is lost from the lake. Although numerous researchers have speculated that water finds its way to Lake Magadi and some proportion flows to the north probably interacting with Lake Elemeinteita and Lake Nakuru, very little is yet known for certain as to where this water disappears. Although often neglected, the groundwater contribution can be significant to the lake water balance. The thesis, therefore discusses the water balance of these lakes and in the process attempts to improve the interpretation of the north south groundwater flow from Lake Naivasha on a more regional scale. This has also been supplemented by isotopic studies in some instances.

1.2 RESEARCH PROBLEM

Previous studies provided detailed descriptions of groundwater flow patterns around Lake Naivasha and quantified groundwater interactions using detailed water budgets and groundwater flow models. As a result, the understanding of the various factors affecting groundwater exchange has greatly improved. The site-specific nature of these studies, however, makes it difficult to extrapolate results to the larger population of lakes in the Rift Valley. Contemporaneous studies of groundwater exchange are needed for a larger number of lakes. With this information we can begin to make comparisons between lakes and characterize how these lakes respond to hydrologic conditions within the region. Basin-scale study approach in the water budgets of the Rift Valley Lakes are clearly needed to enhance understanding on their relative importance on the regional groundwater flow. This study therefore aims at examining lakes at an intrabasin scale to determine groundwater contributions and losses from the lakes in relation to Lake Naivasha.

1.3 OBJECTIVES

The principle objective is to see whether the water loss from Lake Naivasha is appearing as water gain in other lakes.

The specific objectives are:

1. To estimate water balance of Lake Elementeita, Nakuru and Magadi.

2. To describe the general direction of groundwater flow with respect to Lake Naivasha .

1.4 RESEARCH QUESTIONS

1. Are lakes neighbouring Lake Naivasha gaining or losing groundwater from the water budgets.
2. Can the water balance analysis help in the understanding of the North and South flow.
3. Will isotopic hydrochemistry provide evidence to the source of water feeding Lakes Magadi, Elementieta and Nakuru, and also be able to give an insight in the direction of groundwater flow with respect to Lake Naivasha.

1.5 LITERATURE REVIEW

In Kenya Rift Valley there are chains of lakes occupying the valley floor. Fascinatingly, the lakes ranges from fresh as for Lake Naivasha to highly alkaline as for Lake Magadi. Lake Naivasha, of all these lakes has been studied more extensively due to its unique quality.

Previous studies of exploration of the Naivasha area began as early as 1880's by European explorers. Thompson of the Royal Geographical Society of England noted the freshness of the lake water and attributed it to being either of recent origin or the lake having an underground channel (LNROA, 1993). Gregory (1992) suggested that the lakes freshness was due to undiscovered underground outlet. Nilsson (1938) proposed that the Lake's freshness was a result of water both entering and leaving the Lake via underground seepage.

In 1936, Sikes made the first statistical attempt to estimate monthly and annual water budget for Lake Naivasha and magnitude of the proposed underground seepage. It is uncertain which methods he used, but he estimated that water was seeping out of the lake at a rate of 43 mcm/yr.

Gaudet and Melack (1981), on the basis of rain, river and Lake water chemistry concluded that there is a subsurface water outflow from the Lake Naivasha.

Ase et a.l (1986) worked on the surface hydrology of the lake and mass balance equation to derive possible subsurface outflow from the lake, he estimated outflow at 46 mcm per year.

According to Ase et al (1987), assumed that the most probable outlet was towards the south that is towards Lake Magadi although fascinatingly the lake itself is highly alkaline.

Clark et al., (1990) and others used two methods to determine the water flow by waterbalance studies and by application of Darcy's law of groundwater flow. Their calculations based on water balances, estimate that a total of 50 mcm/yr flow out of the Naivasha catchment which represents 20% of the total recharge. The flow to the south is via relatively shallow aquifers less than 500 m depth, and these may account for 50 to 90% of the total flow. Estimate of the northerly flow by the same authors was 11.3 mcm/yr.

Earlier, McCann (1972) estimated a much greater subsurface outflow to the Nakuru and Elementeita catchment to be about 39 mcm/yr using Darcys law. He used Naivasha lake water balance and estimated that at least 34 mcm infiltrates to Naivasha groundwater reservoir. He further estimated that about 14 mcm and 23 mcm/ yr of groundwater inflow is required to maintain constant lake water level for Lake Elemeinteita and Lake Nakuru respectively.

Darling et.al (1990) and others were able to determine the direction, quantity and character of the underground flows in and out of the lake. They used stable isotopic composition of the fumaroles steam from volcanic centres in the areas to infer groundwater composition. Using simple modelling techniques they traced the outflow from the lake up to 30 km south. Lake water has also been detected in Olkaria steam. The work confirmed that of Allen (1989) that most of the water leaving the lake goes out between Olkaria and Longonot, whilst a smaller portion goes north between Eburru and Gilgil. Their estimates of the outflow agreed broadly with the earlier researchers like Sikes, McCann and Ase.

Ojiambo (1992) deduced from piezometric surfaces that the subsurface outflow from Lake Naivasha originates from the southern shores of the lake, and then flows southerly and southwesterly toward Olkaria. And that the main lake outflow fluxes ranges from 18 and 50 mcm /yr.

Mbui (Msc Theses 1999) studied the long-term waterbalance of the basin and calculated a groundwater outflow of 4.6 mcm/mth and lake abstraction of about 57 mcm/mth. He estimated a long term average total combined inflows from Rivers, Malewa, Gilgil, Tutasha and Karati and the surface inflow into the lake about 2.26 mcm/mth.

Githae (Msc Thesis 1998) studied the waterbalance of Nakuru-Elementeita basin and estimated the total groundwater flow in the basin to about 50 mcm per year.

Water flows out of the lake to the north via Gilgil and under Eburru and there is southerly flow following the hydraulic gradient towards Magadi, although there is no evidence at all to suggest that the water ever reaches Magadi. It would appear from all these results and studies that the subsurface flows from Naivasaha catchment, the amount contributed to the flow by the lake Naivasha is 50 to 60 mcm/yr.

1.6 METHODOLOGY

Figure 1.1 shows a schematic representation of the breakdown and sequence of the study process.

1.6.1 PRE-FIELDWORK

In the preliminary stages desk study including literature review was carried out and maps of the study area were prepared. Available data were screened and pre-processed. Appropriate field materials and tools were identified.

1.6.2 FIELDWORK

Fieldwork entailed collection of secondary hydrological and meteorological data that is representative for the research area. Data were obtained from various sources including Kenya Meteorological Department, Ministry of Water Development, Kenya Wildlife Society, Magadi Soda Company and Nakuru Water Department. The data pertained to the following aspects: precipitation, evaporation, river discharge, water abstraction, lakes water level and boreholes records. Additional data requirement included bathymetric survey data for the study lakes. Water samples from springs were collected for isotope analysis.

Field visit was made to all the study lakes and synoptic rivers. River discharges were estimated and gauges checked. The general hydrogeology of the area was examined and verified.

1.6.3 POST-FIELDWORK

DATA ANALYSIS

The water balance requires key hydrological variables as inputs. At this point in time all data collected were, pre-processed/reconstructed and spatially transformed for further applications. This stage provided a graphical overview of the spatial and temporal behaviour allowing good insight into the geophysical dynamics which any hydrological model must incorporate

MODELING

Water Balance Model for study lakes were developed on spreadsheets. The methodology is centered on parameterization, calibration and validation of a conceptual deterministic quasi-distributed hydrological model. The parameters were based on estimates derived from available data sources such as meteorological data. The models were calibrated against historical measurements of lake levels and validated against a separate, independent set of measurements.

WATERBUDGET COMPUTATIONS AND INTERPRETATIONS OF RESULTS

Water balance of each lake was systematically examined and results integrated into the regional hydrologic balance. Isotope interpretations and regional groundwater flow were discussed.

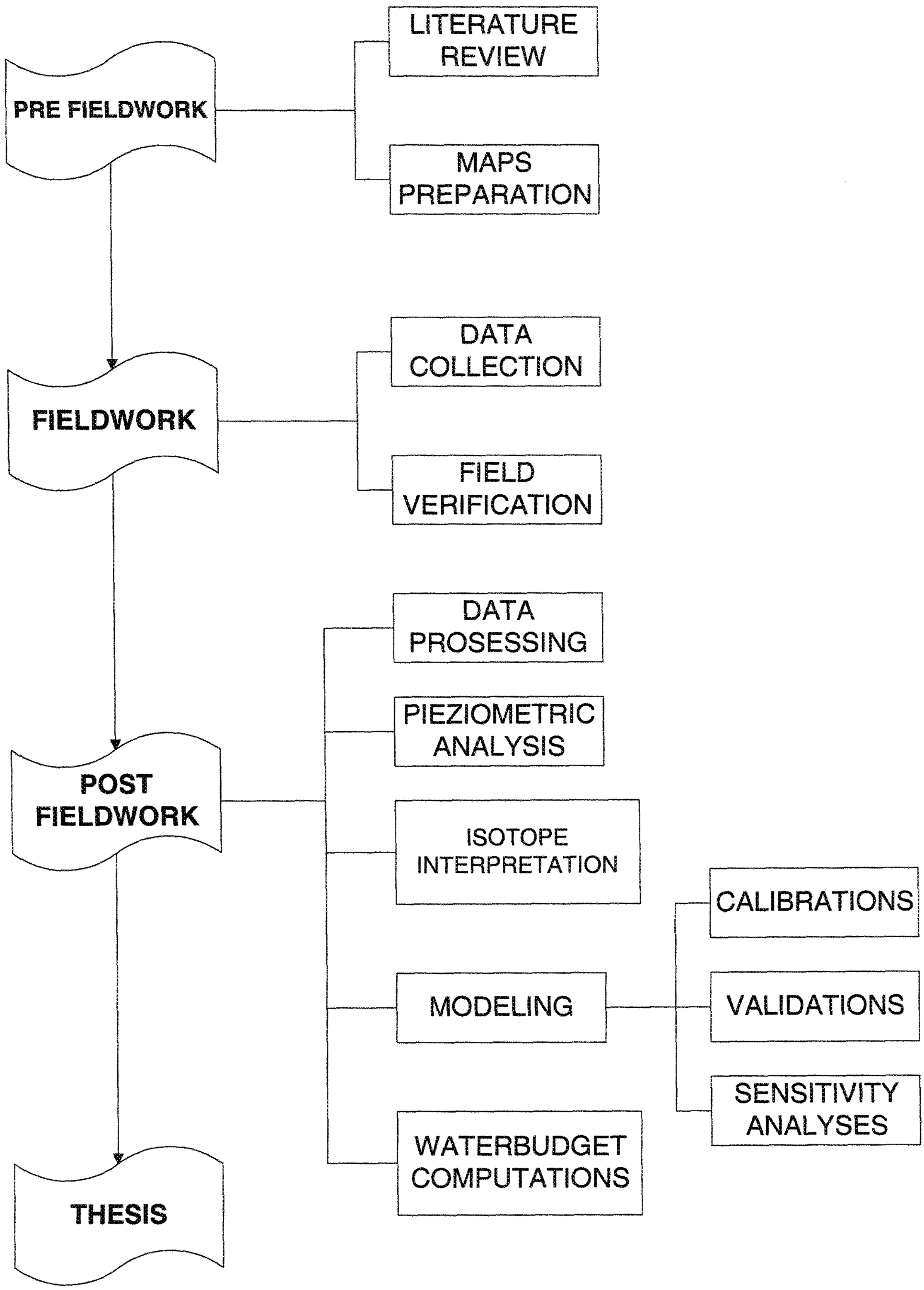
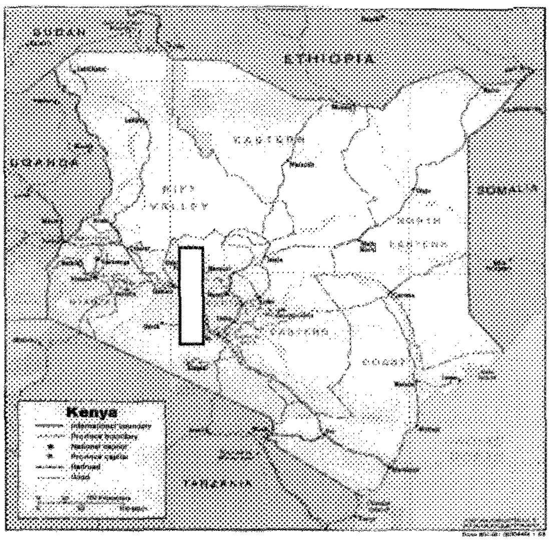


Figure 1.1 Schematic representation of the sequence of the study area

Chapter 2 Description of study area

2.1 GEOGRAPHICAL REFERENCE

The study area lies within the southern portion of the East African Rift that traverses the western part of Kenya in a north-south direction between Menengai Crater and Lake Natron. It is approximately located between latitudes 0° 09' to 2° 15' S and longitudes 35° 50' to 36° 42' E, Figure 2.1.



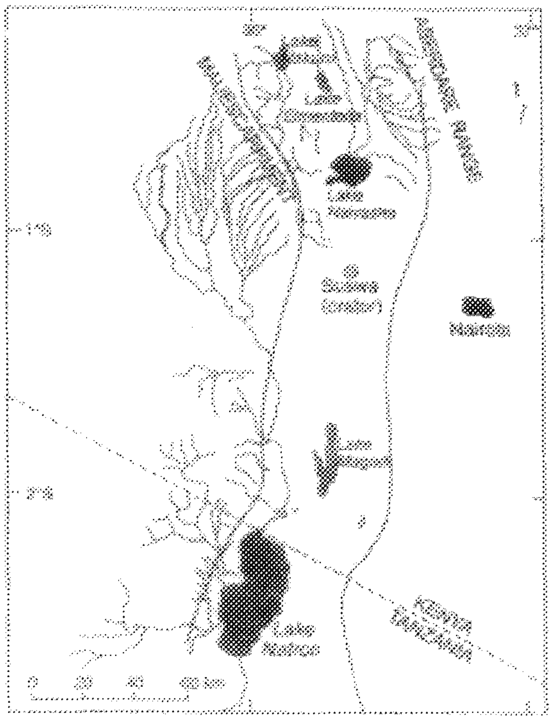


Figure 2.1 Location Map

Lake Nakuru, Elementeita, Naivasha and Magaadi, are members of a chain of lakes within the East African rift valley (a complex graben) that runs from Ethiopia to Tanzania that came into existence due to the numerous late Quaternary central volcanic structures, which often separated them from each other.

The floor of the rift is highest in the central portion between Lake Nakuru and Lake Naivasha where it is almost 2000 m amsl and decreases in elevation northwards towards Lake Turukana (300 m amsl.) and southwards towards Lake Magadi (600 m amsl).

The section of the rift valley is bounded in the west by the Mau escarpment (elevated to over 3000 m) and Nguruman (1950 m), and in the east by the Nyandarua Mountain (elevated over 3960 m) and Kikuyu escarpment (2400 m).

There are a number of perennial streams in the study area. In the Lake Naivasha catchment the Malewa and Gilgil have a perennial discharge to the lake; and the Karati is perennial in its upper reach. In the Lake Elementeita catchment the Mereroni also discharges perennially to the lake although flows are very low. In the Lake Nakuru catchment the Makali and Enjoro are usually perennial except during droughts. Ewaso Ngiro drains a very large area, flows near Lake Magadi and disharges into Lake Natron .

The relationships between these lakes and regional groundwaters vary considerably, with the result that the lake ranges from fresh to highly alkaline in their chemistry. Because the highly alkaline lakes are discharge areas, their relationships with regional waters are made fairly clear. The four closed-basin lakes can be categorise in two classes: Naivasha, being a freshwater lake, Nakuru, Elementeita and Magadi being highly sodic (alkaline). Lake Magadi is one of the largest soda ash reserves of the East African Rift Valley Lakes. The basic hydrological data of the lakes are summarized in the following table (table 2.1)

Lakes	Altitude (m.a.s.l)	Catchment Area (km^2)	Lake Area (km^2)	Maximum depth (m)	Mean Depth (m)	Volume (mcm)	Resid. Time (yr)	Salinity (mg/l)
Naivasha	1890	3387.76	139.2	11.5	6.5	4600	1.5	300
Nakuru	1759	1360.44	45	2.8	2.3	92	1.2	5000-90000
Elementeita	1770	829.44	21	1.2	0.9	40	1.0	3000
Magadi	600	23207 (*Natron incl.*)	164	-	-	-	-	35000

Table 2.1 Basic hydrological data of the study lakes

2.2 CLIMATE

Climatic conditions in the study area are quite diverse due to considerable differences in the altitude and landforms. The annual temperature range is approximately from 8°C to 30°C (Kenya Government, 1976). The maximum daily temperature at Magadi is 35°C (minimum 23°C), while at Naivasha, near the culmination of the Rift; it is 25°C (minimum 9°C). The rainfall regime is influence by the rain-shadow from the surrounding highlands of the Nyandarua range to the east, and the Mau escarpment to the west.

Rainfall is well distributed throughout the year, but at Naivasha and Elementeita, there is a discernable peak in April, whereas at Nakuru, there are lesser additional peaks in July/August and September/October (Kenya Government, 1976).

Within the Rift mean annual rainfall is generally low ranging from 430 mm at Magadi through 627 mm at Naivasha to 981 mm at Nakuru with most of the region experiencing an average of about 750 mm (Met. Dept. data 1931-1980).

Relative humidity is low throughout the Rift (less than 75% at Naivasha, less than 60% at Magadi) and potential evaporation (1600 to 1800 mm) greatly exceeds annual rainfall. Monthly averaged potential evaporation at Naivasha exceeds rainfall over twofold for every month except April when potential evaporation still exceeds rainfall except in the wettest of the years. The figures are not recorded for Magadi where excess of evaporation over rainfall must be considerably higher. However individual storms in the two rainy seasons can be extremely heavy and in areas of permeable material some recharge is probable.

On the Rift escarpments rainfall values are much higher ranging up to around 1250 to 1500 mm annually (McCann 1974). Also evapotranspiration rates at these altitudes are lower at about 1400 mm per year, and much less during rainy seasons. Nyandarua Mountains within Naivasha Lake's catchment receive as much as 1525 mm. Also evapotranspiration rates at these altitudes are lower at about 1400 mm per year, and much less during rainy seasons

2.1.1 RAINFALL PATTERN

The rainfall patterns within the study area are subject to great spatial and temporal variation and a product of both the location of the area in the East African tropics (macro-climate) and the particular topography of the region (meso-climate). The macro-climate gives a regime of two rainy seasons per year, the "long rains" occurring in April and May and part of June; sometimes these rains begin in March, the "short rains" in December and January, occasionally beginning in November. In the rift valley this pattern is distorted by relief, with very much more rain falling at a higher altitudes (1250-1500 mm annually) than on the valley floor, and in some part of the study area a third rainy season occurs in August. Also evapotranspiration rates at these altitudes are lower at about 1400 mm per year and much less during the rainy seasons.

The general pattern of rainfall can be gauged from the graph of long-term average rainfall for four of the stations within the study area given in Figure 2.2. Teret Forest station is situated on the Mau escarpment in the west of the study area, at an altitude of 2438 masl. Naivasha WDD, Elementeita Soysambu Estate and Magadi Soda Works Lab. are situated on the valley floor at 1935 m, 1849 m and 600 m respectively.

The figure indicates clearly that rainfall patterns differ widely across the study area, with notable higher levels of rainfall occurring at the stations located at higher altitudes compared with those situated on the valley floors. It can also be seen that from Magadi in the south, rainfall tends to increase northwards. It is also evident that rainfall patterns follow the typical trend of two rainy seasons whereas Teret Forest shows a well-defined August peak in rainfall. It should be noted that these patterns only emerge when the average of many years of rainfall are taken otherwise the actual pattern and quantity may vary significantly from the long-term average.

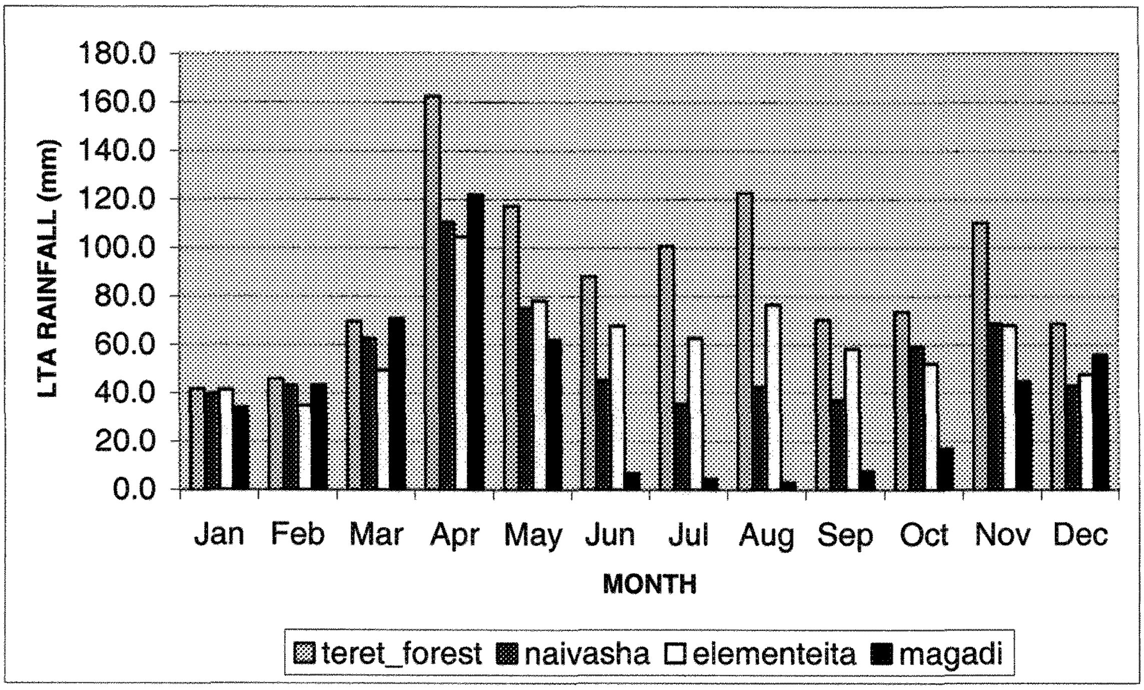


Figure 2.2 Graph of Long Term Average Rainfall

2.3 LANDUSE AND VEGETATION

The principle land use is agriculture which includes irrigated crop farming (horticulture, vegetables, fruits) around the lakes and mixed farming (wheat, maize, potatoes, beans and sunflowers) on the rain fed slopes of the escarpments. Dairy farming is mainly practiced on large farms.

Rift valley lakes and their catchments areas represent important ecological sites in Kenya due to the diversity of fauna and flora which are distributed through a range of vegetation zones. Settlements are mainly concentrated around the main towns with a few homes within the estates and the farms.

The vegetation in the greatest proportion of the low lying rift valley is mainly characterized by grassland, bushland, acacia, cactus trees, savannah and shrubs that provide suitable habitat for wildlife and indigenous livestock farming. Whereas deciduous woodland occupy the escarpments. The montane forest is dominated by hardwood and bamboo that form the main watersheds of the lakes. The *Ericaceae* bush, which tolerates low temperature, extends up to 3600 m where it grades into the afroalphine grassland vegetation (White, 1983).

Naivasha shores are often surrounded by ephermal papyrus colonies and rafts of Salvinia molesta covers some part of the lakes surface. Nakuru and Elementeita do not support this kind of vegetation due to their highly alkaline waters (Harper, 1990) but supports blue green algae (*Spirulina*) that attract flocks of Flamingoes.

Chapter 3 Geomorphology and hydrogeologic setting

3.1 GEOLOGY

In the study area the Rift Valley is mainly composed of a succession of late Tertiary and Quaternary volcanics with, in some areas, intervening lacustrine beds and alluvium principally of reworked volcanic debris. Precambrian Basement rocks are postulated to underlie this volcano-sedimentary succession at or below sea level. The topography of the basement is uncertain and is a subject of continuing geophysical research.

The Rift is defined by major Pliocene boundary faults of the Nguruman and Mau Escarpments in the west, and the Kikuyu, Nyandarua and Bahati Escarpments in the east. In the south east the boundary of the rift is less well defined, there being a succession of smaller escarpment faults with intermediate faults between them. The main fault scarps range from 300 to 1600 m in height, are en echelon in plan, and form a complex graben 60 to 70 km wide, reducing to 17 to 35 km by fault offsets and steps. The volcanic succession of the flanks of the rift valley is over 2000 m thick in places, and the succession in the rift floor is considered to be significantly thicker than this, perhaps reaching 3000 to 4000 m (Baker, Mohr and Williams, 1972). The rift valley floor is obscured by the late Quaternary volcanic piles such as Longonot and Suswa, and by lower and middle Pleistocene sediments around Magadi and between Naivasha and Nakuru.

The oldest rocks found in the study area are the Archean Basement gneisses which outcrop near the summit of the Nguruman Escarpment in the south-west (Baker, 1958). These are overlain by Pliocene basalts, which also occur beneath a cover of a younger volcanics along parts of the rift valley such as the Nyandarua (Aberdare) range composed of basalts, phonolites, trachytes and mugerarites. Others are the Oloregesailie, Ol Esayeti and Ol Esakut volcanos to the southwest of Nairobi which are composed of basalts, trachytes, phonolites and nephelinites. The Ngong volcanos, also to the southwest of Nairobi contains melanephelinities, basanites and phonolites (Baker, Williams, Miller and Fitch, 1971).

Plio-Pleistocene trachyte lavas and ignimbrites occupy nearly all the floor of the central and southern Rift in Kenya and occur in places on the marginal plateaux. The lower part of the group consists of trachytic tuffs with prominent ignimbrite units which are best exposed on the Bahati and Kinangop Escarpments on the eastern side of the rift (Thompson and Dodson, 1963). Further east ash flows of this age are found on the flank of Nyandaeua Range and elsewhere.

West of the Rift Plio-Pleistocene ignimbrites form most of the Mau Range and extend northward (Baker, Williams, Miller and Fitch, 1971). On the Rift floor trachyte and some basalt occurs within the ignimbrite succession.

In the Magadi area the extensive plateau trachyte represent the upper part of the group (Baker, 1958), and extend onto eastern side of the rift to form the Limuru trachyte west of Nairobi. On the Kikuyu Escarpment and in the Kijabe area trachytic flows and pyroclastics are interbeded (Thompson, 1964).

The late Quaternary phase of mainly trachyte caldera eruptions occurred along the floor of the rift valley and is represented by the large central volcanoes of Suswa and Longonot, which date from the middle Pleistocene and comprise phonolite, alkaline trachyte and rhyolite lavas and extensive pyroclasts. Also included in this phase of activity are basaltic cinder cones, rubbly lavas and tuff rings of the Elementeita region, the Eburru volcanic pile (heavily mantled with pyroclastic but with Phonolite and trachyte reported (Thompson and Dodson, 1963) and the highly comenditic lavas of the Olkaria area.

Sedimentary deposits are mainly found in the central southern and northern part of the study area. In the south a thin layer of lake beds (the Oloranga beds), mainly reworked volcanic debris with thickness of up to 15 m, overlie the plateau trachytes and precede the extensive grid faulting which determines the present day topography. Succeeding Middle Pleistocene sediments include the Olorgasaile lakebeds of diatomaceous clays and the fine silts and clays of the Ewaso Ngiro basin, sediments of Kedong valley (predominantly clays and fine sandstones with poorly sorted conglomerate), and the silicified clays of the earliest Magadi Lake. Subsequent minor faulting disturbed these sediments and was followed in the Magadi area by extensive lucustrine deposition (the High Magadi beds) to a level off 12 m above the present lake surface, and by further sedimentation in the Ewaso Ngiro basin (Baker, 1958). At Magadi deposition of the evaporite Series is thought to mark the onset of alkaline spring activity, which continues to, the present day.

In the northern part of the study area Lower Middle Pleistocene sediments (mainly subaqueously deposited pyroclastic) have been found in the Kinangop scarp and in the Njorowa George (Thompson and Dodson, 1963). There are also diatomaceous sediments of the upper middle Pleistocene age east of lake Elementeita. However the most widespread sediments were deposited during Gamblian Pluvial period towards the end of the Pleistocene and cover much of the Rift floor between lake Naivasha and the northern boundary of the study area.

During this period relatively stable conditions existed in the area and extensive lucustrine deposits were laid down and subsequently partly eroded. Three lake levels have been recorded and it was only during the first maximum of the Gamblian Pluvial that the lake occupying the Naivasha basin joined that occupying the Nakuru basin, when the respective levels were 122 m and 120 m higher than at present. The Gamblian lake deposits are composed of volcanic ash, silts, clays and a few bands of diatomite. They are tectonically relatively undisturbed and have a maximum thickness of 33 m (Thompson and Dodson, 1963).

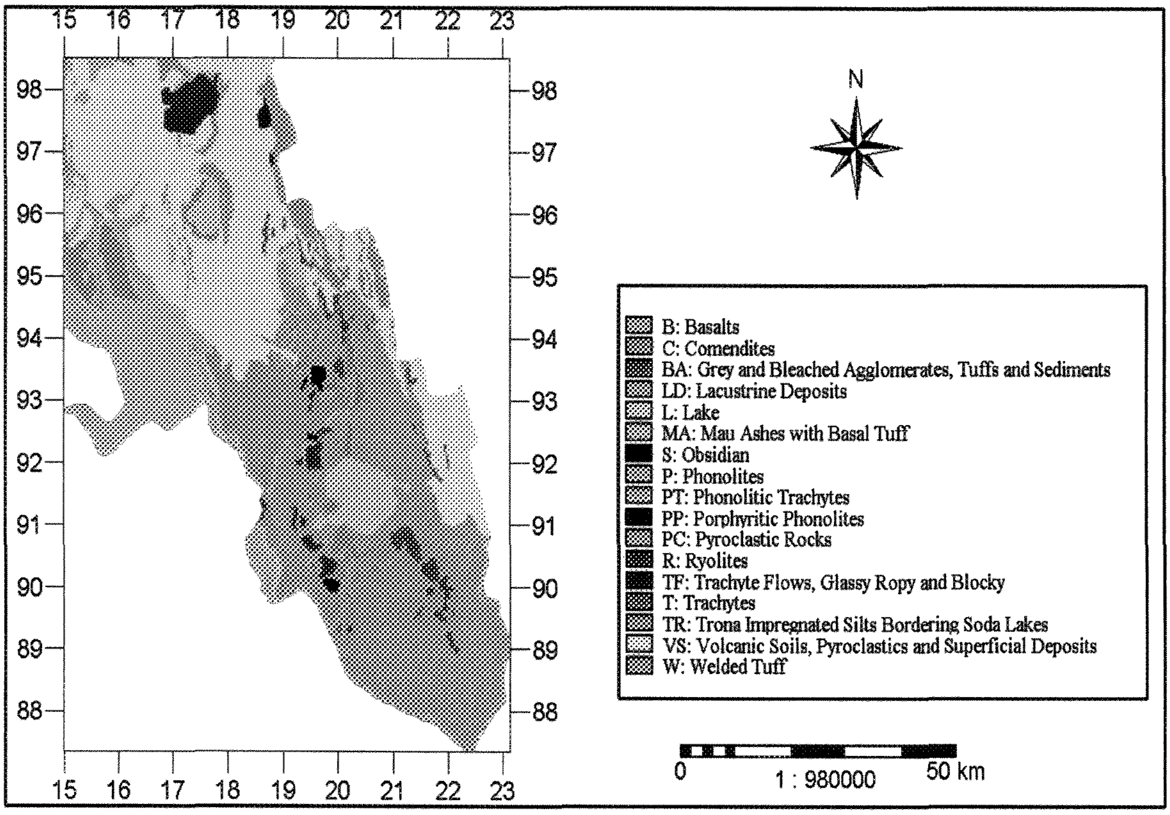


Figure 3.1 Geological map of the northern part of the study area

PLATE 3.1 Rounded boulders believed to have been deposited by ancient river south of Lake Naivasha. The river left en echelon depressions which have been turned to animal watering points by the masai.

3.2 HYDROGEOLOGY

3.2.1 SURFACE HYDROLOGY

Drainage into Lake Nakuru

Lake Nakuru (1757 m) is a shallow pan with an average depth of 2.3 meters. The water is extremely saline (sodium bicarbonate type) due to rapid evaporation of shallow water body. The lake pan is re-charge mainly by rainfall and increments from surface drainage in wet seasons and groundwater. The rivers Njoro, Larmudiac, and Nderit drain from the Mau escarpment towards Lake Nakuru, but most of the flow is lost as groundwater recharge before the lake is reached. The Ngosur River is permanent and several minor streams flow off the Bahati uplands westwards toward Lake Nakuru although none of them reaches the lake but instead feeds groundwater systems that recharges the lake

Drainage into Lake Elementeita

Lake Elementeita (1776 m) is a shallow pan similar to Nakuru and its floored by rather coarser salt impregnated sedimentary material. Its surface water comes from Mereroni Karaiandushi and Mbaruk streams and possibly groundwater sources. During dry seasons, Mbaruk is virtually dry. Evaporation rates are high and this also accounts for the lakes high salinity. The Mereroni, Mbaruk and Kariandusi streams flow southwards off the Bahati Escarpment and feed Lake Elementeita. However, these streams taper showing a considerable water decrement through percolation and seepage to groundwa-ter system and the amount of water reaching the lake is very little. Maji Moto on the south-eastern end of the lake is a major contributor to the lake level during the dry season.

Drainage into Lake Naivasha

The surface of Lake Naivasha reaches a height of 1884 m. Naivasha catchment is separated from the Nakuru-Elementeita catchment by the Eburru volcanic pile which is linked to the Mau Escarpment by a ridge at an altitude of around 2600 m

Southeast of the drainage divide the perennial Gilgil and Malewa Rivers provide much of the recharge to Lake Naivasha. The Gilgil River has its headwaters high in the Bahati Forest and drains parts of the eastern slope of the Bahati Escarpment. These slopes also provide some tributaries of the much larger Malewa River, however at its upper reaches, derives from the western slope of the high Nyandrarua Range. Further downstream the Malewa is joined by the Turasha River, which is also perennial and drains the north Kinangop Plateau via deeply incised tributaries. On the west side of the Naivasha catchment is main river draining the Mau Escarpment is the Marmonet, which flows towards the lake but fails to reach it instead recharging the alluvium of the Ndabibi plain.

To the south of lake Naivasha surface drainage at lower altitudes is limited only river Karati provides perennial flow in its upper reaches, and cutting a deep gully as it descends the step platforms east of Naivasha Town. The drainage originating on the Olkaria Complex including the Hell's Gate-Njorowa Gorge. All the above drainage systems, except those from the Kinangop Plateau, terminate as alluvial fans on the Akira Plains.

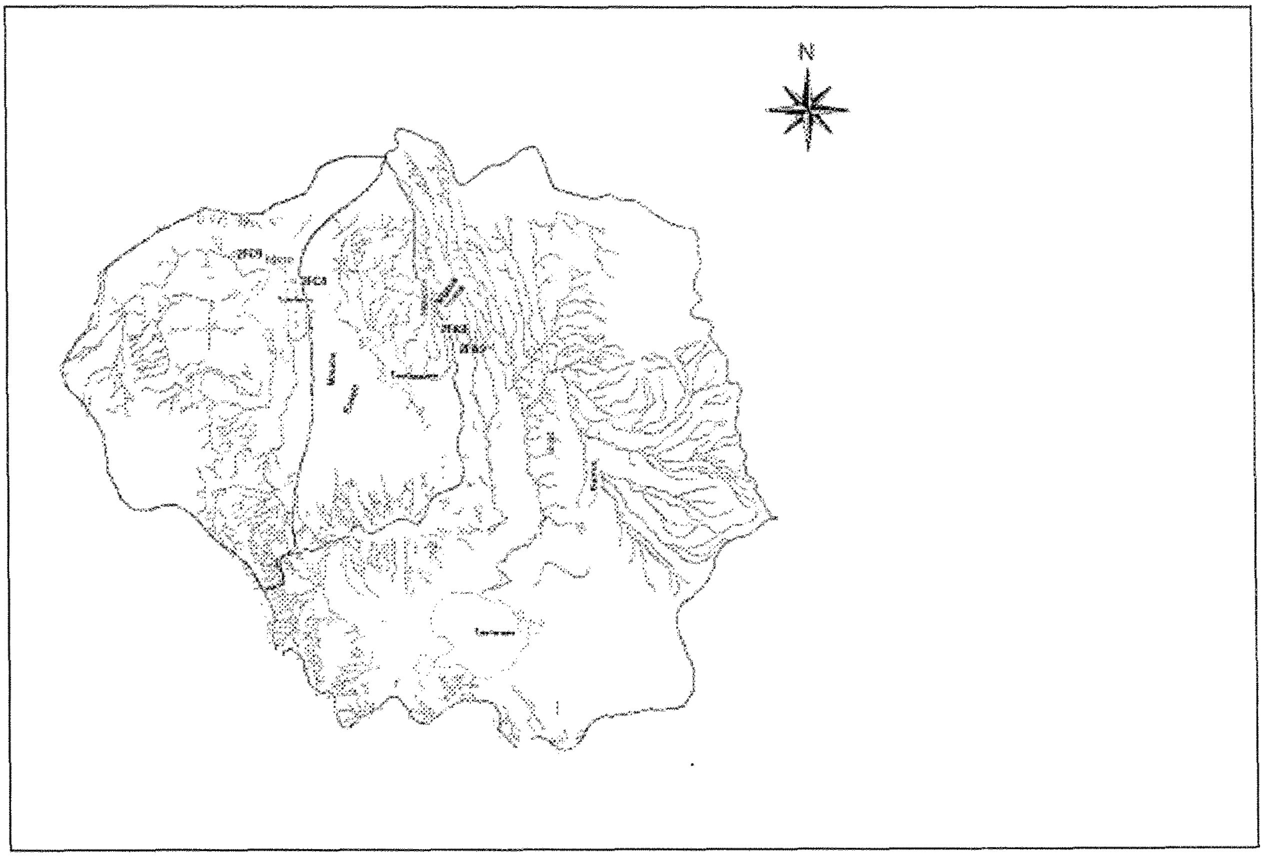


Figure 3.2 Drainage in the Lake Nakuru, Elementeita and Naivasha basins

Drainage into Lake Magadi.

There is no perennial surface drainage to, nor any outlet from, Lake Magadi. A number of springs and seepages which feed the lake occur around its margin, some of which have a significantly elevated temperature (maximum 86°C at the northern extremity of Little Magadi. As a result of extreme evaporation, Lake Magadi has developed some of the most concentrated brines to be found in the alkaline saline lakes of the rift valley and a layer of trona (crystalline carbonate of sodium) covers the surface. The only perennial river in the Suswa- Magadi area is the Ewaso Ngiro River which passes west of lake Magadi and discharges into the Engare Ngiro swamp at the north end of Lake Natron to the south of the study area. (Figure 3.3)

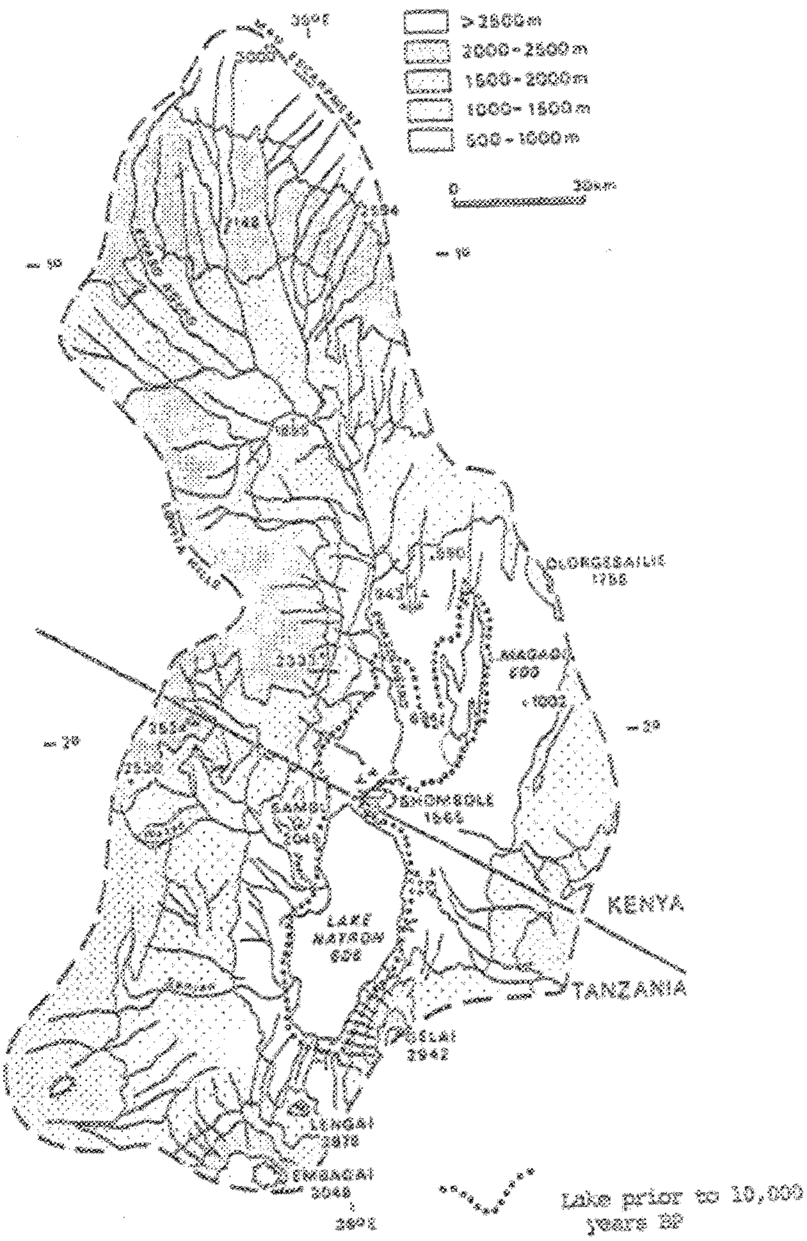


Figure 3.3 Drainage in the Lake Magadi-Natron basin (Vincens and Casanova 1987)

3.2.2 GROUNDWATERS

As indicated in the geological outline, the geology of this area is fairly complex and tied to geodynamic evolution of the rift valley and its volcanic systems. Considering the area's geodynamic situation, it includes various geothermal manifestations such as fumaroles, high-temperature sources, etc. The majority of geothermal activities are associated to volcanic complexes in Eburru, Olkaria, Longonot and Suswa. These complexes affect groundwater flow.

In general the permeability of rocks in the Rift Valley is low, although there is considerable local variation. Aquifers normally found in the fractured volcanics, or along the weathered contacts between different lithological units.

These aquifers are often confined or semi-confined and the storage coefficients are likely to be low. In addition aquifers with relatively high permeability are found in the reworked volcanics composing the sediments of the Naivasha area. Such aquifers are often unconfined and have relatively high specific yields

Its rather difficult to provide a description of the hydrological features for every volcanic formation since the tectonic movements in the Rift Valley strongly affect the aquifer properties, both at small scale by creating local fracture systems that contain aquifers, and on large scale, forming regional hydraulic barriers generally or shatter zones of enhanced permeability.

Most of the drillings were over 50 years period. Maximum-drilled depth ranges from 200 to 250 m. Deep geothermal drillings are present in the area mainly in the Ebburu and the Olkaria geothermal fields where in some cases drilling could reach depths in excess of 1000 m in the recent past. Unfortunately, in most of the wells the stratigraphy and the hydraulic features of the encountered aquifers are not known since regular flow rate tests were not carried out during or after drilling.

Table 3.1 shows the average characteristics of aquifers located in the selected areas (Clarke et al., 1990) attempted several hypotheses on the regionalisation of data according to which the highest values of permeability are found in the reworked volcanics composing the sediments of the Naivasha area where the specific capacities of wells often exceed 3 l/s/m and where estimated hydraulic conductivities greater than 10 m/d are common. In the Rift floor to the north, where the sediment size decreases, borehole specific capacity fall, to around 0.3 l/s/m in the Elementeita-Nakuru area (leading to an estimated average hydraulic conductivity of 2 m/d). On the Rift escarpments the permeability of the different rock types are uniformly low. Mean borehole specific capacities and estimated hydraulic conductivities range from 0.031 l/s/m and 0.1 m/d for the Kinangop Tuff to 0.21 l/s/m and 1.1 m/d for the Limuru Trachyte to the east of Suswa and the Mau Tuff.

These figures are only applicable to the drilled depths of the boreholes, normally less than 250 m. Below this depth permeabilities will decrease, mainly as a result of closure of fissures by overburden stresses. The only deep boreholes drilled in the Rift are those in the Olkaria geothermal field where permeability of the reservoir rocks is low (around 5 m/d). Translated in cold water for comparison with the water borehole values these figures indicate hydraulic conductivity and transmissivity values of around $3*10^{-3}$ m/d and 1-4 m^2/d respectively. Simple modeling in the present study has suggested that the average hydraulic conductivity of rocks at depth under the Rift in the Naivasha's area is much less than 0.1 m/d.

Area	Lithology	Geometric mean estimated Transmissivity m^2/day	Geometric mean estimated permeability m/day	Total number of boreholes
NE Naivasha	Sediments & volcanics	307 (1170)	12 (33)	35
SE Naivasha	Sediments & volcanics	502 (3082)	20 (114)	22
SW Naivasha	Sediments & volcanics	297 (940)	63 (169)	17
NW Naivasha	Sediments & volcanics	1601 (5308)	148 (818)	26
Naivasha Elementeita	Sediments & volcanics	78 (143)	1.4 (3.9)	12
Elementeita-Nakuru	Sediments & volcanics	32 (261)	2 (7)	31
Bahati Escarpment	Tuffs	14 (47)	1.2 (3.7)	25
Kinangop Plateau	Tuffs	14 (106)	0.8 (5)	32
S Kinangop	Pyroclastic	4 (5)	0.1 (0.2)	11
E Suswa	Trachyte	20 (325)	1.1 (35)	48
Mau Escarpment	Pyroclastic	22 (174)	1 (10)	23
MauForest(W Nakuru)	Pyroclastic	20 (119)	1.1 (22)	43

Table 3.1 Average aquifer characteristics of the selected areas and lithologies from boreholes data, figures in brackets are geometric means, (Clarke et al., 1990).

Chapter 4 Hydrogeologic assessment of groundwater flows

4.1 INTRODUCTION

This chapter is to determine the direction of groundwater flow and to estimate groundwater flux from hydrogeological perspective. Our conceptual model of groundwater flows in the region is shown in the cross section in Figure 4.1

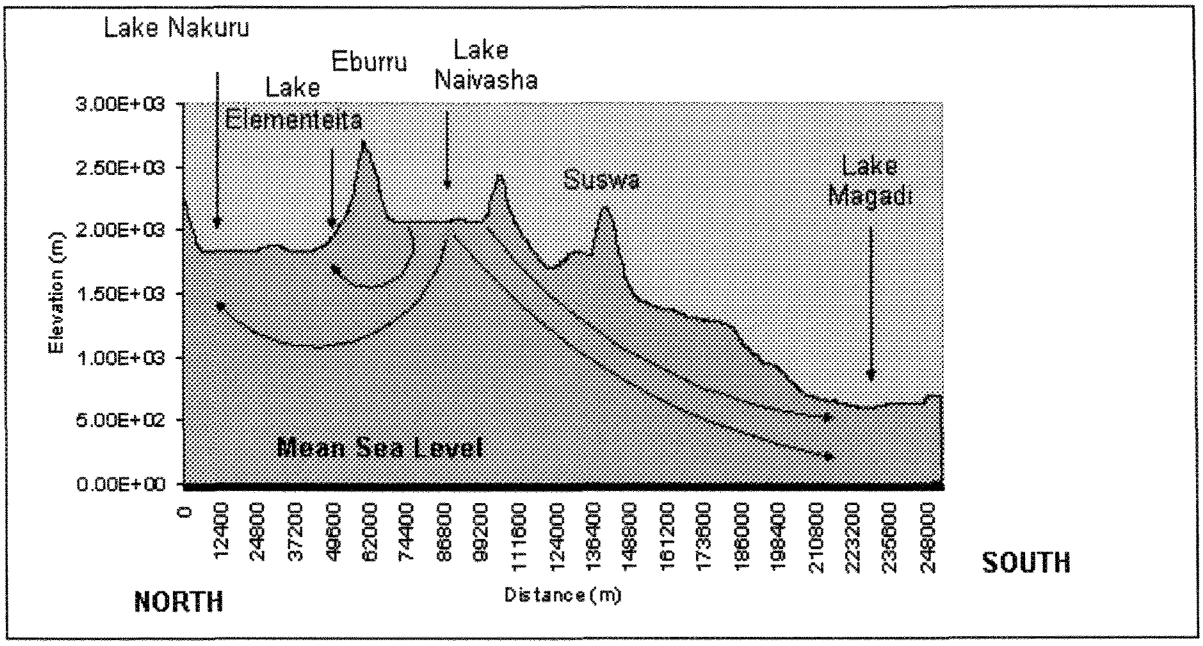


Figure 4.1 A north-south topographical profile of the rift valley floor from Lake Nakuru to Lake Magadi showing our conceptual model of groundwater flow from Lake Naivasha catchment.

4.2 GROUNDWATER FLOW PATTERN FROM PIEZOMETRIC MAP

Measurements of hydraulic head obtained from leveled wells or piezometers in a confined aquifer can be contoured on a map. Such a map of hydraulic heads is referred to as a piezometeric surface map, defined by Meinzer (1923) as an imaginary surface that everywhere coincides with the level of water in the aquifer. If the aquifer is unconfined, the contoured surface is referred to as a map of the water table. The groundwater flow direction and the groundwater gradient are calculated and, in combination with transmissivity value, the groundwater flow rate can be obtained.

Figure 4.2 shows the potentiometric surface covering some part of the southern rift valley. On a regional scale, the map shows the features expected in a valley/ interfluve system, with groundwater flowing from elevated recharge areas to low lying discharge areas, the flow occurring both laterally and longitudinally according to the Rift geometry. The structure of the rift valley and in particular the major marginal Rift faults and the system of grid faulting on the rift floor have a substantial effect on the groundwater flow systems.

The high hydraulic gradient developed across the rift valley escarpments seen around Bahati escarpment and the escscarpment to the east of Suswa is clear manifestation of axial faults acting as zone of low permeability and thus inhibiting flows from the escarpments towards the lakes. This effect doest seems to be pronounced along the Mau escarpment as the contours relatively spread suggesting that the flows towards the lakes are not greatly affected. In contrary grid faulting which is so predominant on the rift valley floor seems to act as conduits and provide pathways for groundwater. This has been supported by seismic survey which indicated that grid faults unlike the escarpment faults are still active (Tobin, Ward and Drake, 1969) which suggest that they are open. All in all, the effect of faulting appears to cause groundwater flow to align along the rift axis.

In Lake Elementeita and Nakuru area groundwater gradients and therefore flows are generally directed to the lakes. It is speculated that at depth groundwater, flows away from the Nakuru_Elementeita basin beneath Menengai Crater into the Lake Baringo catchment. In the Naivasha catchment, groundwater generally flows towards the lake from the Mau and Aberdere escarpments, although it is diverted locally by the presence of faults that may at times constraint or enhance groundwater flow described above. Contours in the northern part of the Naivasha catchment suggest that some groundwater may flow into the Lake Elementieta catchment. Between Longonot and Lake Magadi the contours suggest that groundwater flows from the side of the rift towards the center, and southwards along the rift towards Magadi. The flow directions are confirmed using isotope geochemistry and lake water budget discussed in proceeding chapters.

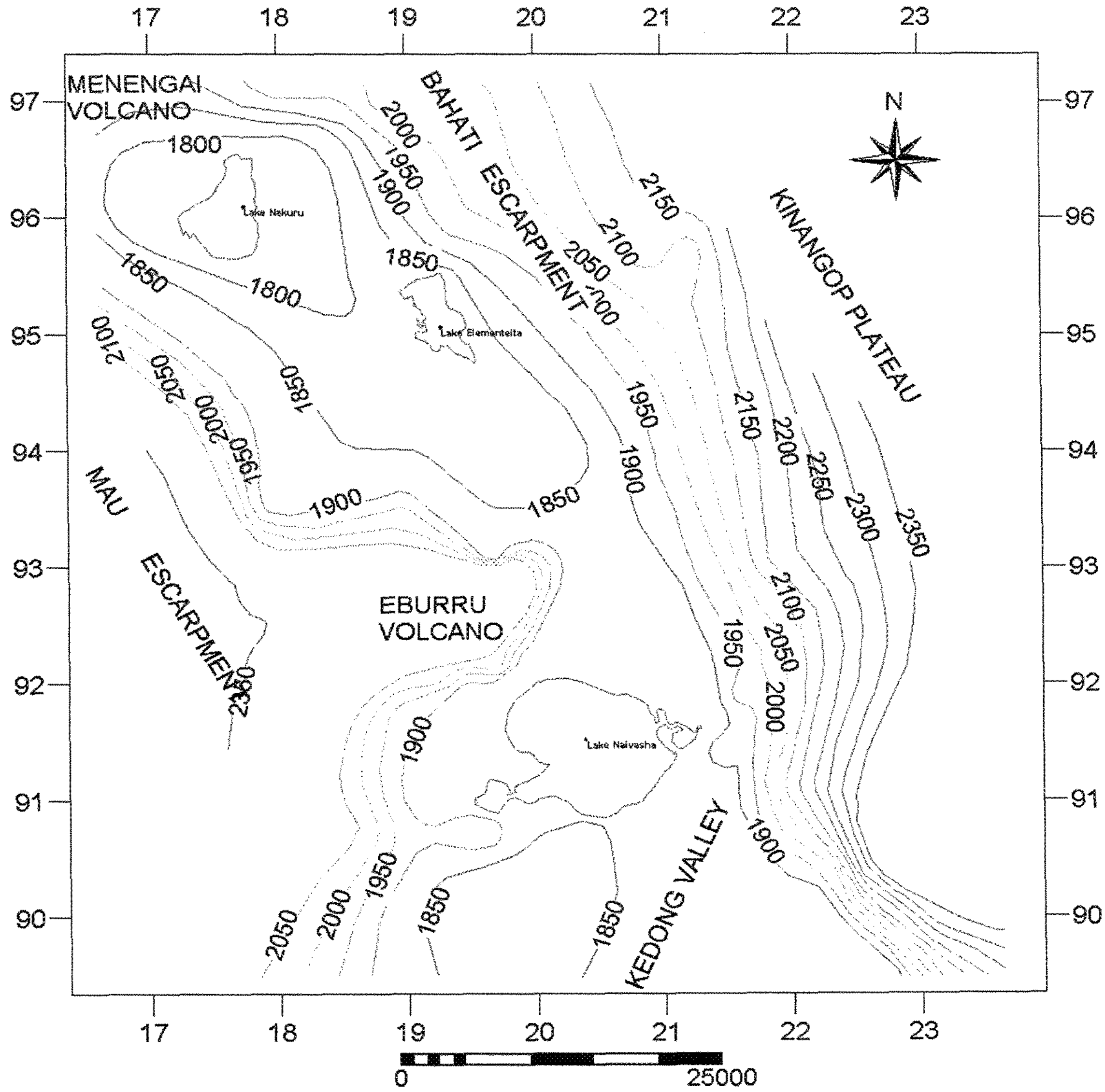


Figure 4.2 Piezometric map of the northern part of the study area

4.3 QUANTIFICATION OF GROUNDWATER FLOWS

At best, groundwater flows are usually estimated from the gradients observed in a few observation wells and assumptions about the saturated thickness and hydraulic conductivity of the surrounding geologic formations.

Groundwater flux is calculated base on Darcy's equation for horizontal flow.

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

Where Q is the quantity of water flowing through a cross section of area A, composed of material having a hydraulic conductivity K and in which the hydraulic gradient is dh/dl. In applying the law to an aquifer, the area may be expressed as saturated thickness (b) times the width (W). Thus, the equation becomes

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

$$Q = KIA$$

Darling et al, 1990 attempted to quantify regional groundwater flows out of the Naivasha catchment using Darcy's Law. In his estimates from the piezometric map, he took the hydraulic gradient of 0.1 over the area between Olkaria and Longonot and the hydraulic conductivity of 0.003 m/d to represent 25 km width across the rift and assumed that flow occurs to a depth of 5 km below which fissures are unlikely to be open.

The southerly flow at depth from Naivasha catchment was estimated to be 14 mcm per annum. For the shallow component of around 500 m (the depth to the caprock), assuming the same hydrulic gradient and the average depth to the water table to be 200m ie. the saturated thickness of 300m, and hydraulic conductivity to be between 0.1 and 1 m /d, he obtained the southerly flow estimate to fall between 27 mcm and 270 mcm.

For the northerly flows he took transmissivity value of 100 m^2/d as suggested by the table 3.1 for boreholes drilled between Naivasha and Elementeita. The mean groundwater gradient of 0.004 was taken and assumed the width of the rift to be 15 km; he obtained 11 mcm for the shallow northerly flow. Deep northerly flow over the same cross section was estimated as 0.3 mcm assuming the same permeability.

Taking the higher value of the range given above, the total flow out of Naivasha catchment is estimated to be around 295 mcm which agrees reasonably well with McCann's estimate of 250 mcm. Darcy's equation can also be written as:

$$V = \frac{Q}{A}$$

The average actual groundwater velocity is calculated as follows:

$$V_a = \frac{Kh}{\alpha l}$$

Where α is the specific yield, h is the average head difference, K is the hydraulic conductivity and l is the distance from the recharge area to discharge point.

$$V_a = \frac{0.003 \times 1300}{0.2 \times 100000} = 0.000195 \text{ m/d}$$

This means that it would take some 1.4 million years for water to travel the 100 km from Naivasha to emerge as spring in Magadi under the prevailing head conditions. The calculation assumes uniform groundwater flow and homogeneous aquifer, which in this context of a regional system is valid. Similarily, the flow to Lake Elementeita

$$V_a = \frac{1.67 \times 113}{0.2 \times 30000} = 0.031452 \text{ m/d}$$

It takes about 2,613 years for water to reach Lake Elementeita 30 km to the north of Naivasha.

4.4 GROUNDWATER CONDITION AROUND LAKES ELEMENTEITA AND NAKURU.

The hydrostratigraphic units influencing groundwater/lake interactions are the sediments. Groundwater flow around the lake is influenced by the lake's local hydrogeologic setting. Githae, (1998) indicated from the hydrologic section that there is only one aquifer system in the Elementeita-Nakuru basin ranging from less than 50 to 500m in thickness. The main aquifers in the basin are composed of fractured volcanic basalts and pipe flows, pumice and Oldland surfaces. In addition, sandy units of sediment intercalations and lakebeds deposits form good aquifers as well. The aquiferous zones are known to have alternating beds of clay-rich sediments, with poor lateral continuity and extremely varied thickness. However, at times these impermeable sediments are affected by very recent fault systems that often modify and breach the confining units allowing different aquifers to be hydrologically interconnected.

The recharge of the lake and the underlying aquifers are assumed to be from the intermittent surface streams together with precipitation and partly by subterranean recharge from the water table. Aquifer recharge areas are situated near the surrounding escarpments and according to the piezometric trend the flows are directed towards the center of the basin through the pervious sediments. The waters then find their way into the lake issuing from springs scree at the base of the fault escarpments bounding the lakes.

A cross section through a typical lake is shown in Appendix B. Lakes receive groundwater inflow from the surrounding surficial aquifer layers. Its not very clear whether there is any other subterranean inlet. However, it has been hypothesized (Final Report, Monitoring Lakes in Kenya) that water that escape along faulted zones into deep conduits rise towards the geothermal fields and a small portion of these waters rise through the impervious clayey silty sediments that underlies the lakes by capillarity and thus recharge the lake. The contribution to this effect to water budget during wet seasons is expected to be negligible. However, capillarity can play a significant role in groundwater outflow by supporting evaporation from a shallow watertable. This kind of circulation justifies the formation of trona along the lakeshores seen around Lake Elementeita.

CHAPTER 5 Data analysis

5.1 INTRODUCTION

The model requires key hydrological variables as inputs. This section describes how these variables were collected, pre-processed/reconstructed and spatially transformed for further applications. It also provides a graphical overview of the spatial and temporal behavior allowing good insight into the geophysical dynamics which any hydrological model must incorporate. The basic data needed to calculate an accurate monthly lake water balance are:

- Bathymetry (lake surface area and volume at each elevation)
- Monthly lake levels
- Monthly lakewide average precipitation
- Monthly surface water and groundwater inflows and
- Monthly lakewide average evaporation

5.2 PRECIPITATION

Long-term series of observations of precipitation were obtained from the Kenya Meteorological Office. The data consisted of monthly totals. The monthly data series taken at stations 9136167, 9036310 and 9036147 were used to represent the lakewide precipitation into lakes Magadi, Nakuru and Elementeita respectively. The estimated longterm average precipitation at these stations are 427, 637and 742 mm respectively.

5.2.1 MASS CURVE AND DOUBLE MASS CURVE METHOD

Changing type, location and/or environment of a gauge associated with weather station can bring about inconsistency in precipitation data. This can significantly affect any sound hydrologic analyses. Mass Curve and Double-mass curve techniques for revealing and rectifying for inconsistency are normally applied.

The accumulated rainfall values are plotted against time and if the statistics of the designated station is correct, the accumulated total plotted year after year would lie very close to a straight line passing through the origin. A marked change in gradient would indicate a change of location or exposure of the gauge; a displacement would indicate an error in the record. The errors revealed by mass curve is carefully scrutinized for the source and rectified. The correction applied is done such that the adjusted accumulated precipitation for the designated station is brought into line with the accumulated group average in the double mass curve.

From the mass curve it became clear that the anomalous displacement on Figure of station 9035021 was due to an error in recording instead of 77.6 it was recorded 7007.6 for the year 1956. The observation taken at Bwami Daniel Farm (9036310) were anomalous in that they differed by approximately a factor of ten from reading taken at the neighboring stations.

5.2.2 FILLING IN MISSING DATA

The data gaps were infilled using the neighboring stations (refer to Figure *indicating location of rainfall, and regular gauging stations).* The rainfall data considered include that for the direct precipitation into the lakes and for the general catchment area that has been used for the runoff and recharge estimates

To reconstruct the missing monthly values neighbouring synoptic rainfall stations were used. The regression equations developed were used to predict the missing values. Continuous records covering at least 30 years, preferably coinciding with the stream flow records were found desirable for long-term estimates. Several broken records were then made up or extended to cover the runoff period.

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5.3 EVAPORATION

The pan evaporation data collected from Nakuru Show Ground Meteorological Station was obtained from the Kenya Meteorological Department. The existing data from 1963 to 1995 had been screened for outliers and typing errors using scatter plots. The monthly evaporation rates were assumed to be constant each year. The long-term monthly averages (1965-1990) were therefore used for infilling the months with missing data and backdating the records. Due to lack of evaporation station in and around Lake Elementieta, the data was regarded as representative in the Elementieta-Nakuru basin.

Pan evaporation generally results in figures too high due to the walls of the pans giving an extra heating effect. In view of this fact, in most literature, pan coefficients are given to convert pan data to potential evapotranspiration. In Kenya, a pan factor of 0.8 has been adopted in most recent studies but this value was not used in the model efforts fearing to introduce discrepancies in balancing the hydrological equation due to lack of locally calibrated coefficient.

The long-term average (1965-1990) pan evaporation from Nakuru Show Ground ranges from 117 mm in November to 188 mm in March as presented in Figure 5.2

Comparison between pan evaporation (AVMTEV) and potential evaporation calculated by Penman method (PET) was made(APPENDIX I-A). The monthly average values were lower than the Penman data but followed a similar seasonal pattern. Although the monthly values show wider variation the annual values, differences are relatively small. Assuming that the Penman evaporation rates reflect actual field condition, pan records would require application of a pan coefficient of 1.1 at Nakuru Show Ground.

For the purpose of this study pan evaporation has been taken, as equal to the potential evapotranspiration as there would be little advantage in using a factor other than unity in the absence of actual comparative field studies.

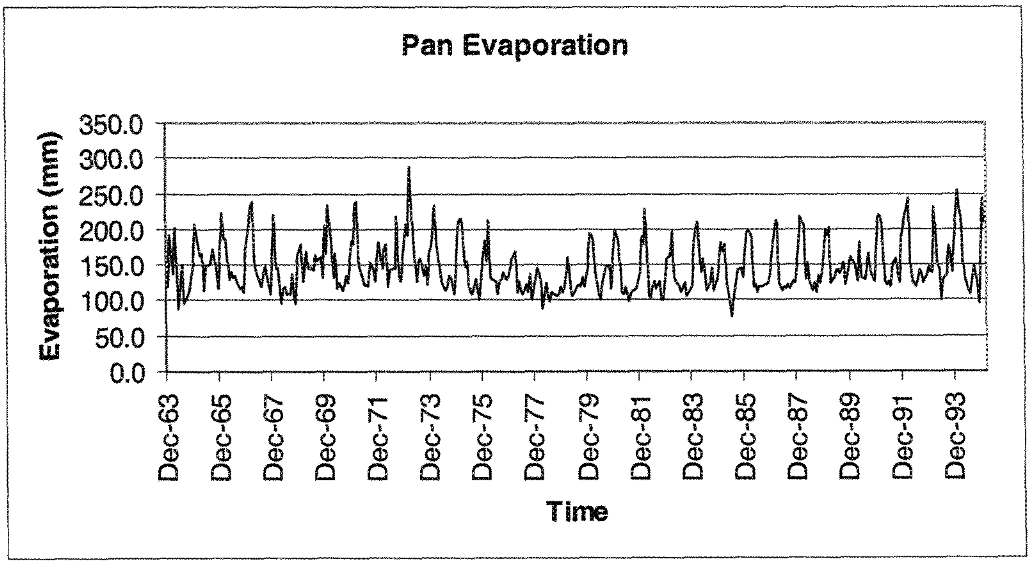


Figure 5.1 Long-term monthly average lake pan evaporation, 1963-1995

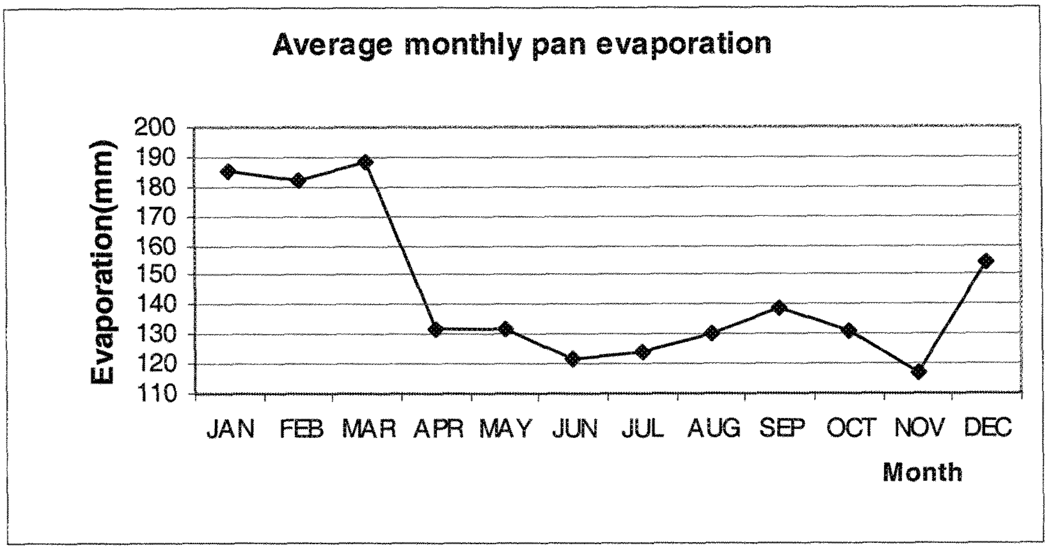


Figure 5.2 Long- term average monthly pan evaporation

5.4 RIVER FLOWS

The stream discharge stations 2FA08(1958 to 1999) and 2FC09(1934 to 1990) on rivers Mereroni, Njoro with catchments areas of 240 km^2 and 128 km^2 respectively, were used as inputs to the model.

They were chosen for their proximity to their respective lakes to reduce the need for estimating the amount of river diversions. Using linear interpolation, simple and multilinear regression with the neighboring stations, the data gaps were infilled, the results of which are shown in Figures3.6 and 3.7. Rivers Ngosur, Lamudiac whose proceeds do not reach the lakes or drain the smallest of the catchment and therefore considered to contribute negligible were not included in the model. Most of these rivers infiltrate and enter the lake as groundwater flow.

5.5 LAKE LEVELS

The main lake level stations used for the lake level estimates are: 2FA9(1985-1993) and 2FC4(1985-1993) for Lake Elementeita and Nakuru respectively. The 2FA9 station data existing in hard copy was transferred into excel spreadsheet. The data was screened for recording and typing errors and outliers using time scatter plots and aggregated into monthly levels after linear regression. A plot of the two sets of data for station 2FA9 one from the hard copy and one in digital form showed synchronism. The hard copy record was adjusted by adding 1.5 m to those originally on digital format, so that the elevations were consistent with the digital record. The two series were combined to extend the levels from April 1948 to 1999. Data gaps in the series were filled. Three sets of complete reconstructed lake levels for the periods 1930 to 1995 are shown in Figure 5.3

The maximum gauge height for the month is plotted at the end of the month. Nakuru level was extended from July 1992 to December 1995 by correlating it with Lake Naivasha levels. The relationship is expressed in the regression equation below:

Nakuru Level = 0.6765*(Naivasha Level) + 481.73: $r^2 = 0.847$

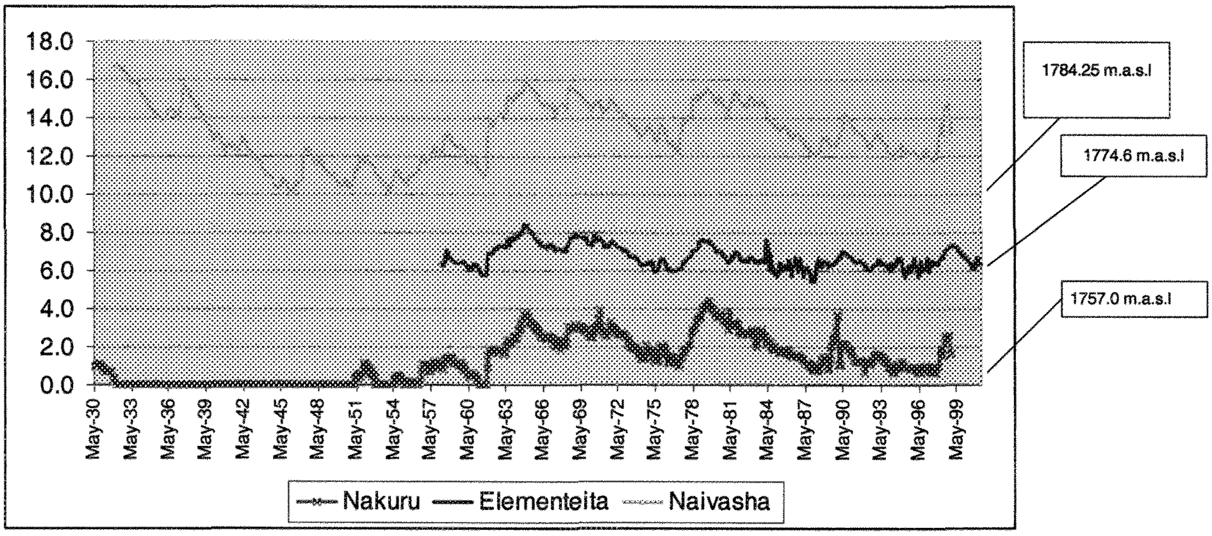


Figure 5.3 Graph showing lake levels variations for Nakuru, Elementeita and Naivasha

5.6 BATHYMETRY AND VOLUME/DEPTH RELATION

A detailed bathymetric survey of Lake Naivasha, Nakuru and Elementeita was conducted by REM-CONSULT for Water Resources Assessment and Planning (WRAP) project when the lakes where at 1885.50, 1759.85, 1776.83 m respectively. The basic data was augmented with some data points of the lakeshores from existing analogue maps from which, stage-area and stage-volume relations were computed.

The depths were first plotted into grids and contoured from which the area within each contour interval were estimated using Surfer Golden Software. The Kriging method was applied to interpolate the data to cover the lake surface. Lake volumes and surface area values corresponding with the lake levels were subsequently produced. These data sets were then imported to Excel Spreadsheet where transform curves for each lake were finally generated as shown in Figures 5.4 and 5.5.

It should be noted that the due to the complexity of the geometry of the lake the surface area stage curve had to be splitted into two curves resulting into two set of transform equations. The first part of the relationship is valid for height between 1775 and 1776 m and the second part from 1776.1 to 1780 m for the case of Lake Elementeita. Likewise for Lake Nakuru, the first part of surface area stage curve is only valid between 1757 and 1757.4 m and second part between 1757.5 to 1762 m.

The curves show that, the lakes can dramatically change in size and volume over very slight, change in level periods. Bathymetric maps of three study lakes are shown in Figures 5.6 and.5.7

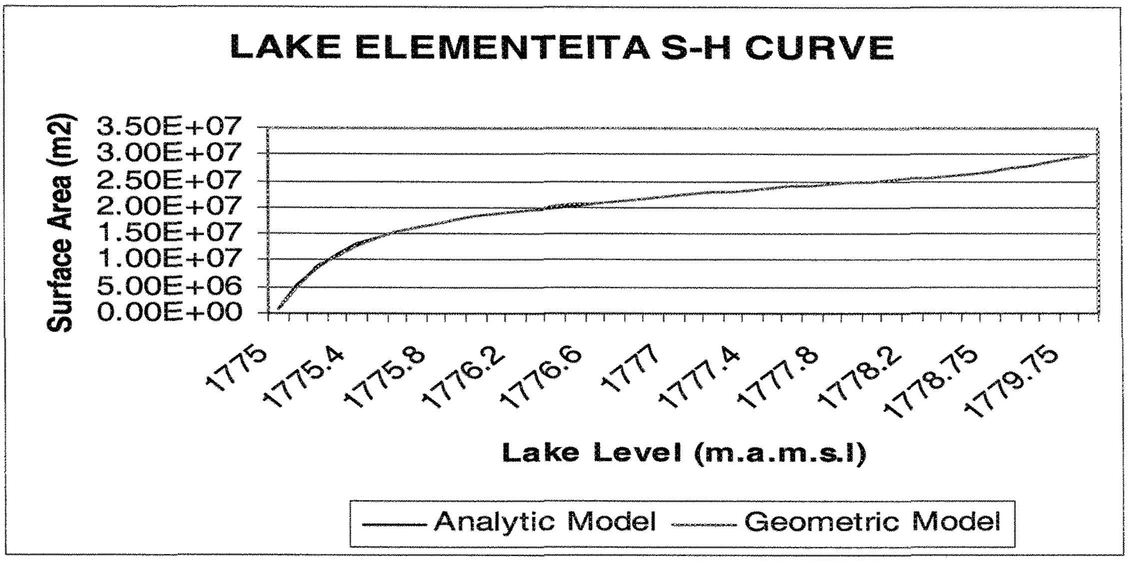
Lake Elementeita transform polynomial equations:

$V(H) = -189.98-(1613270*X)+(12262177*X^2)-(2694303*X^3)+(228334.8*X^4)$

Part 1, $S(H) = 701479.1+(49444866*X)-(56435410*X^2)+(24812943*X^3)$

Part 2, $S(H) = 13311261+(6036004*X)-(965600.9*X^2)+(83884.06*X^3)$

where $X = (H-1775)$ and H = lake surface elevation (m.a.s.l)



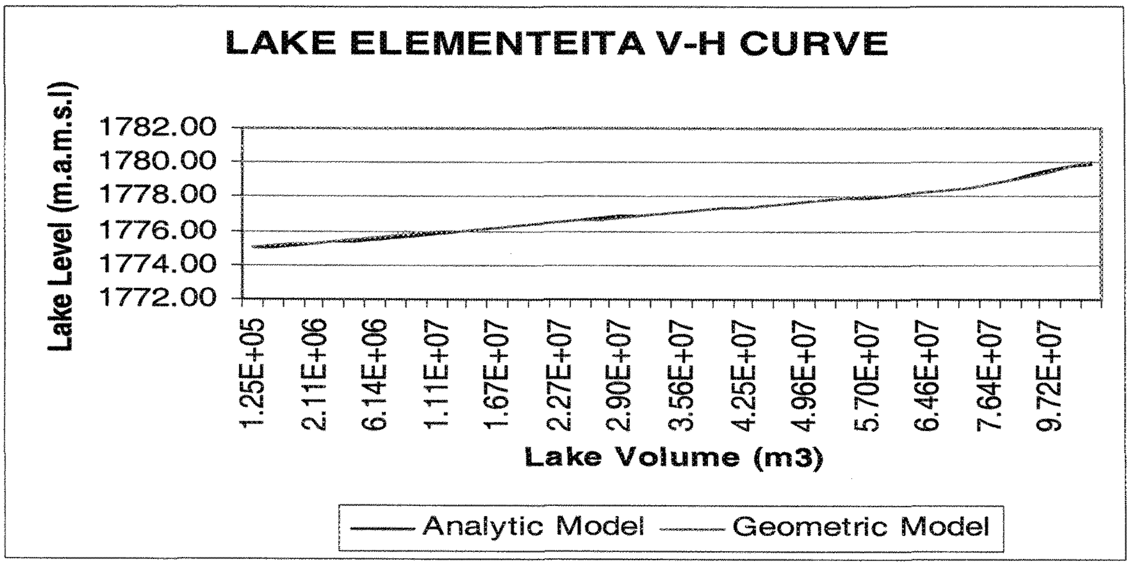


Figure 5.4a and 5.4b Lake Elementeita S-H and V-H curves

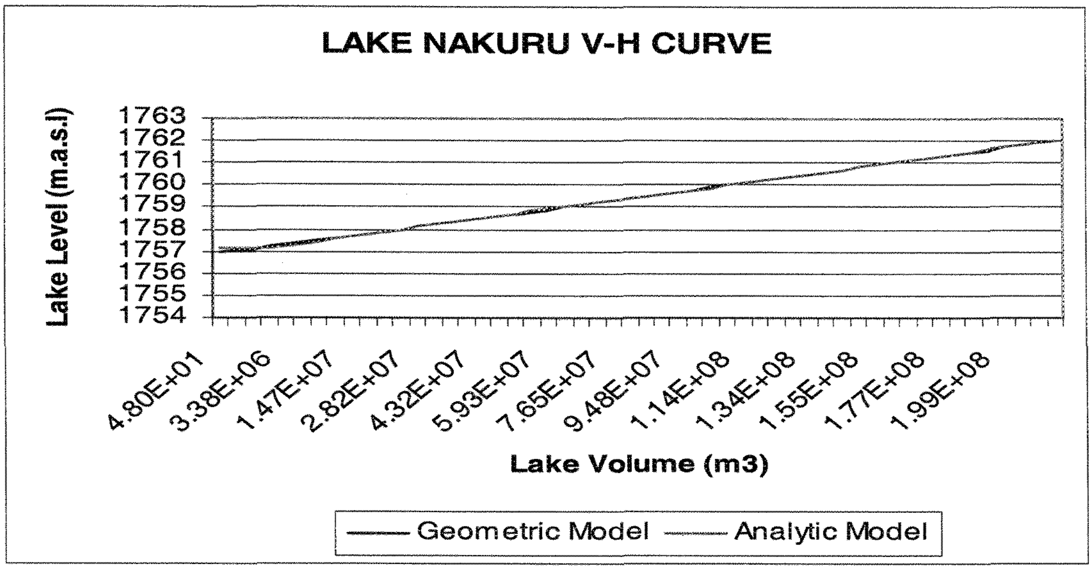
Lake Nakuru transforms polynomial equations:

$V(H) = 0.12+(3.99E\text{-}08*X)-(2.18E\text{-}16*X^2)+(1.07E\text{-}24*X^3)-(2.02E\text{-}33*X^4)$

Part 1, $S(H) = 90055.27+(62688049*X)-(1.16E+08*X^2)-(2.66E+08*X^3)$

Part 2, $S(H) = 23868965+(12133250*X)-(1573649*X^2)+(95694.05*X^3)$

where X = (H-1757)) and H = lake surface elevation (m.a.s.l)



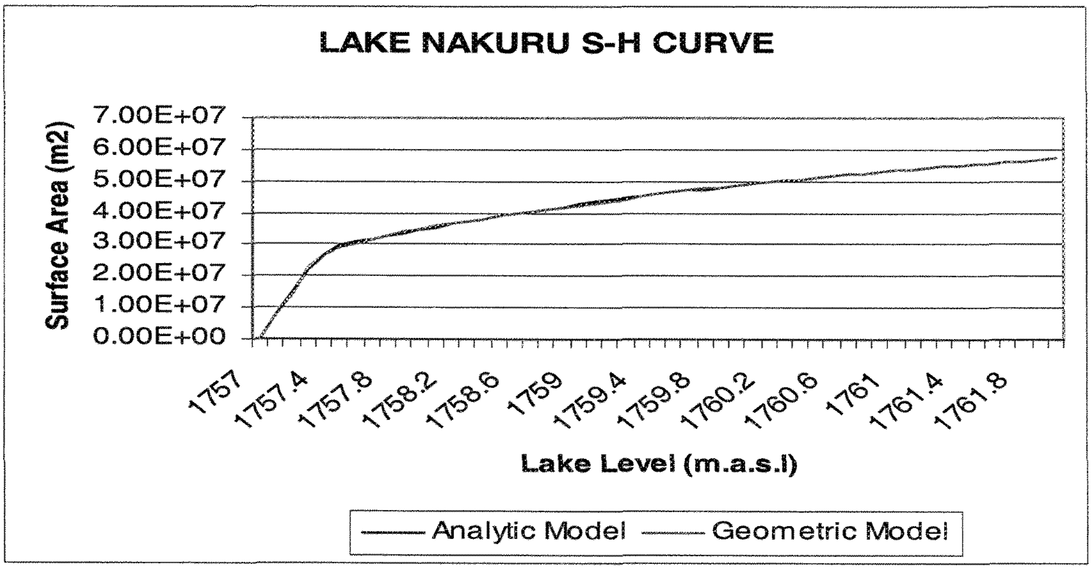
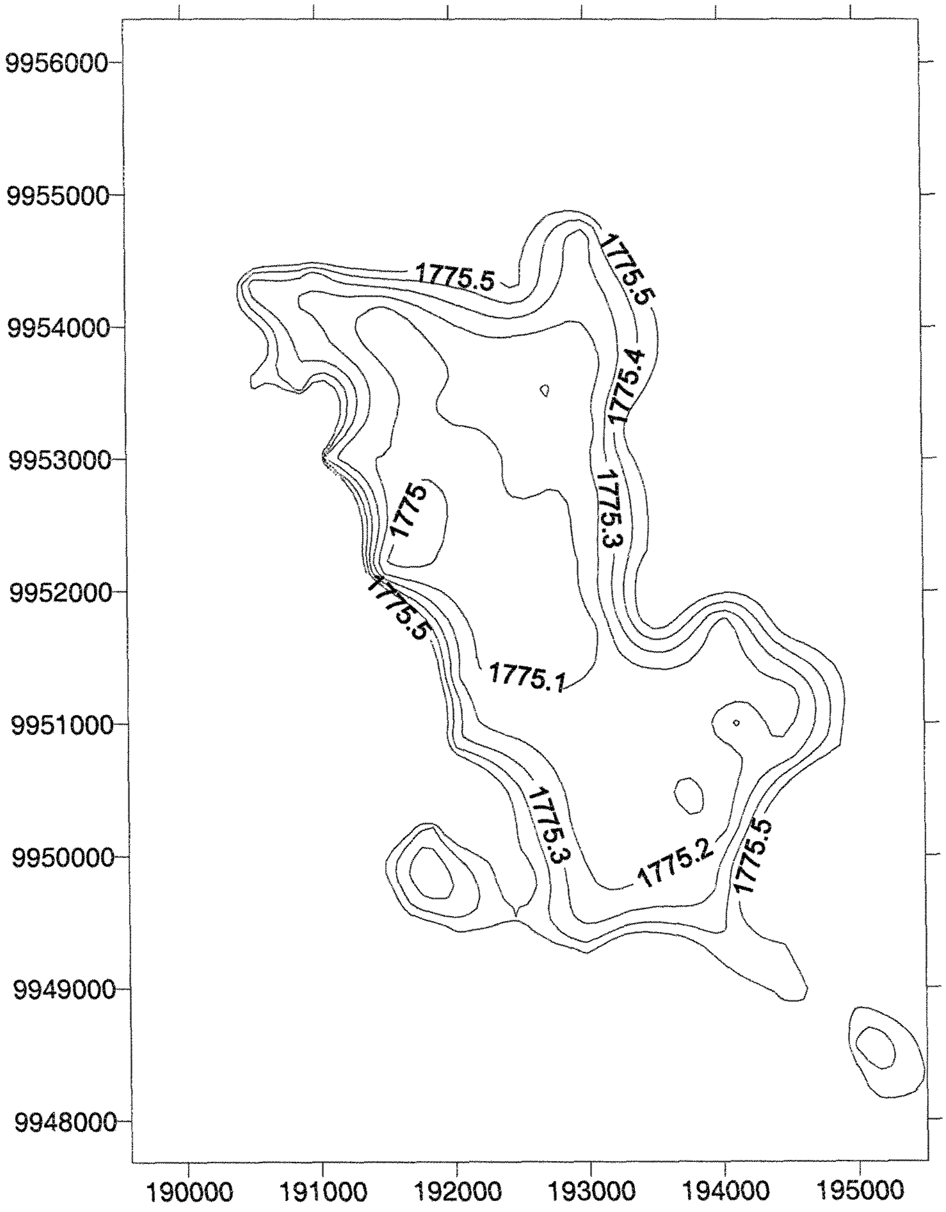
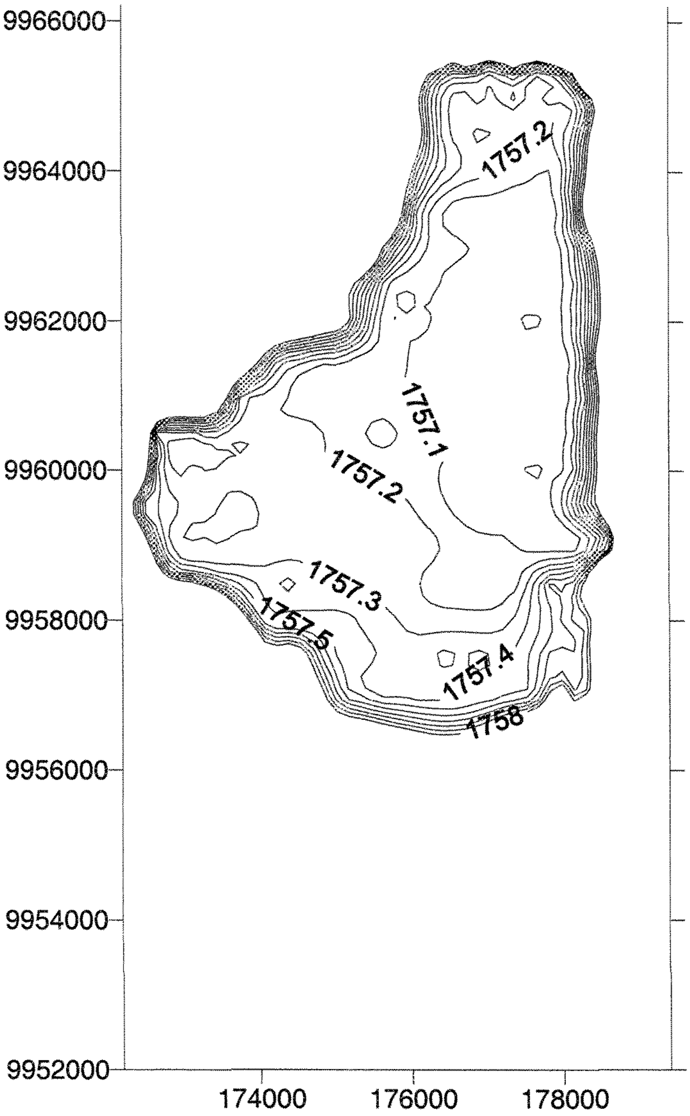


Figure 5.5a and 5.5b: Lake Nakuru S-H and V-H curves



Bathymetric contours are marked in metres above mean sea level datum

Figure 5.6 Bathymetric map of Lake Elementeita



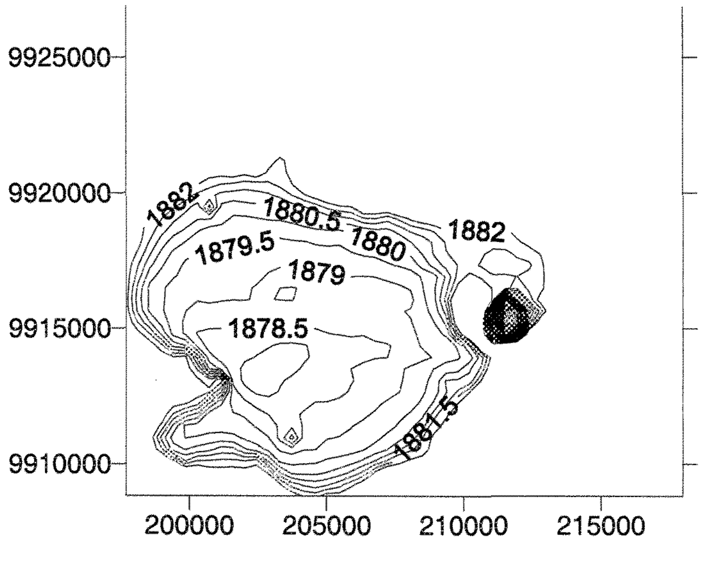


Figure 5.7 Bathymetric maps of Lake Nakuru and Lake Naivasha

Chapter 6 Isotope

6.1 INTRODUCTION

Lake Naivasha has been suspected for at least 60 years of significant subsurface leakage (Sikes, 1935). In this respect calculations of the lakes's waterbalance are important. Most attempts at assessing its water balance have arrived at an annual loss of around $50*10^6$ m^3/yr (Allen and Darling, 1990). Owing to its situation on the topographic culmination of the floor of the domed Kenya Rift Valley, the potential exist for the leakage to occur in both northerly and southerly directions. It is tentatively concluded from well water data that between 50 and 90% of lake flow is directed towards the south but data are sparse and cease within a few kilometre of the Lake (Allen *et al.*, 1989). It has been suggested that the Magadi and Elementeita hot springs could have their origin in the groundwater recharge from lake Naivasha. Owing to its high evaporation rate, Lake Naivasha has raised amounts of the heavy isotopes ^{18}O and ^{2}H, in the lakewater to the concentration considerably higher than those of river and groundwater from direct meteoric sources. The strong signal provided by this enrichment has been used to trace subsurface outflow from the lake. Thus, stable Oxygen-18 isotope has been used to test the hypothesis that Lake Naivasha leaks into the Lake Elementeita to the north and Lake Magadi to the south

6.2 BASIC PRINCIPLES AND DEFINATIONS

The isotopic tracing can only be observed and interpreted to solve some hydrological problems on the basis of the general knowledge of isotope variation in nature. Isotopes of oxygen and hydrogen, the chemical elements which constitute the water molecule are, in a certain sense, ideal geochemical tracers of water because their concentrations are not subject to changes by interaction with the aquifer material. Isotopes are atoms of the same element that have the same numbers of protons and electrons but different numbers of neutrons. The difference in the number of the neutrons between the various isotopes of an element means that the various isotopes have similar charges but different masses. Because of the mass differences the various isotopes of an element have different chemical and physical properties. These mass differences are large enough for many processes or reactions to fractionate or change the relative proportion of various isotopes. As a consequence of fractionation processes, waters and solutes often develop unique isotopic compositions (ratios of heavy to light isotopes) that may be indicative of their source or the processes that formed them.
The stable isotopic compositions of low mass elements are reported as "delta"(δ) values in parts per thousand (denoted as ‰) relative to the SMOW ("Standard Mean Ocean Water" (Craig, 1961). The δ values are calculated by:

$$(\delta)\ (\text{in}‰) = (R_{sample} / R_{standard} - 1)*1000$$

where "R" is the ratio of heavy to light isotope in the sample or standard. A positive δ value means that the sample contains more of the heavy isotope than the standard; a negative value means that the sample contains less heavy isotope than the standard. During equilibrium reactions, the heavier isotope generally becomes richer (preferentially accumulates) in the species or compound with the higher energy state. During phase changes, the ratio of the heavy to light isotopes in the molecules in the two phases changes. For example, as water vapour condenses (equilibrium process), the heavier water isotopes (^{18}O and ^{2}H) become enriched in the liquid phase while the lighter isotopes (^{16}O and ^{1}H) tend toward the vapour phase.

6.3 GLOBAL METEORIC WATER LINE

Craig (1961) observed that and $\delta^{2}H$ (δD) values of precipitation that has not been evaporated are linearly related by:

$(\delta D) = 8\delta^{18}O + 10$

This equation, known as the "Global Meteoric Water Line" (GMWL), is based on precipitation data from locations around the globe, and has an $r^2 > 0.95$. This high correlation coefficient reflects the fact that the oxygen and hydrogen stable isotopes in water molecules are intimately associated. The slope and intercept of any "Local Meteoric Water Line" (LMWL), which is in the line derived from precipitation collected from "Local" sites, can be significantly different from the GMWL. This is characterized by slope of 8±0.5, but slopes ranging from 5 to 9 are not uncommon.

Several processes cause waters to plot off the GMWL Water that has evaporated or mixed with evaporated water typically plots below meteoric line along lines that intersect the MWL at the location of the original un-evaporated composition of water: slopes in the range of 2 to 5 are common. Geothermal exchange also increases the ^{18}O content of waters and decreases ^{18}O the content of rocks as water attempt to reach a new state of isotopic equilibrium at elevated temperature. This cause a shift in the $\delta^{18}O$ values but not the δD values of geothermal waters. Low temperature diagenic reactions involving silicate hydrolysis can sometimes cause increases in the values of waters.

6.4 TEMPERATURE, ALTITUDE AND AMOUNT EFFECT ON $\delta^{18}O$ and δD OF PRECIPITATION

The two main factors that control the isotopic signature of precipitation at a given location are 1) the temperature of condensation of precipitation and 2) the degree of rainout of the mass (the ratio of water vapour that has already condensed into precipitation to the initial amount of water vapour in the air mass). Most water vapor in the atmosphere is derived from the evaporation of low –latitude oceans. Precipitation derived from this vapor is always enriched in relative to the vapour, with fractionation between rain and vapor a function of condensation temperature. Therefore, progressive rain-out as clouds move across the continent causes successive rainstorms to become increasingly lighter (more negative δ values). Because the degree of condensation of a vapour mass depends on the temperature, a relation between isotopic composition of precipitation and its temperature should be expected: as the formation temperature decreases, the δ value of precipitation decreases (Dansgaard, 1954)

The dependency on temperature produces seasonal isotope variations of precipitation for example winter precipitation is depleted in heavy isotopes with respect to summer precipitation, latitude variations (high latitude precipitation is depleted with respect to low altitude) and altitude variations (the heavy isotope content of precipitation decreases with increasing altitude); (Friedman et al, 1964; Moser and Stichler, 1970)

6.4.1 TEMPERATURE

The theoretical relationships describing the relation between surface air temperature, $\delta^{18}O$ and δD of mean annual precipitation are given by Dansgaard (Klaus and co, 1991) and as follows:

$\delta^{18}O = 0.69T(^{o}C)_{annual} - 13.6$ ‰ SMOW

$(\delta D) = 5.6T(^{o}C)_{annual}$ - 100‰ SMOW

The mean monthly formula (Yutsever and Gat, 1981) is:

$\delta^{18}O = (0.338 \pm 0.028)$ Tmonthly – 11.9 ‰VSMOW

Boteng (2001) used mean annual temperature of 18°C in the above equations and obtained change of –1.2‰ in $\delta^{18}O$ and +0.8‰ in δD. He indicated that samples collected in March are enriched in isotopic composition while those collected in April to July the same year are quite depleted as a result of temperature variation.

6.4.2 ALTITUDE

Altitude effect is especially important in regional hydrological studies, where for instance groundwaters deriving from recharge areas are at different elevations may be differentiated. The high topographic relief of the study area makes it likely that significant variations with altitude in the mean isotopic composition of rainfall is a possibility

This variation was investigated by using the rainfall sample dataset obtained from (Darling 1990). The scatter plots of $\delta^{18}O$ and δD against altitude are as shown in figures 6.1 and 6.2.

The least squares of regression line of the plots are defined by the equations:

$\delta^{18}O = -0.0028 * \text{altitude (m)} + 1.67$

$\delta D = -0.0137 * \text{altitude (m)} + 7.81$

The altitude effect estimated from the equations is about 0.3‰ decrease in ^{18}O content and 1.5‰ decrease for D content per 100 meters increase in elevation.

The altitude effect correction was not done for Elementieta as the effect was considered to be minimal due to small elevation difference relative to Naivasha area.

Clarke et al, 1990, examined the possible effect of latitude on the isotopic composition. The hypothesis was regarded as inadequately supported by the available data and that there was no evidence of systematic variation in isotopic composition from one side of the Rift to the other.

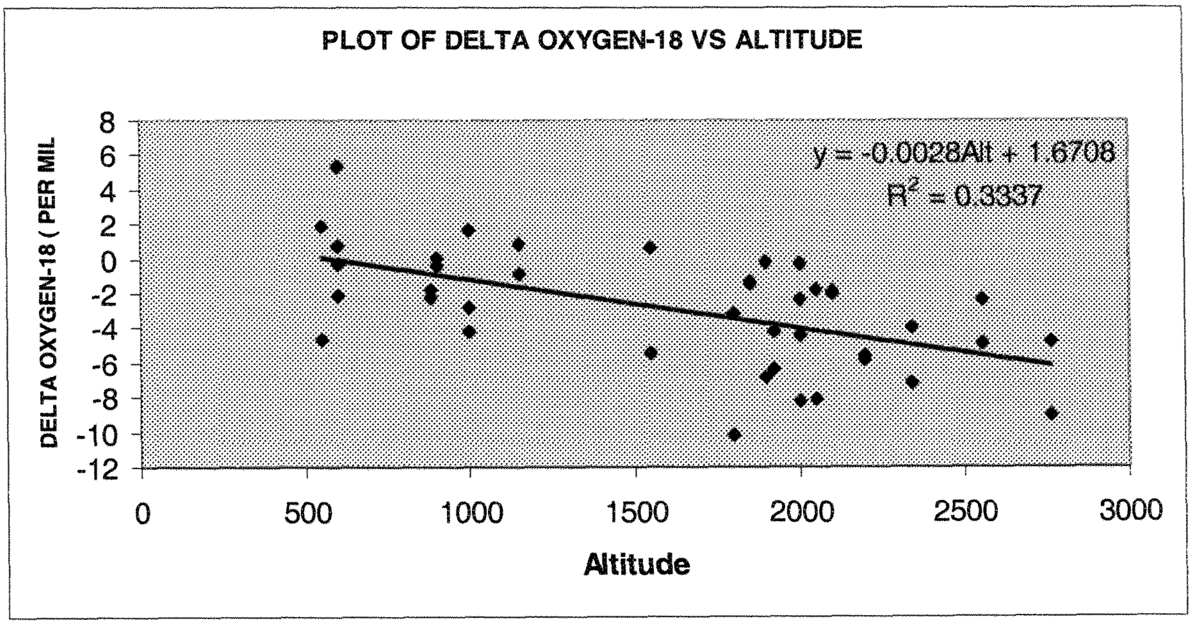


Figure 6.1: Plot of $\delta^{18}O$ against Altitude

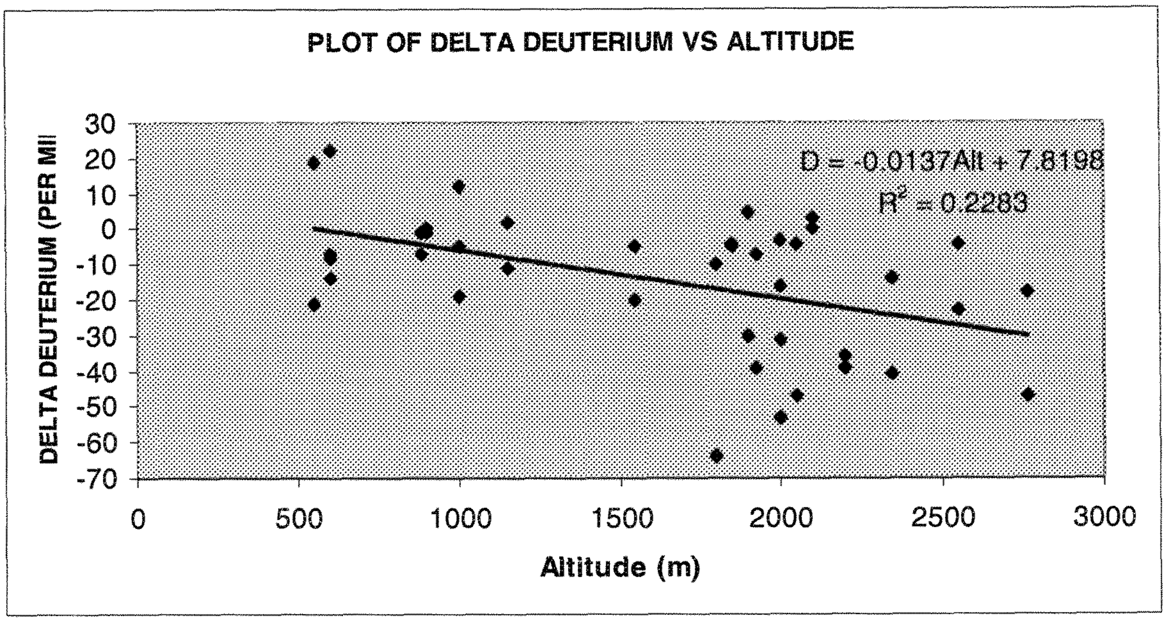


Figure 6.2: Plot of δD against Altitude

6.4.3 AMOUNT EFFECT

The greater the amount of rainfall, the lower the $\delta^{18}O$ and δD values of the rainfall. This is evident in the dataset where low rainfall values correspond to higher δ values and high rainfall intensity yielded more depleted δ values.

The month of March experiences the heaviest rainfall and the samples are depleted in isotopic composition compared to the samples collected in the period from April to July in the same year which are isotopically enriched.

6.5 SAMPLE COLLECTION AND ANALYSIS

Samples for isotopic analysis were taken from major springs within the study area as shown in Figure 5.8 Samples IS11at location 11, IS17 at location 20 and IS18 at 8 were taken from the hot springs around Lake Magadi, and IS10 and IS31 were taken from the hot springs at the southern shore of Lake Elementeita. These include one sediment pore sample.

These samples were analysed at the Centre for Isotope Research University of Groningen, in the Netherlands for ^{18}O and D stable isotopes. The analysis was carried out by mass spectrometry of CO_2 produced by equilibration with water (for $\delta^{18}O$) and H_2 produced by reduction of water by zinc (for δD). All data are reported in standard δ notation with respect to Vienna Standard Mean Ocean Water (VSMOW) with standard deviations of ± 1‰ and 0.2‰ for δD and $\delta^{18}O$ values respectively.

Isotope dataset from Darling 1990 were used in the interpretation. The locations marked on the map are sampling points of hot springs around the shore of lake Magadi. In addition to springs samples were taken from the Ewaso Ngiro and borehole at Oltepesi.

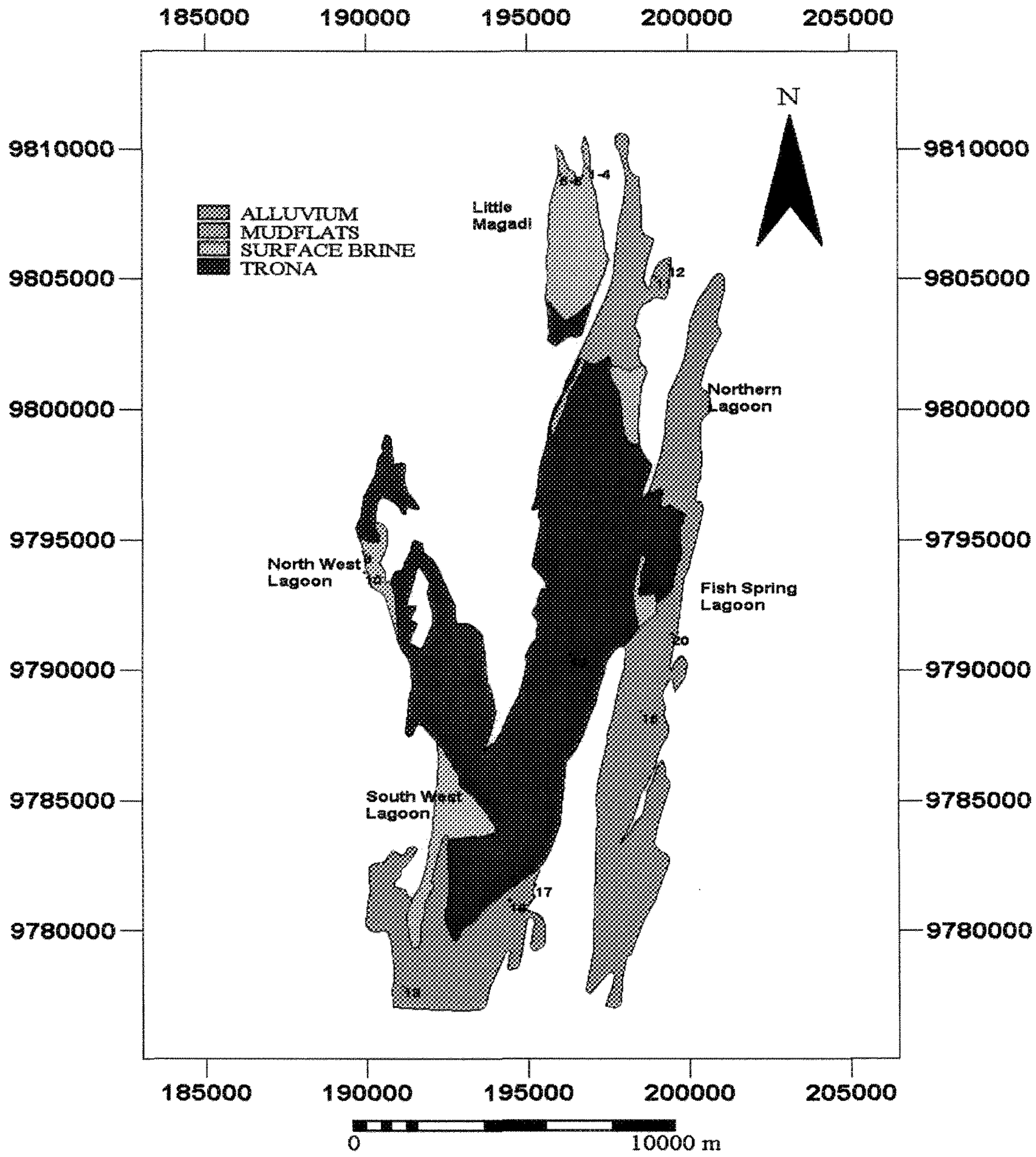


Figure 6.3 Lake Magadi and some springs and sampling locations

6.6 OXYGEN-18 AND DEUTERIUM PLOT

The variation of deuterium and oxygen-18 contents in precipitation are linearly correlated according to relationship given by the equation in section 6.3. Precipitation which has undergone significant evaporation during its fall does not obey the equation referred above. Evaporation does tend to enrich both the heavy isotopes in water but not in the relative proportion indicated by the above relationship (Craig, 1961; Ehhalt *et al.*, 1963; Woodcock and Friedman, 1963)
The isotopic characteristics of the thermal springs fall mainly in two groups (Darling 1990). The northern, hotter springs from the north shores of Little Magadi and the North –Eastern Lagoon form a tight cluster about the local meteoric line, with an average value of -5‰ δD and -1‰ -$\delta^{18}O$ (samples 1-8, 11-12). The cooler spring groups of the North-West Lagoon (samples 9-10) and the spring groups to the east and south east of the lake (samples 13-17) form a looser more isotopically more depleted cluster near the meteoric line with an average value of -17‰ δD, -2.5 $\delta^{18}O$.

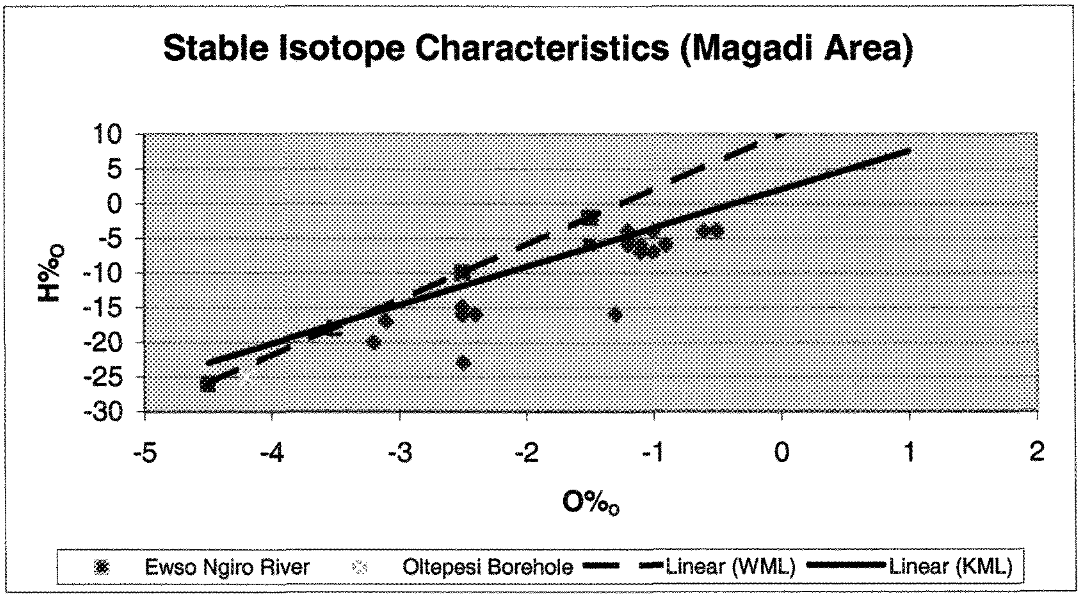


Figure 6.4 Stable isotope characteristics of waters in Magadi area (The clusters in dark blue represent the thermal springs)

6.7 ANALYTICAL RESULTS AND DISCUSSION

Lake Magadi located to the south, forms a natural sump for drainage in the southern Kenya Rift. It is presumed that much of the outflow from Lake Naivasha terminates there. There have been a lot of controversies over the sources of water supplying the Magadi thermal springs. The isotopic investigation is thought to provide a better alternative in determining the likely source and thus be able to cast more light on subsurface flow from Lake Naivasha.

The figure 6.4 indicate that the hottest springs water are of the meteoric water type, and their tight clustering indicates that they have not mixed substantially with waters of different composition. The figure clearly indicates that the Magadi waters are more enriched than the sampled groundwater obtained from a significant distance to the northwest. This in turn suggests that their original source had a similar isotopic composition to the springs. The most likely source is the Ewaso Ngiro River, which has an isotopic composition which is similar to those of the hot springs in fact it is very slightly depleted with respect to the spring isotopes, but this difference could be accounted for by a small amount of evaporation. The lower therefore river has undergone some evaporation and is somewhat enriched isotopically compared with waters upstream. River Ewaso Ngiro flows along the base of Nguruman Escarpment approximately 20 km to the west of Lake Magadi and is perennial. The recharge mechanism is postulated to be via the river alluvium on the Ewaso Ngiro plain.

Magadi hot springs show no connection with the highly enriched samples obtained from Lake Naivasha to link their groundwater recharge from to lake water. Some evidence that do not support the possibility of tracing the Naivasha water is shown by heavy dilution of lake water in the vicinity of Lake Naivasha. (APPENDIX B) Thus, there is very little prospect of detecting lake water at a distance of about 100 km considering excessive dilution from the Rift-flank before it reaches Lake Magadi.

Many thermal waters throughout the world exhibit significant increase in shift $\delta^{18}O$ as a result of interaction with silicates or carbonates at depth, an effect known as 'oxygen shift'. However the Magadi show very little evidence of any shift and surprising the hottest spring fall very close to meteoric line whereas these would be expected to be the most shifted. The lack of an oxygen shift in the hot springs also suggests a local origin thus implying a short contact time between water and rock, and therefore a short flow path.The short distance between the Ewaso River (recharge) and Lake Magadi (discharge area) suggests that a local heat source exist in the vicinity.

Lake Elementieta is assumed to be considerably enriched due to evaporation. The isotopic composition of –1.5 ‰ -$\delta^{18}O$ -9 ‰ δD indicate flow that lake water is already diluted. The warm springs at the southern end of lake Elementieta show evidence of water from Naivasha

The typical Lake Naivasha composition is +35‰ δD, +6.6 ‰ $\delta^{18}O$ and has been well contoured (ALLEN et al) showing contribution of lake water to the wells and springs (Figure 6.5). The contour map demonstrates a tendency for the proportion of the lake water to diminish with the increasing distance from lake Naivasha as would be expected. The map confirms largely the flow directions based on the piezometric analysis

North of Naivasha the groundwater table is expected to be very shallow to facilitate detection of outflow. Despite the scarcity of wells, the few in Elementeita area suggest that the lake water is more diluted than that below parts of Suswa, which is slightly further away from Naivasha. This in itself indicates a smaller proportion of lakewater to the north of Lake Naivasha.

Using the mean δD and $\delta^{18}O$ concentrations of Elementeita springs, borehole and the lake water, the following mixing computation was done to establish the proportional ratio in the Elementeita Spring. The composition of δD and $\delta^{18}O$ of Lake Naivasha, Elementeita spring and borehole located north of Nakuru are 6.6,36; 4.5,20; 1.04,0.88

$$6.6\delta^{18}Ox + (-4.5\ \delta^{18}O(1-x)) = -1.14\delta^{18}O$$

$11.1\delta^{18}Ox = 3.36\delta^{18}O$
$x = 0.30$ or 30%

This mass computation shows that Lake Elementeita spring is composed of about 30% lake water. Comparing the values for the Eburru (Allen and Darling) ranging from –7.9 to –13.5 and the Elementeita hot springs it is clearly evident that the Eburru values are more depleted than the Elementeita Spring value of -1.14, indicating lakewater. The sediment sample isotopic composition of —$1.14\delta^{18}O$ reflects its origin from Naivasha whereas the enriched sample taken from the surface with the isotopic composition of $0.71\delta^{18}O$ reflects a local origin. The heavier isotopes content have undergone evaporation and consequently enriched.

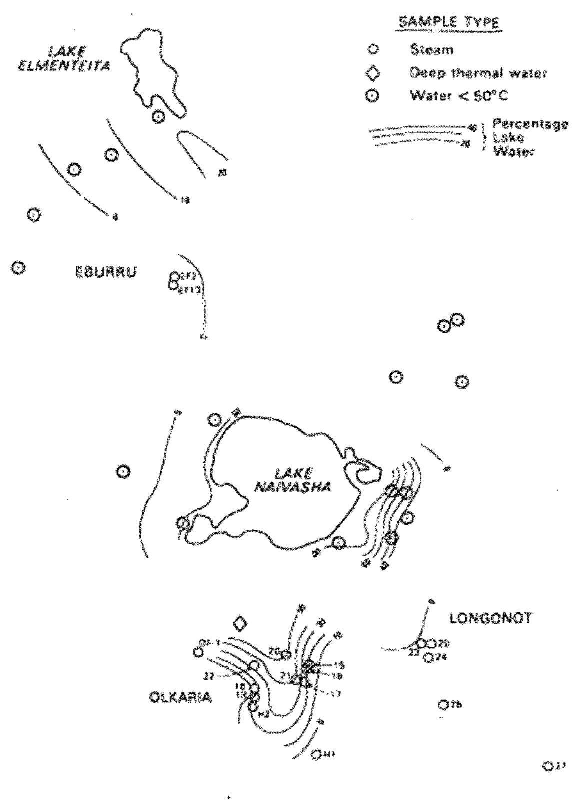


Figure 6.5 Contour map showing the contribution of Naivasha lake water to groundwaters in the Suswa-Elementeita sector based on geochemical evidence from wells, springs and fumuroles(Source Allen 1990)

6.8 CONCLUSION ON GROUNDWATER ORIGIN FROM ISOTOPE GEOCHEMISTRY

The interpretation of the stable isotope measurements presented here indicate that The Magadi hot springs appear to derives its waters from River Ewaso Ngiro and possibly from local groundwater recharge from the rift flanks.

Stable isotope data confirms that Lake Elementeita receives about 30% of lake contribution from Lake Naivasha through the hot springs located in its southern shore.

The interpretation based on sparse data, supports the hypothesis that larger proportion of lake water flows to the south and lesser proportion to the north of Lake Naivasha.

Chapter 7 Lake water balance

7.1 INTRODUCTION

The water-budget method was used to compute ground water for the three Rift lakes namely Nakuru, Elementeita and Magadi. Groundwater flow estimates can give an insight into seasonally important processes and allow comparisons between lakes. However, absolute groundwater inflow and outflow cannot be distinguished because only the net flow is computed.

7.1.1 WATER BALANCE EQUATIONS

A lakes water budget is computed by estimating all of the lake's water gains and losses, and the corresponding change in volume over the same period Δt. The model is base on mass conservation equation formulated below:

$$\Delta V = W - E + SW_{in} - SW_{out} + GW_{in} - GW_{out},$$

Where W is precipitation on the lake, E is lake evaporation, SW_{in} and SW_{out} are the inflows and the outflows of surface water, respectively, GW_{in} and $GW_{out,}$ are the inflows and the outflows of groundwater, respectively, ΔV is the change in the amount of water stored in the lake during Δt.

Water budget terms can be expressed in volumetric units (precipitation and evaporation multiplied by the average lake surface area during that time), or in linear units over the given time period by (dividing change in lake volume and volumetric fluxes by lake surface area). However, groundwater fluxes are inherently more important in the water budget of a smaller lake because of the higher ratio of lake perimeter to surface area, compared to a larger lake (Millar, 1971: Fellows and Brezonik, 1980).

The lake water budget equation can be rearranged to solve for the net groundwater flow:

$$G_{net} = GW_{in} - GW_{out} = \Delta V - W + E - SW_{in} + SW_{out},$$

When G_{net} is positive, groundwater inflow exceeds outflow, and this value can be considered the minimum amount of groundwater inflow in the lake water budget, similarly, when G_{net} is negative, net groundwater outflow occurs from the lake and this value can be considered to be minimum amount of groundwater outflow in the lake's budget.

7.1.2 WATER BALANCE MODEL DESIGN

The model was developed on a Microsoft excel spreadsheet based on work performed by Mmbui, 1999. The available hydrologic data are given in the basic data file. The year and month is provided in the first column. The stream flow measurements are given in the next several columns. The model uses the various sums and adjustments to arrive at an index of surface runoff into the lake. The sum of these values is then taken as the surface inflow to the lake. The next three columns are provided for observed precipitation, evaporation and net evaporation depth in millimetres. Following this is a column for net evaporation volume estimate calculated from the months average lake surface area and the net evaporation depth. Following the column for abstraction is a column for the month total inflows and outflows representing lake storage change. Then columns are provided for observed lake level, calculated lake level, calculated surface area and calculated volume consecutively. The calculated surface area and volume are derived from stage volume/surface area relationships. A column is provided for the square difference between the observed and calculated lake area.

The monthly change in storage is calculated from the total inflows and outflow. The monthly inflows are the gaged and ungaged monthly streamflows, groundwater inflows and direct precipitation on the lake surface. Ungaged stream flow and groundwater inflows are called "unmeasured inflows". The outflow term is estimated from the evaporation and abstraction.

Find below (Figure 7.1) the flowchart of the model design:

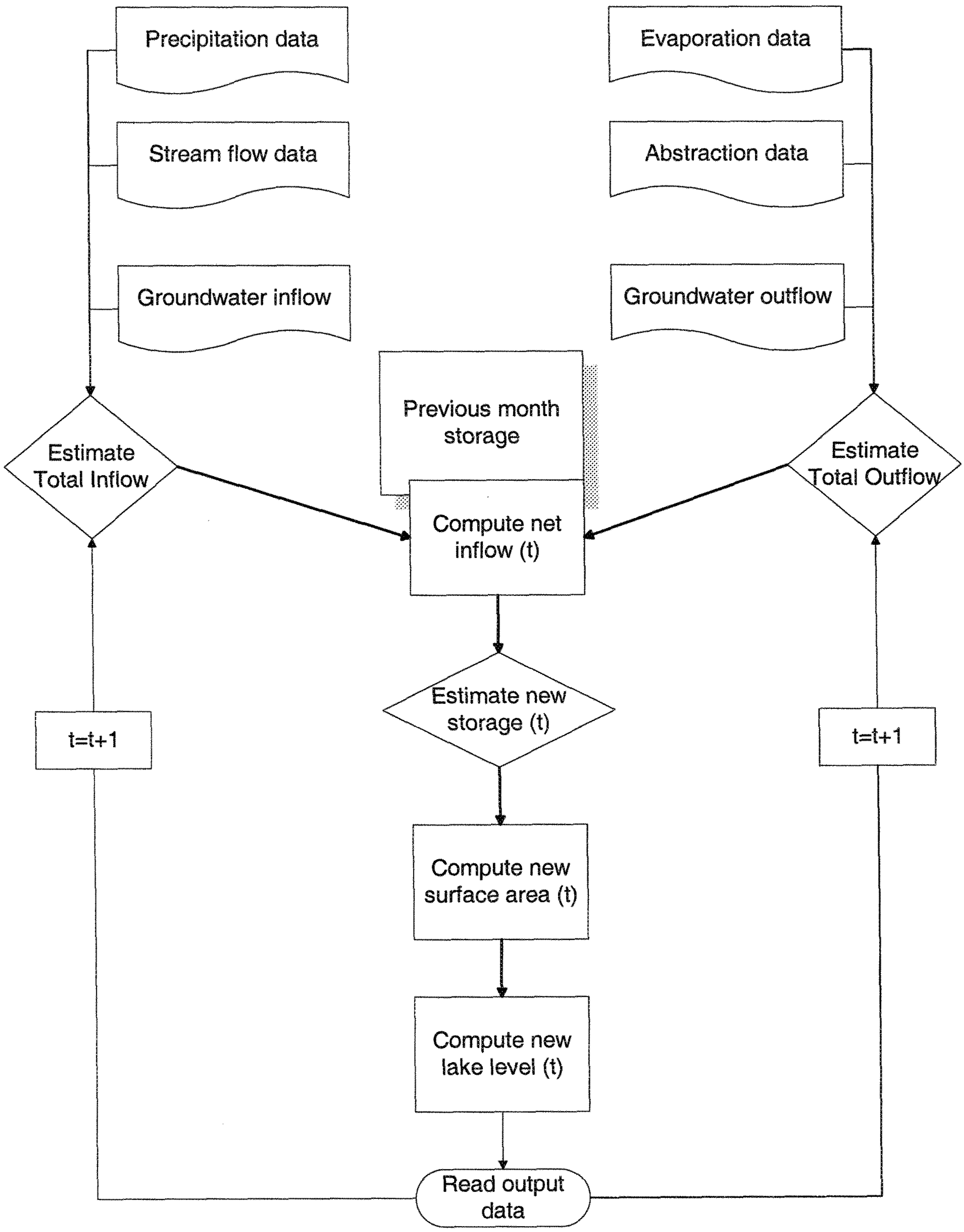


Figure 7.1 Flowchart showing how the mass conservation is used in modeling the lakes.

7.1.3 RUNNING OF THE MODEL

The observed lakes levels for December 1951 and December 1957 were used as the initial lake levels for Nakuru and Elementeita respectively. The volume and the surface area of each lake were computed using Volume and Surface area relationship assessed from the bathymetric information. Using these values, the model start running as from January 1952 and January 1958 for Nakuru and Elementieta respectively. The model is based on the mass balance equation for the lake and as output provides monthly total volume of water in the lake (in cubic meters) as follows:

$$VL_t = VL_{t-1} + Vbasin_t - RL_t - EvL_t - Deep_t - Abstractions_t$$

Where:

VL_t = Volume of water stored in the lake at the end of time step 't'

VL_{t-1} = Volume of water stored in the lake at the end of time step 't-1'

$Vbasin_t$ = Volume of water flowing into the lake during time step 't'

RL_t = Volume of direct rainfall into the lake during time step 't

EvL_t = Evaporation from open water, plus actual evapotranspiration from papyrus swamps around the lake during time step 't'

$Deep_t$ = Deep percolation from the lake during time step 't'

$Abstructions_t$ = Volume of water being abstucted from the lake system during time step 't'.

Having calculated the lake volume at the end of each time step, the corresponding elevation is calculated by means of Volume – Height rating equation. The lake level (H_t) is subsequently used to calculate the surface area (A_t)

The surface area (A_t) is then used to calculate the evapotranspiration and direct precipitation into the lake during time step (t+1). The computation continues until the last month 't' of the input data.

The model uses a single groundwater node to externally extract a known amount of groundwater to the lake over the whole simulation period.

7.2 MODEL CALIBRATION AND VALIDATION

Prior to application of the model, all the available data was analysed in detail. Depending upon the length and continuity of the historic data and in relation to the data quality, and simultaneous availability of data (such as precipitation, lake level, discharges, evaporation) specific time periods for model calibration was identified.

Model protocol requires that before any predictive simulation is made, model should be calibrated and verified.

7.2.1 MODEL CALIBRATION

The purpose of calibration is to obtain estimates for parameters in the model which by some circumstances cannot/ have not been estimated directly. The unknown parameter in this case is groundwater contribution that is impossible or infeasible to estimate by independent means.

A graph of observed and calculated lake levels versus time was plotted. The plot was automatically updated whenever various parameters were adjusted. In the first instance the probable ranges of the parameter values to be determined during the calibration were assumed. Based on these results calibration was carried out by adopting a "Trial and Error" procedure.

Visual inspection of the plot of observed and computed water levels provided a qualitative evaluation of the calibration effort.

To quantify the error in the calibration, a column was included to compute the sum of the square difference between the calculated and the historical (observed) levels.

7.2.2 MODEL EXECUTION

The first run of the model was done without groundwater components. The calculated water levels followed the same trend as observed lake levels but was on average lower than the observed Figure 7.2. The lower calculated lake level implies that the total observed lake storage is higher than what is expected as if the lake did not have groundwater inflow (gains). After the first model runs, some erroneous data inputs became also apparent and these errors were adjusted accordingly. The simulation results improved but there were still unacceptable differences between computed and observed lake levels. Based on analysis of the errors river Mereroni inflow was adjusted by a factor of 0.6 and abstraction (outflow) value was later introduced. In the preliminary calibration it was assumed that no losses originated by withdrawals thus accepting an overestimate in the monthly inflows The initial Specific yield and hydraulic conductivity used was based on published values for similar materials (Freeze and Cherry, 1979) and these values were adjusted during calibration

7.2.3 MODELING GROUNDWATER INPUTS

The groundwater is lumped into an aquifer reservoir which is linked to the lake through a contractor expressed simply as follows: $Q_{exchange} = C * (h_{lake} - h_{aquifer})$

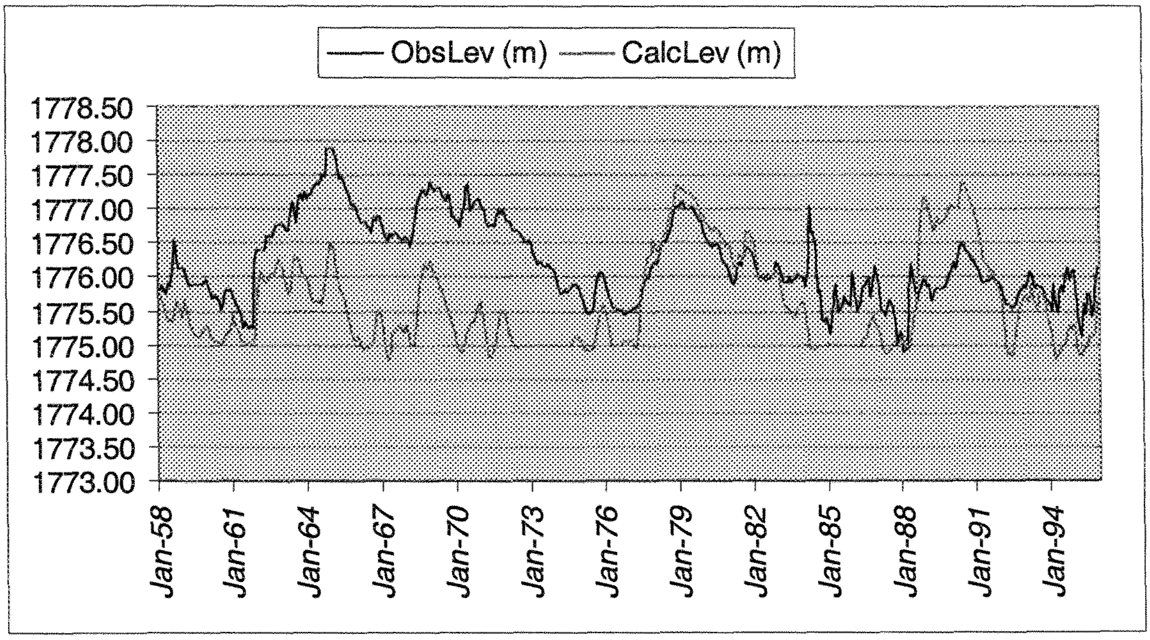


Figure 7.2 Results of first run without groundwater component.

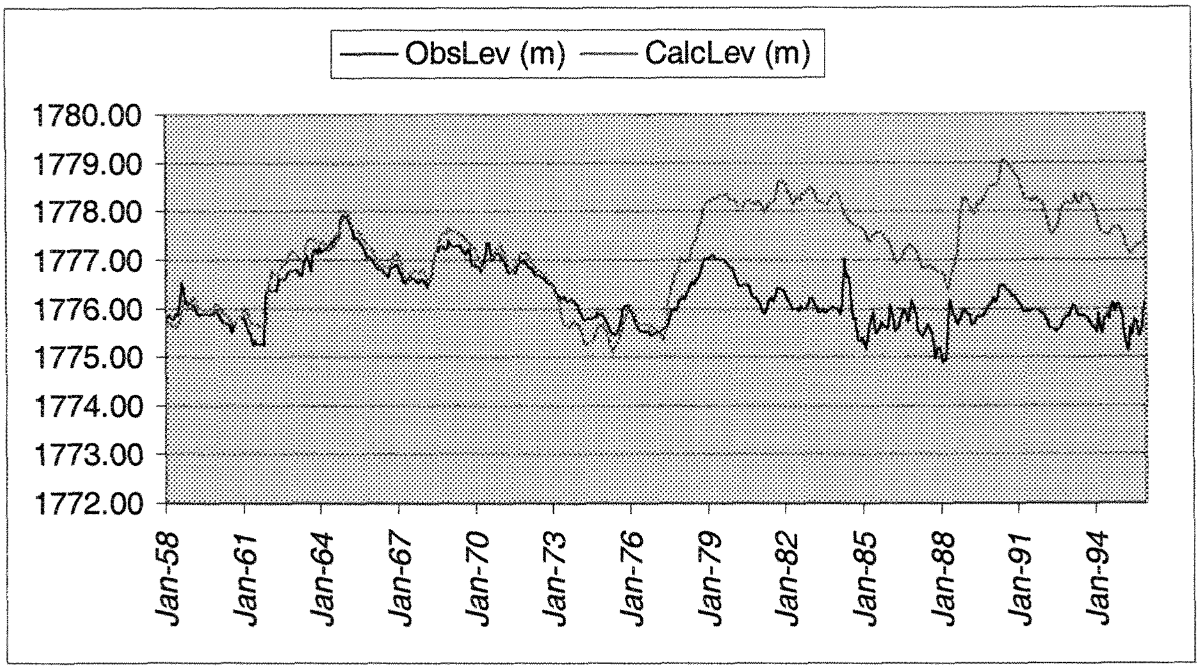


Figure 7.3 Results of optimized model with groundwater input.

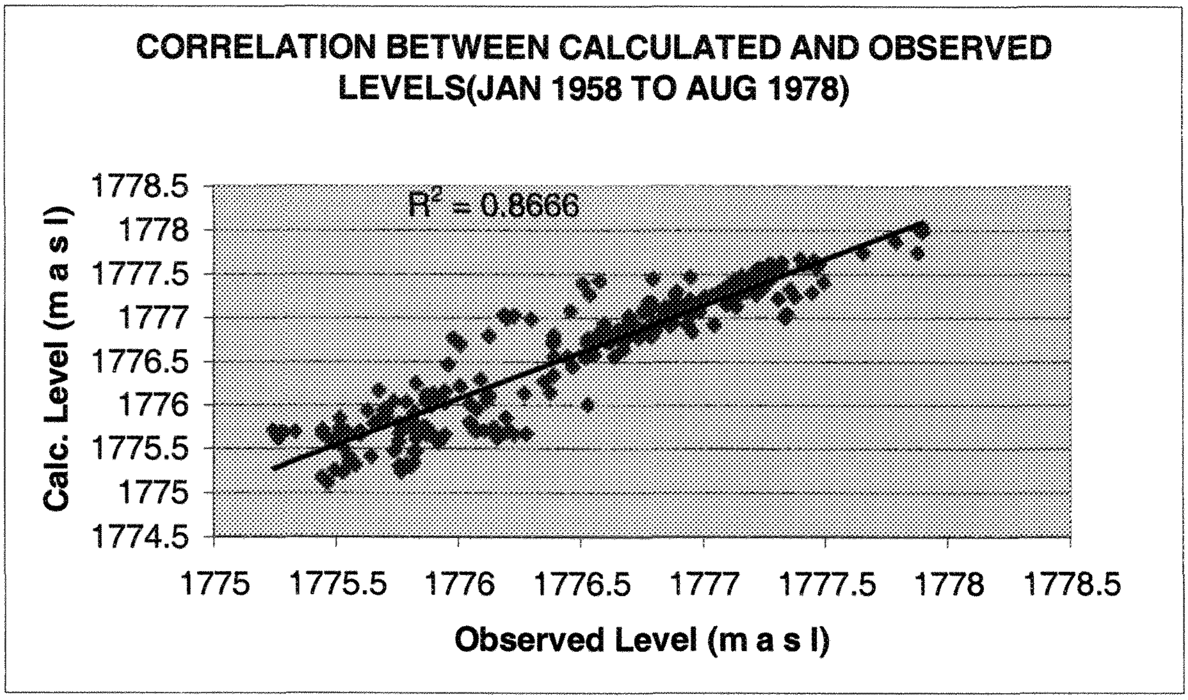


Figure 7.4 Scatter Plot of observed and simulated lake levels before1979

7.3 OPTIMIZATION

Model optimization was done to improve the groundwater parameters. This was done using the solver function available in the Microsoft excel program. Optimization was each time done with a view to minimizing the sum of square of difference between the observed and calculated lake levels. After optimization the groundwater inflow stabilized at 1.31 and 2.0 mcm per month for Lakes Elementeita and Nakuru respectively. These values are within the range calculated by other researchers as mentioned in section one.

7.4 SIMULATION RESULTS

7.4.1 LAKE LEVELS

From the Figure 7.4, it can be seen that observed and calculated lake levels agree to within acceptable limits up to 1978 after which there is a notable divergence. This is clearly illustrated by good correlation between the two for the period of 20 years from 1958 to 1978 as well as the temporal distribution of the difference Figures 7.6. The model can therefore plausibly be considered calibrated.

Lake Elemeinteita levels mimic the fluctuation of Lake Naivasha levels except for a sharp decline from September 1979 with consistent offset of 2 meters. The offset from 1978 onwards can be attributed partially to inaccuracies in reading the gauge from September to November 1984; a case admitted in the report filed by the Ministry of Water Department, Kenya dated 13 March 1984. It's also reported that, there was much water recession and the last gauge was left behind implying that the readings at that time were totally unreliable. Another speculation suggests that the decrease in the lake levels could be a result of diversion (water abstraction) of the river to supply the mushrooming irrigation activities around the Nakuru area. The lower part of Mereroni catchment including Lanet and Dundori areas are densely settled and intensively cultivated and hence increase in water abstraction from the river for domestic and other uses can not be underestimated. The observation is further supported by comparisons of satellite images taken before 1978 and one taken in 1986. The irrigation activities and the associated damming of river water are quite imminent in the images taken in the1980's. How this phenomenon can be related to the effect reflected on the graph is still a bizarre.

Assuming similar hydo-climatological environment, Elementeita lake levels were adjusted to the levels of Lake Naivasha by 1 meter from 1978 to 1995 giving comparatively a better fit, Figure 7.7. If that is the case, it implies therefore, that there is a deficit in the water balance and this can only be explaining in term of water diverted away from the river upstream or a systematic error in the lake levels record.

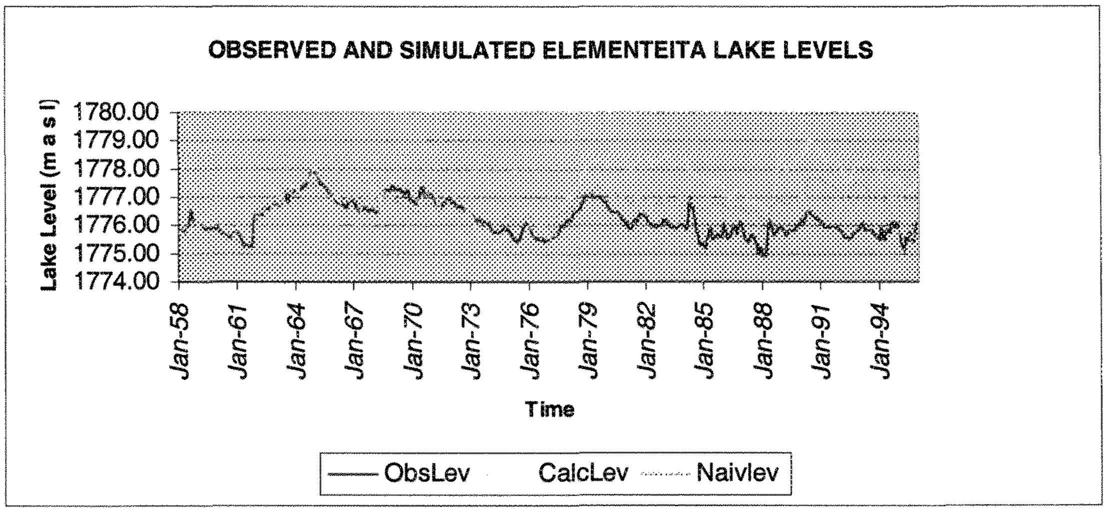


Figure 7.5 Comparison between observed Elementieta Levels and Linearly transformed Naivasha levels

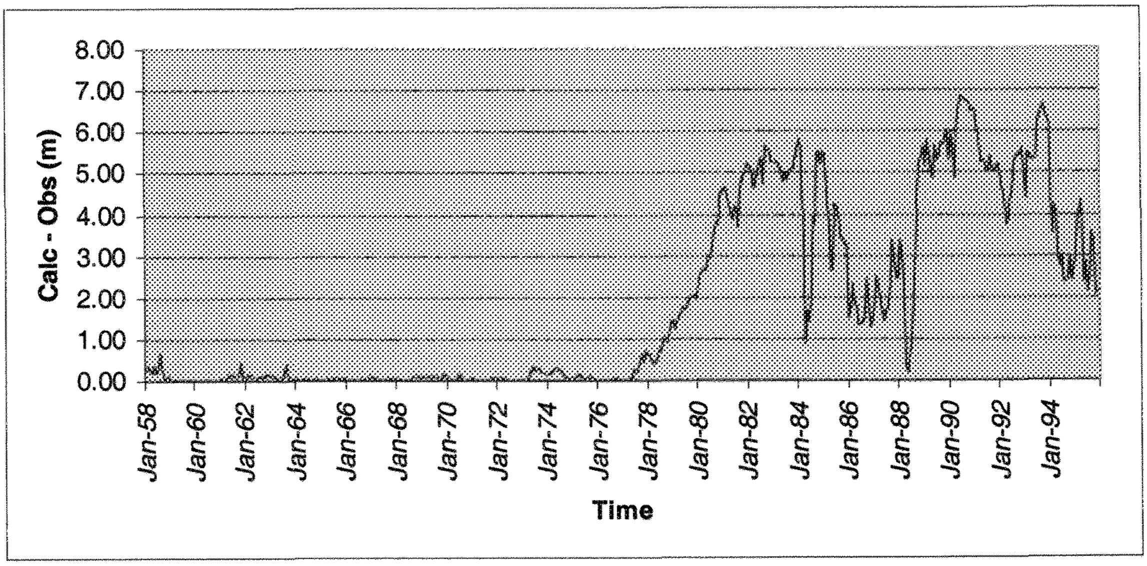


Figure 7.6 Temporal distribution of the differences between the calculated and observed Elementeita Lake levels

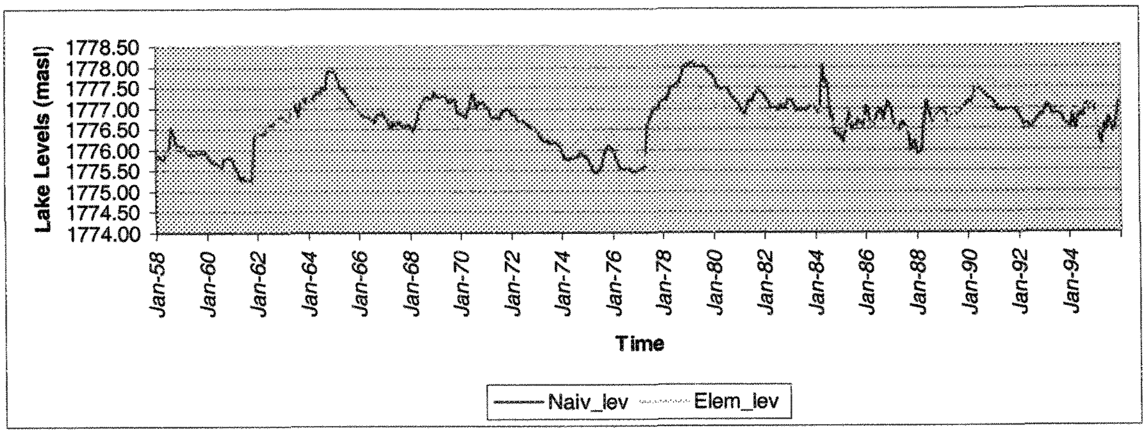


Figure 7.7 Adjusted Elementeita levels to Lake Naivasha trend line

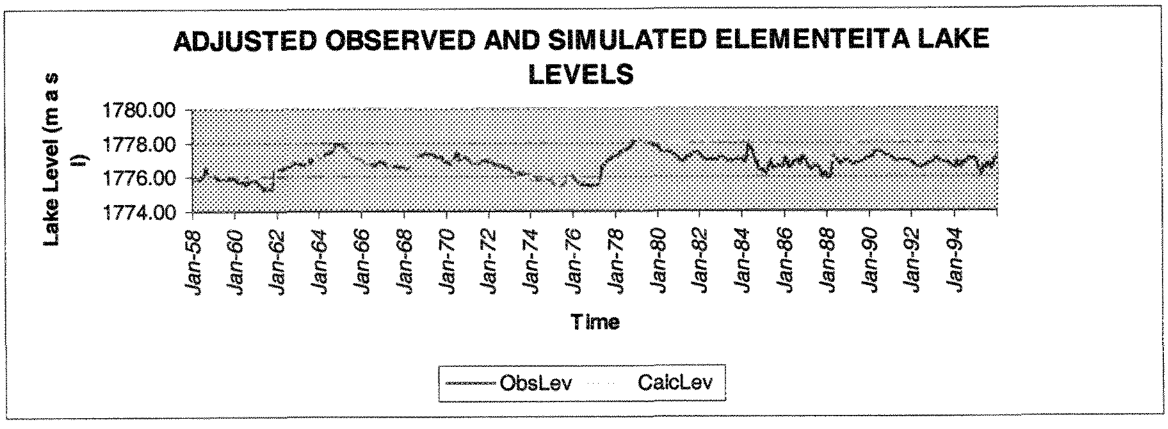


Figure 7.8 Adjusted observed and simulated Elementeita lake levels

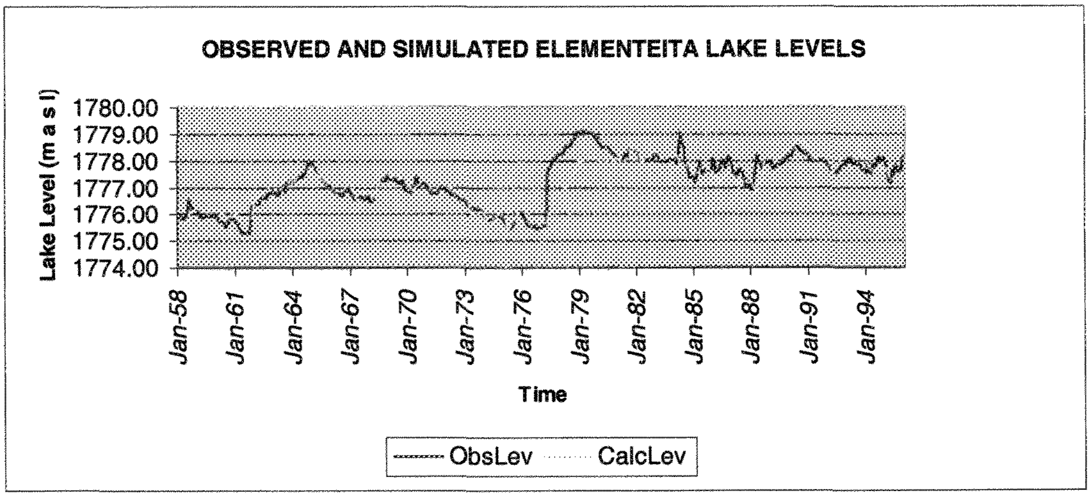


Figure 7.9The observed and simulated Elementeita lake levels.

7.4.2 LAKE STORAGE

The calculated and observed storage values showed the same trend as the lake levels, although the divergence commencing around 1978 is still apparent, Figure 7.10. The observed storage was derived from the observed level using the Stage–Volume relationship. The temporal difference between the observed and the simulated lake storage volumes were used to obtain the maximum deficit of $30*10^6$ $m^{3,}$ Figure7.11. It is envisaged that this deviation can be a result of a systematic error and if that is not the case ,then it could imply that loss of water is probably caused by abstraction. Given that the latter is true, withdrawals from the lake over a period 6 years can be estimated to be $5*10^6$ m^3 /yr. This implies that by disregarding the losses due to withdrawals, monthly volume changes the model is being overestimated by the quantity equal to the withdrawals. This is tantamount to accepting an error of 39% in the calibration. The monthly withdrawals of $4.1*10^5$ m^3 was optimized to $3.42*10^5$ m^3 value which is alone about 54% the monthly river inflow to the lake.

The cumulative relative error *(CRE)* in volume calculation is given by:

$$CRE = \frac{(M - C)}{M}$$

where M = measured cumulative volume and C = calculated cumulative volume. The negative sign indicates an average overestimate by the model. In this case the control element is represented by conservation of volumes extended to the entire calibration period and expressed by a relative error given by the equation above (Final Report).

INFLOW (m^3)	SMSE	CRE (%)	COEFFI-CIENT	REMARKS
1.31E+06	80.3	1.66	0.696	2 m shift, from May 1977
1.31E+06	51.66	-4.71	0.696	2 m shift, from May 1979
1.00E+06	837.16	-116.02	1	Original observed, no shift
1.31E+06	173.16	14.8	0.696	2.5 m shift from May 1977
1.31E+06	240	-48.3	0.696	1 m shift from May 1979
1.31E+06	230	-39.06	0.696	1 m shift from May 1977.

Table 7.1 Levels of Calibrations

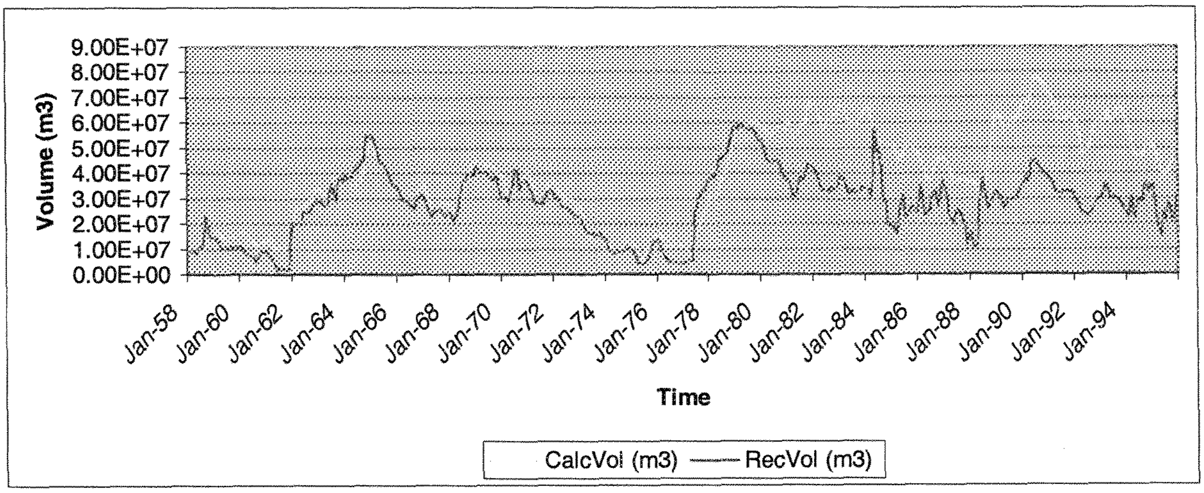


Figure 7.10: Temporal distribution of lake storage for 37 years. The deviation between the observed and simulated storage is apparent after 1979.

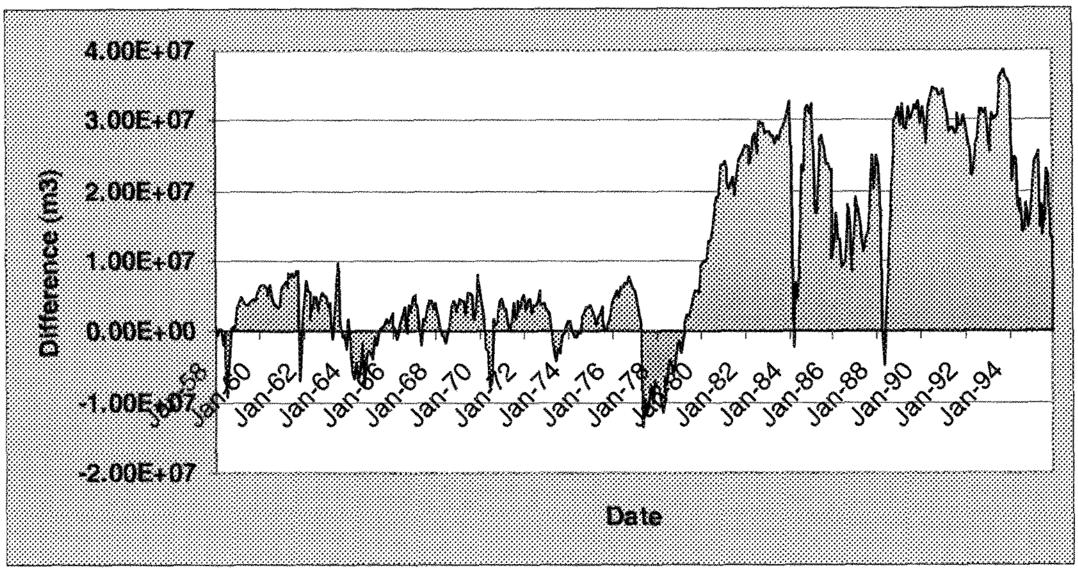


Figure 7.11: Temporal differences between the observed and simulated lake storage

7.5 VALIDATION

The model was validated against independent data for all the two lakes and shown to perform fairly well demonstrating a genuine correspondence between the behavior of the model and reality.

Validation of the calibrated model was carried out by comparing:

- Lake level
- Volume
- Surface Area

The results of these calibrations are discussed in section 7.5.1/2/ below.

7.5.1 LAKE ELEMENTEITA MODEL

The lake level trend for Elementita was compared to that of Lake Naivasha. The fluctuating trends were found to mimic each other. The scatter plot of the observed lake levels covering the entire calibration period gave a correlation coefficient of 0.678.

The surface area of the lake was obtained from the polygon map of a digitized lake perimeter from analogue topographic map produced from aerial photos taken between. February and April 1969. The resultant surface area was compared with the surface area computed using lake – surface area rating curve. The two agrees well with the rating curve area giving 23 km^2 while the polygon map gave 19.95 km^2. Meanwhile, the contour line defining the lake surface elevation stood at approximately 1776.m comparing favorably with the observed level at 1777.3m.

The monthly volumetric fluctuations of the lake were analysed, giving a computed value of $1.32*10^{10}$ compared with the recorded value of $1.28*10^{10}$ m^3. The relative error in volumes extended over the calibration period is –2.66%. The negative sign indicates a very small average overestimate by the model.

7.5.2 LAKE NAKURU MODEL

Similarly, the surface area of the lake was obtained from the polygon map of a digitized lake perimeter from analogue topographic map produced from aerial photos taken between. February and April 1969. The resultant surface area was compared with the surface area computed using lake – surface area rating curve. The two agrees well with the rating curve area giving 48 km^2 while the polygon map gave 45 km^2.

The cumulative observed levels, gave 928643 value and a computed value of 928702. The relative error in levels extended over the calibration period is –0.006%. The negative sign indicates a very small average overestimate by the model.

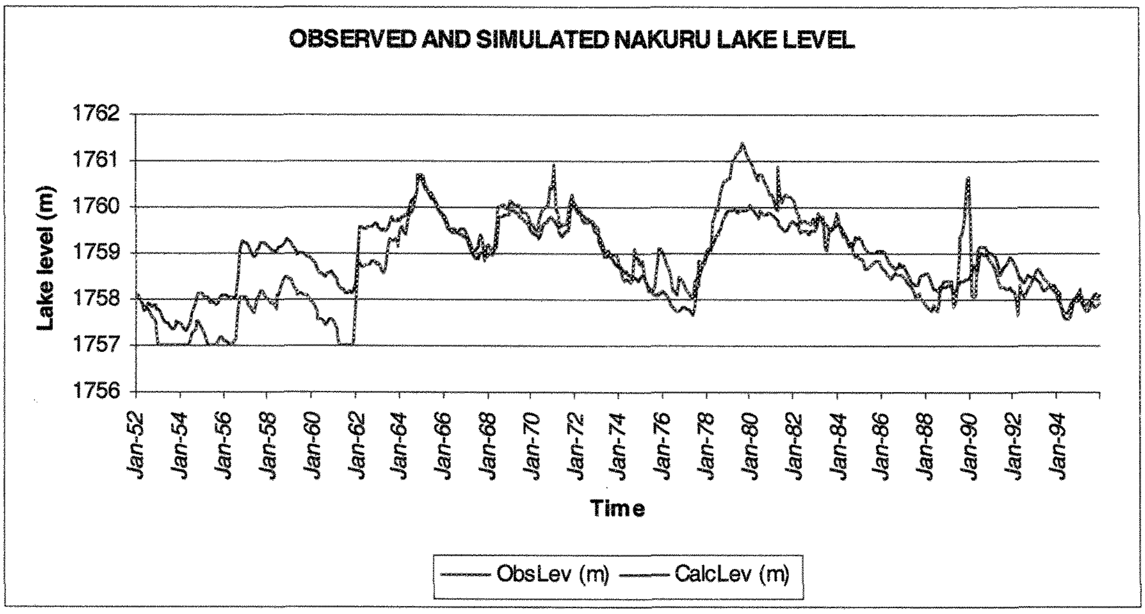


Figure 7.12 Observed and Simulated Nakuru lake levels

7.6 SENSITIVITY ANALYSIS

7.6.1 INTRODUCTION

During calibration of the model various coefficients were adjusted but the static and dynamic inputs were not changed at all. This section presents methods and results for further set of model runs in which its sensitivity to extreme changes in input data were examined.

The purpose was to examine whether the model behaves robustly when its input data is different from that on which it is calibrated. It should be noted however that these changes were not meant to be realistic.

The objective of sensitivity analysis was to evaluate the impact of changing input parameters on the lake level in the model. It was also performed to determine if the response of the model to the input variables agree to the knowledge and hypothesis that led such variables to be chosen. The capacity of the model to reproduce the non-linearity of the physical system was also tested. It means that if we increased or decreased the variable by a factor of two, for example, then we would not expect the response to increase or decrease by the same factor.

Starting from the " base" model, a certain number of changes are performed for each single variable according to a defined number of intervals and ranges. This technique identifies the most sensitive parameters in the estimation of the lake level and allows a quantitative analysis of how errors are fed through the input parameters.

The output values were analysed using the following relation in order to evaluate the effect of the perturbation:

$$D(\%) = \frac{O_p - O_b}{O_b} * 100$$

where O_b represents the base value, and O_p represents modified parameter. Negative deviations would indicate decline in lake level elevation.

The sensitivity analysis was performed on the input variables thought to be of significance in the model calculation such as Rainfall, Evaporation, Discharge and as well as the established plausible calibrated values including Groundwater inflow, Abstraction, Specific yield, Hydraulic conductivity and Aquifer area.

7.6.2 SENERIO 1 (Rainfall)

The rainfall values for February, March and April 1958 were increased stepwise by 10 to 120% and the model was run each time with the amended input file.

The results of the sensitivity analysis (Figure 7.13) demonstrate that the lake has immediate response to change in rainfall but the offset diminishes with time (4-5years). It suggest that there could be a feed back mechanism in the model that tends to return the lake level to its original values. This occurs possibly via open water evaporation. An increase in lake levels as a result of the perturbations increases the surface area, which consequently increases losses caused by evaporation from the lake than would have been if perturbations had not taken place. The reverse is also true where decreasing rainfall values would lead to decline in lake level.

It can be concluded that, the perturbation on a total monthly rainfall can have a significant effect on the model. It can be seen that changes are approximately linear.
By increasing the rainfall monthly total for April 1958 by ten percent gives approximately 0.36 m rise in lake level in the following month but this level anyway is not retained.

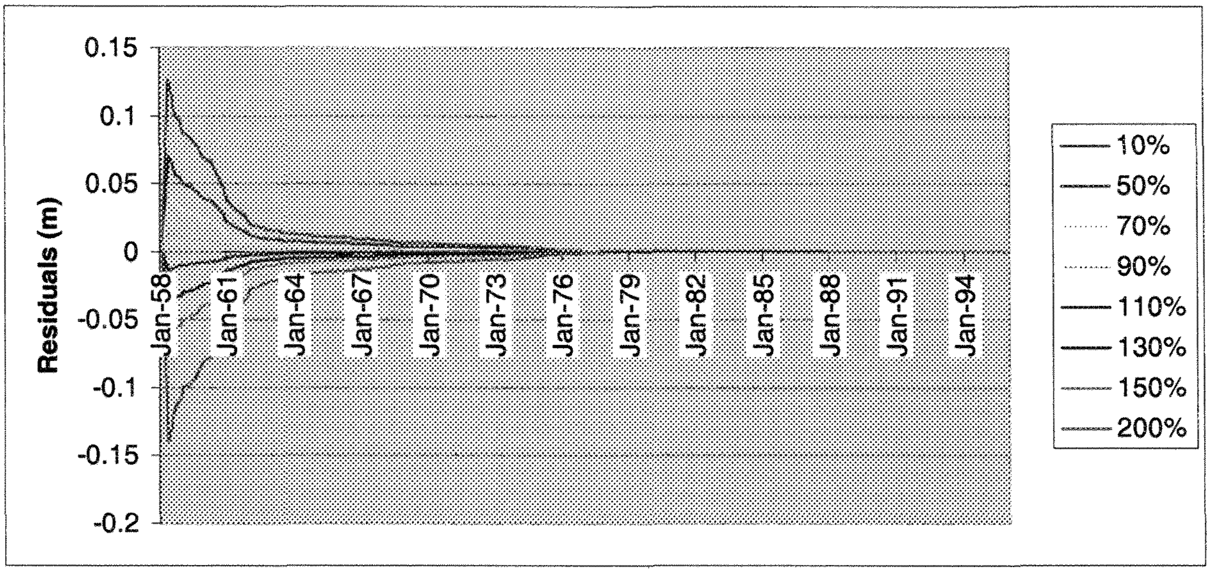


Figure 7.13 Lake level residual produced by perturbations in Feb. Mar and April 1958 rainfall values.

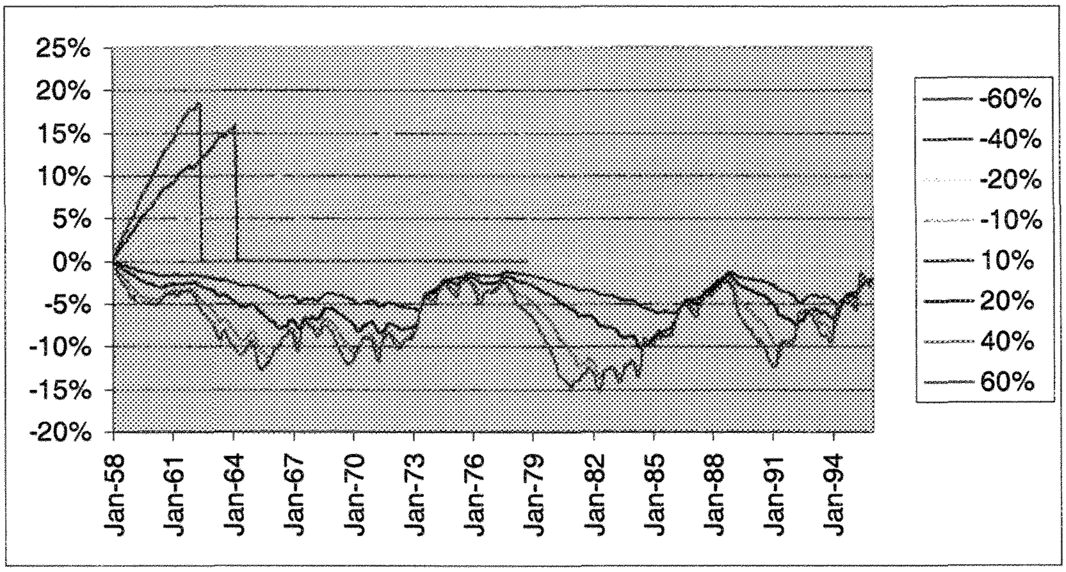


Figure 7.14 Variation of Lake level for different perturbation in evaporation values.

7.6.3 SENERIO 2 (Evaporation)

The evaporation values for the whole period of the calibration were modified by increasing and decreasing by a certain percent.

The results of the tests (Figure 7.14) indicate that, even with limited reduction in evaporation, there is a significant increase in discharge in relative terms and thus increase in lake level. The model crashes when the lake level reaches abnormally high value of 1780 m the case for –60%, -40% and –20%. The rate of increase in the level depends on the magnitude of the perturbation. In an opposite situation the increment of evaporation values results in decrease in discharge and hence decline in the lake level. But in a period when the lake is reported dry deduction of evaporation values has insignificant effect as can be seen around 1976 and 1988. It is therefore evident that the variation of the lake level depends upon the amount of precipitation in different period of interest.

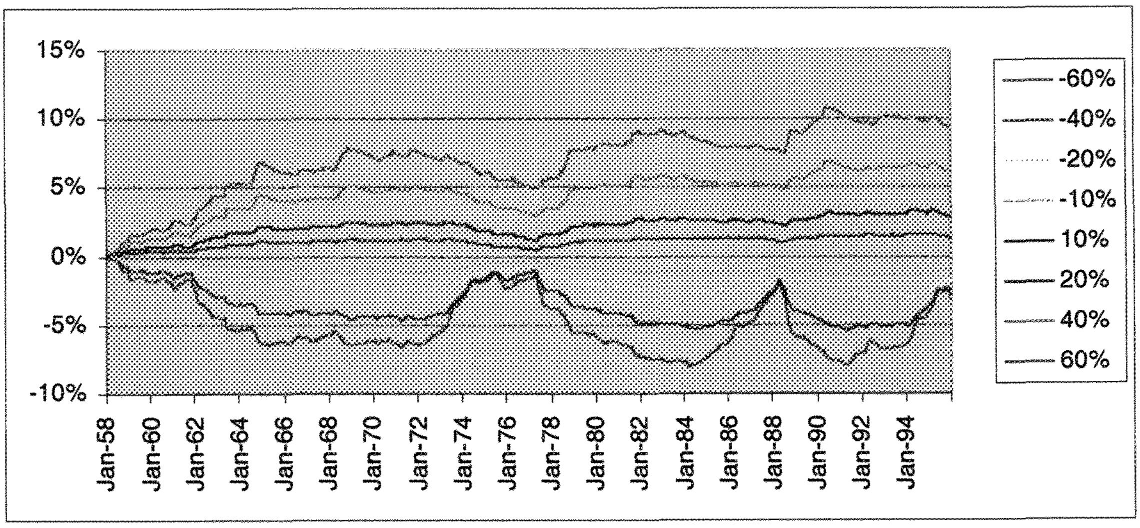


Figure 7.15 Variation of Lake level for different percentage perturbation in discharge values.

7.6.4 SENERIO 3 (Discharge)

Increase in lake level is again evident with increase in discharge values commensurate with the degree of increment (Figure 7.15). The converse is true and there is also insignificant change in lake level during the period when the lake is dry. It's quite evident again that variation of lake level depends upon the discharge as well.

7.6.5 SENERIO 4 (General)

Here (Figure 7.16), the influence of the individual input variables on the lake level elevation estimates are analyzed by varying arbitrarily their value by ±10%. When possible, this 10% change is compared to the variable uncertainties, as they can be empirically but realistically inferred. The most sensitive input variable to lake level fluctuation is evaporation followed by rainfall and groundwater inflow. The changes in lake levels induced by a 10% increase in evaporation, rainfall and groundwater inflow are 0.031% (117 cm), 0.024% (32 cm) and 0.022% (39 cm) respectively for Lake Elementeita. Stream flow is also an input variable in the water balance but it appears that it does not significantly influence the lake level. Variations in aquifer surface area affects weakly the results of the water balance by only 0.001%. The 10% increase in (abstraction) can reduce lake level by 1.78 cm but the level tends to gain more rapidly with the decrease in abstraction. While the water balance model is rather insensitive to hydraulic conductivity. Lake Nakuru on the other hand, is generally more sensitive to changes than Lake Elementieta (Table 7.2).

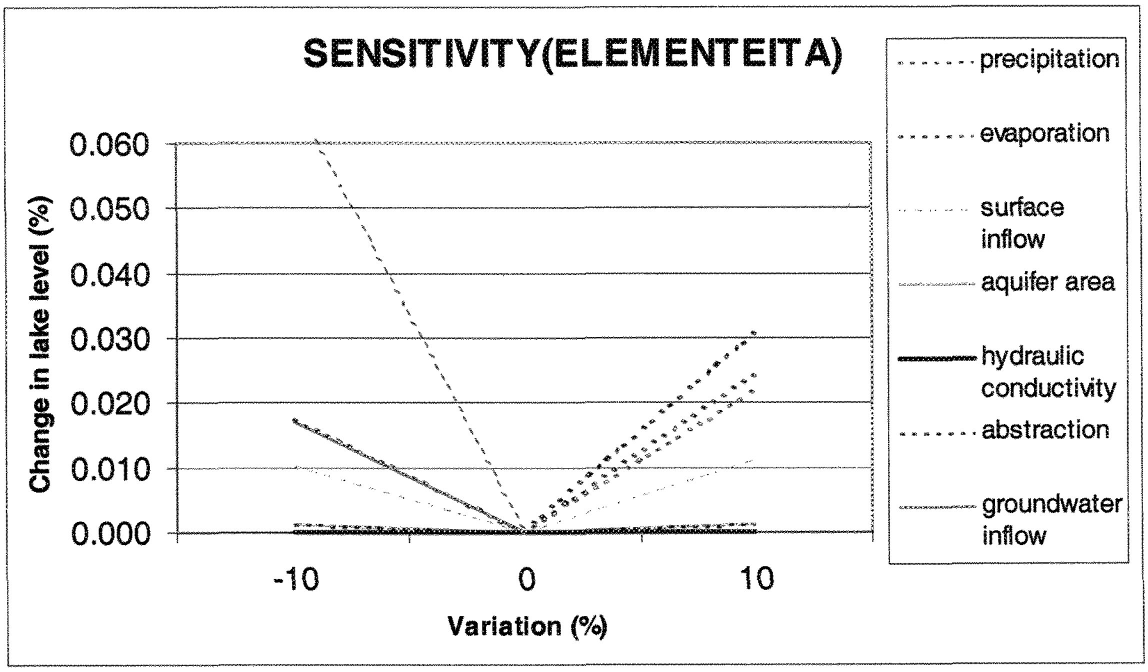


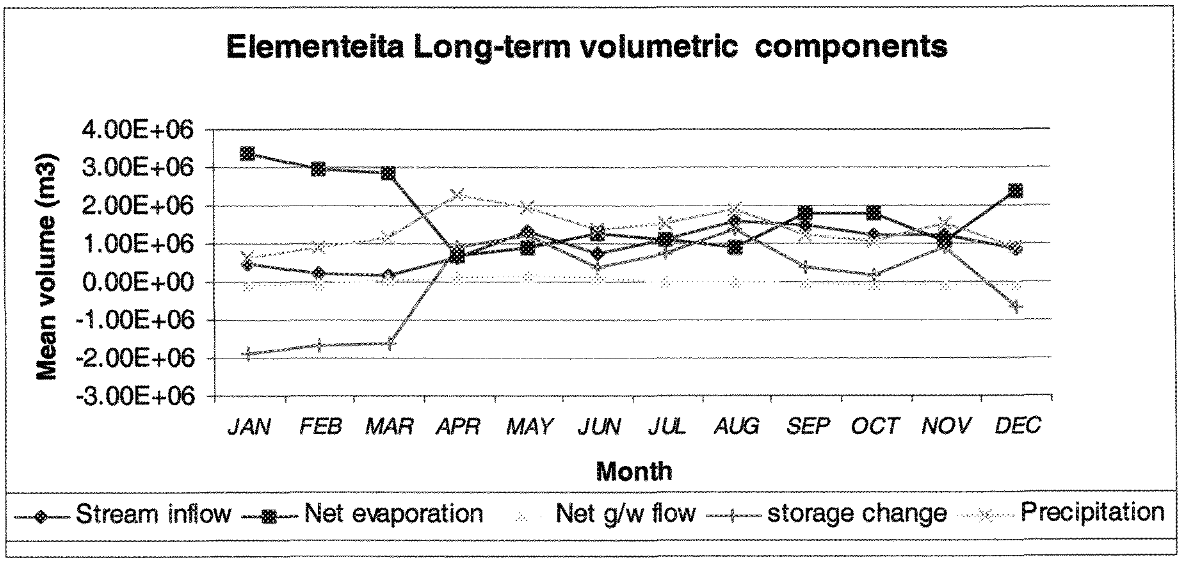
Figure 7.16 and 16b: Sensitivity of input parameters. Vertical axis represents the percentage of variation in the lake level obtained from the water balance method

Change in lake level		Elementeita D%	Elementeita (cm)	Nakuru D%	Nakuru (cm)
10% Perturbation	precipitation	0.024	42.66	0.025	44.17
	evaporation	-0.031	-55.11	-0.044	-77.23
	discharge	0.011	19.55	0.018	31.51
	aquifer area	-0.001	-1.78	0.000	-0.05
	conductivity	0.000	0.00	0.000	0.42
	gwinflow	0.022	39.11	0.017	30.01
	abstruction	-0.001	-1.78	n/a	n/a
(-)10% Perturbation	precipitation	-0.018	-32.00	-0.021	-37.78
	evaporation	0.066	117.32	0.065	114.04
	discharge	-0.010	-17.78	-0.017	-30.60
	aquifer area	0.001	2.03	0.000	0.00
	conductivity	0.000	0.00	0.000	0.44
	gwinflow	-0.017	-30.22	-0.016	-27.86
	abstruction	0.001	2.34	n/a	n/a

Table 7.2 Summary of sensitivities to input parameters and corresponding lake level changes

7.7 THE LONG-TERM WATER BALANCE

The long-term water balance for the three-modeled rift valley lakes are shown in following tables. The available data were used to provide the initial estimate of monthly water budgets. The Figures 7.17 through 7.19 compares the long-term monthly components of each lake volumetric budget in relation to the monthly change in lake volume. The seasonal pattern is quite reasonable.



Month	Stream Inflow (m^3)	Net evaporation (m^3)	Lake surface Area(m^2)	Storage change (m^3)	lake level change (m)	Net groundwater flow (m^3)	Groundwater inflow (m^3)	Precipitation (m^3)	Evaporation (m^3)
January	4.78E+05	3.36E+06	2.15E+07	-1.89E+06	-0.09	-1.04E+05	1.31E+06	6.38E+05	3.98E+06
February	2.30E+05	2.97E+06	2.11E+07	-1.67E+06	-0.08	-5.36E+04	1.31E+06	9.05E+05	3.90E+06
March	1.69E+05	2.86E+06	2.07E+07	-1.61E+06	-0.08	4.80E+04	1.31E+06	1.13E+06	4.08E+06
April	6.46E+05	7.04E+05	2.03E+07	8.83E+05	0.04	1.23E+05	1.31E+06	2.24E+06	2.98E+06
May	1.33E+06	8.71E+05	2.05E+07	1.19E+06	0.06	1.82E+05	1.31E+06	1.93E+06	2.87E+06
June	7.16E+05	1.27E+06	2.08E+07	3.69E+05	0.02	1.02E+05	1.31E+06	1.37E+06	2.65E+06
July	1.09E+06	1.13E+06	2.09E+07	7.59E+05	0.04	2.37E+04	1.31E+06	1.53E+06	2.67E+06
August	1.59E+06	8.77E+05	2.11E+07	1.35E+06	0.06	-2.61E+03	1.31E+06	1.92E+06	2.80E+06
September	1.47E+06	1.77E+06	2.14E+07	3.76E+05	0.02	-4.28E+04	1.31E+06	1.21E+06	3.02E+06
October	1.22E+06	1.80E+06	2.14E+07	1.71E+05	0.01	-1.01E+05	1.31E+06	1.08E+06	2.90E+06
November	1.19E+06	1.07E+06	2.14E+07	8.89E+05	0.04	-9.86E+04	1.31E+06	1.53E+06	2.59E+06
December	8.37E+05	2.37E+06	2.16E+07	-6.59E+05	-0.03	-8.46E+04	1.31E+06	9.19E+05	3.30E+06
Grand Average	9.13E+05	1.75E+06	2.11E+07	1.36E+04	0.00	-6.98E+02	1.31E+06	1.37E+06	3.14E+06

Figure 7.17 Lake Elementeita long term volumetric components

Month	Surface inflow (m³)	Lake evaporation (m³)	Precipitation (m³)	Lake surface area (m²)	Evaporation (m3)	Storage change (m3)	Groundwater inflow (m³)	Groundwater flow (m3)	Lake level change (m)
January	8.63E+05	4.88E+06	2.70E+06	4.17E+07	7.62E+06	-2.04E+06	2.00E+06	-2.04E+04	-0.05
February	4.44E+05	4.59E+06	2.70E+06	4.06E+07	7.25E+06	-2.17E+06	2.00E+06	-1.99E+04	-0.05
March	3.88E+05	4.88E+06	2.62E+06	4.03E+07	7.58E+06	-2.51E+06	2.00E+06	-1.84E+04	-0.06
April	1.72E+06	2.85E+06	2.85E+06	4.04E+07	5.60E+06	8.57E+05	2.00E+06	-1.67E+04	0.02
May	1.91E+06	2.55E+06	2.92E+06	4.06E+07	5.48E+06	1.34E+06	2.00E+06	-1.48E+04	0.03
June	9.73E+05	2.66E+06	2.42E+06	4.08E+07	5.05E+06	3.04E+05	2.00E+06	-1.54E+04	0.01
July	1.43E+06	2.41E+06	2.79E+06	4.01E+07	5.03E+06	1.01E+06	2.00E+06	-1.63E+04	0.03
August	2.83E+06	2.56E+06	2.79E+06	4.05E+07	5.36E+06	2.26E+06	2.00E+06	-1.65E+04	0.06
September	2.07E+06	2.89E+06	2.88E+06	4.15E+07	5.90E+06	1.17E+06	2.00E+06	-1.74E+04	0.03
October	8.88E+05	3.00E+06	2.79E+06	4.18E+07	5.80E+06	-1.32E+05	2.00E+06	-1.90E+04	0.00
November	1.40E+06	2.96E+06	2.15E+06	4.17E+07	5.08E+06	4.17E+05	2.00E+06	-1.98E+04	0.01
December	1.65E+06	4.22E+06	2.17E+06	4.18E+07	6.38E+06	-5.84E+05	2.00E+06	-1.97E+04	-0.01
Grand Average	1.38E+06	3.37E+06	2.65E+06	4.10E+07	6.01E+06	-5.83E+03	2.00E+06	-1.79E+04	0.00

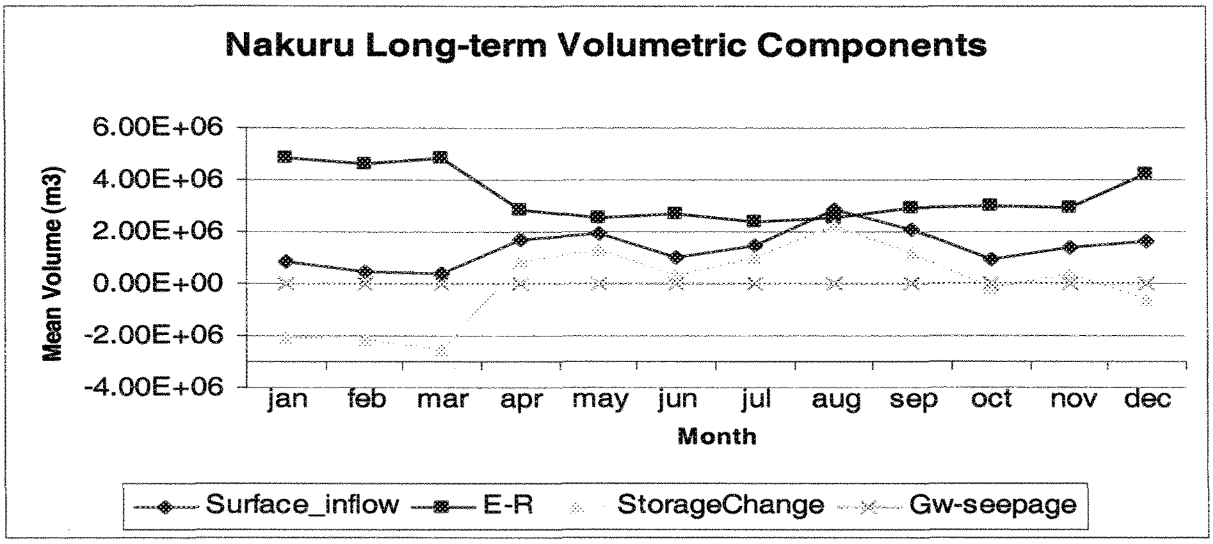
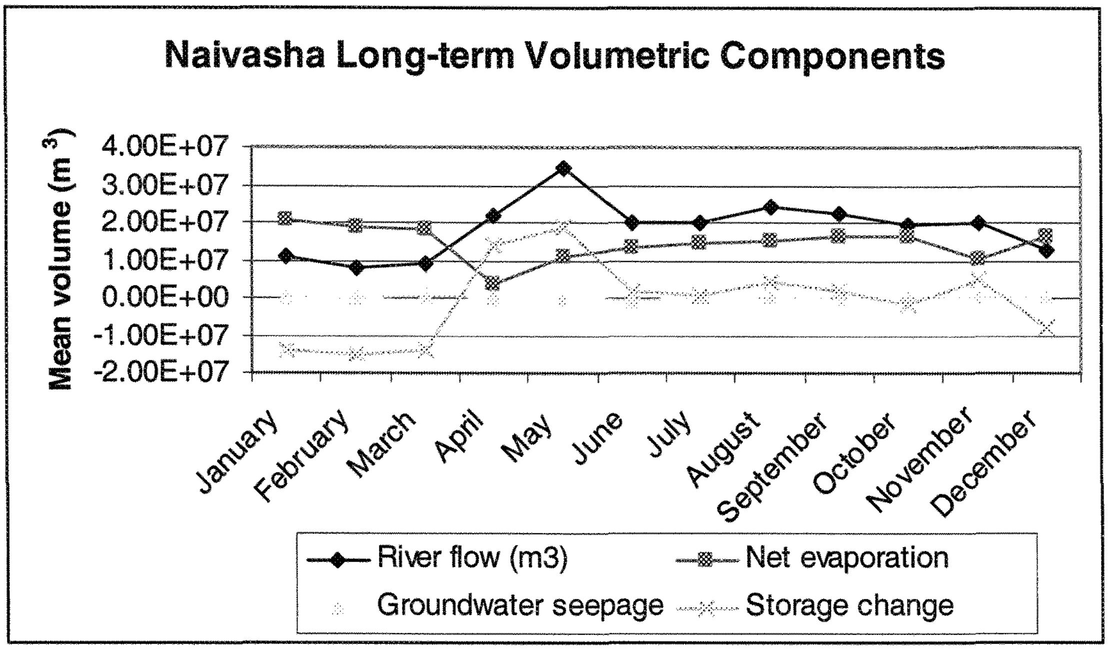


Figure 7.18 Lake Nakuru long term volumetric components



Month	River flow (m^3)	Net Evaporation (m^3)	Precipitation (m^3)	Groundwater flow (m^3)	Groundwater outflow (m^3)	Evaporation (m^3)	Storage change (m^3)	Lake level change m
January	1.10E+07	2.06E+07	4.87E+06	9.48E+04	4.60E+06	2.54E+07	-1.40E+07	-0.097
February	8.03E+06	1.89E+07	5.32E+06	2.72E+05	4.60E+06	2.42E+07	-1.50E+07	-0.103
March	9.19E+06	1.84E+07	8.12E+06	3.23E+05	4.60E+06	2.65E+07	-1.40E+07	-0.097
April	2.19E+07	3.85E+06	1.69E+07	3.00E+05	4.60E+06	2.08E+07	1.40E+07	0.097
May	3.47E+07	1.06E+07	1.16E+07	-1.16E+05	4.60E+06	2.22E+07	1.90E+07	0.131
June	2.01E+07	1.34E+07	6.81E+06	-3.39E+05	4.60E+06	2.02E+07	1.80E+06	0.012
July	1.98E+07	1.46E+07	5.73E+06	-1.39E+05	4.60E+06	2.03E+07	4.20E+05	0.003
August	2.41E+07	1.52E+07	6.79E+06	-6.70E+04	4.60E+06	2.20E+07	4.20E+06	0.029
September	2.24E+07	1.61E+07	7.15E+06	-1.25E+05	4.60E+06	2.32E+07	1.60E+06	0.011
October	1.93E+07	1.66E+07	7.89E+06	-8.46E+04	4.60E+06	2.45E+07	-1.90E+06	-0.013
November	1.98E+07	1.03E+07	9.22E+06	1.38E+04	4.60E+06	1.96E+07	4.90E+06	0.034
December	1.30E+07	1.62E+07	6.12E+06	-6.49E+04	4.60E+06	2.23E+07	-7.90E+06	-0.054
Grand Average	1.86E+07	1.46E+07	8.04E+06	5.60E+03	4.60E+06	2.26E+07	-5.73E+05	-3.95E-03

Figure 7.19 Lake Naivasha long term volumetric components

7.7.1 GROUNDWATER FLOWS

Annual groundwater inflow for Lakes Elementieta and Nakuru estimated by the models at best are at $15*10^3$ m^3 and $24*10^3$ m^3 respectively. These values agree closely with the estimates of 14 $*10^3$ m^3 and $23*10^3$ m^3 calculated by McCann (1974) and$11*10^3$ m^3 and $24*10^3$ m^3 computed by Githae (1998).

7.7.2 PRECIPITATION AND EVAPORATION

Monthly rainfall ranged from 2.92 mcm in May to 2.15 mcm in November for Elementeita and from 4.87 mcm in January to 16.9 mcm for Nakuru.

Evaporation is higher during the dry season and invariably exceeds rainfall. Its lower during the rainy season, but exceeds rainfall except during April and May.

The difference between gross evaporation and precipitation on the lake is a factor that represents the net rate of removal of water from a closed lake. The figures (7.18-20) show that when the net evaporation is considerably high, the storage change tends to be proportionally low. This mechanism tends to maintain the lake levels low otherwise the inflow would cause the lakes to overflow, in which case has never been reported.

7.7.3 SURFACE WATER INFLOW

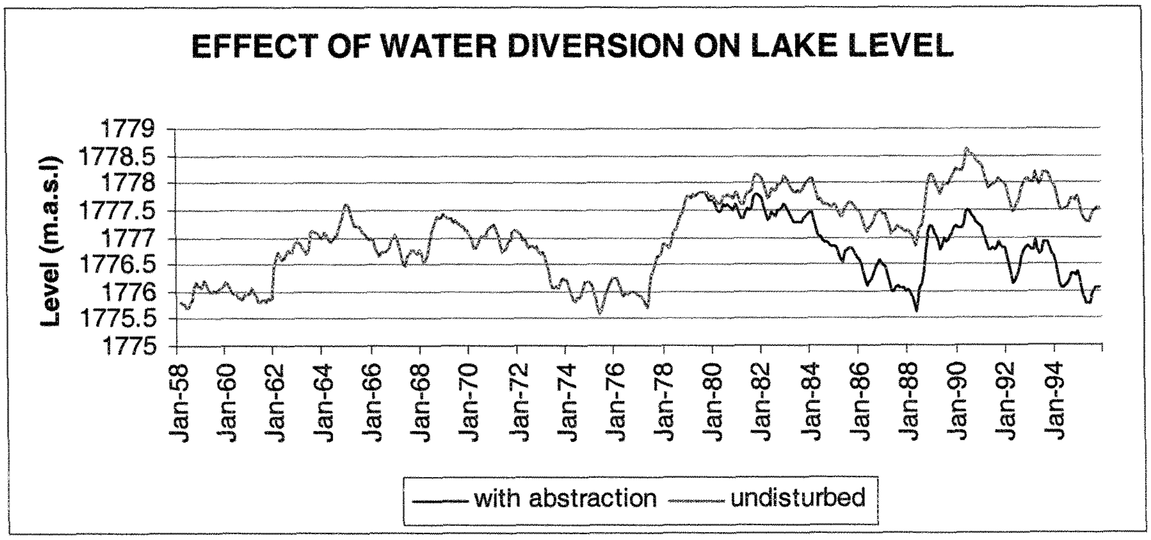
The minimum and maximum average monthly inflows into Lake Elementeita were 0.169 mcm and 1.59 mcm, which occurred during the March and August respectively (refer to the Tables). Lake Nakuru registered maximum inflow in May and August with the estimated values of 1.91 mcm and 2.83 mcm respectively. The months with least net evaporation correspond to when there is most stream inflow.

7.7.4 LAKE LEVEL AND STORAGE

The graph indicates a relationship between the lake volume changes which corresponds to lake level change that correlate well with the rainy seasons. Mean monthly lake storage changes were used to calculate the stage changes for each month. An interesting feature of these graphs is that the peaks in the lake volume changes for Lakes Elementita and Nakuru occur in May, August and November. The lake levels appear to be immediately affected by high rainfall occurring in August and November and lag in response to April rain in May a month later after prolong dry season. The level progressively declines from December to March corresponding to period of high net evaporation. This could be attributed to high atmospheric demands for water in the form of evaporation that cannot be met by effective rainfall. Lake Elementeita registers a low level in February to April being followed by a general rise to a maximum in September. The disturbance is seen in a form of third rainy season in July and August in addition to widespread April-May and October-November maxima. Lake Nakuru responds to the April-May rains and remarkably to the local July-August rains and to a smaller extent to the October-November rainfall. This feature confirms the importance of the July-August rainfall. It can be concluded that lake levels fluctuate in response to the net inflow and evaporation changes.

7.7.5 ABSTRACTIONS

Agricultural activities in the basin before mid 1980s were negligible. Owing to this reason all water losses from the lake was due to evaporation. Notwithstanding the possibility of a systematic error, the difference between the observed and calculated lake levels after mid 1980s were taken to be due to diversion from the rivers for the agricultural, industrial and domestic purposes after correction for inaccuracies in gauge readings.



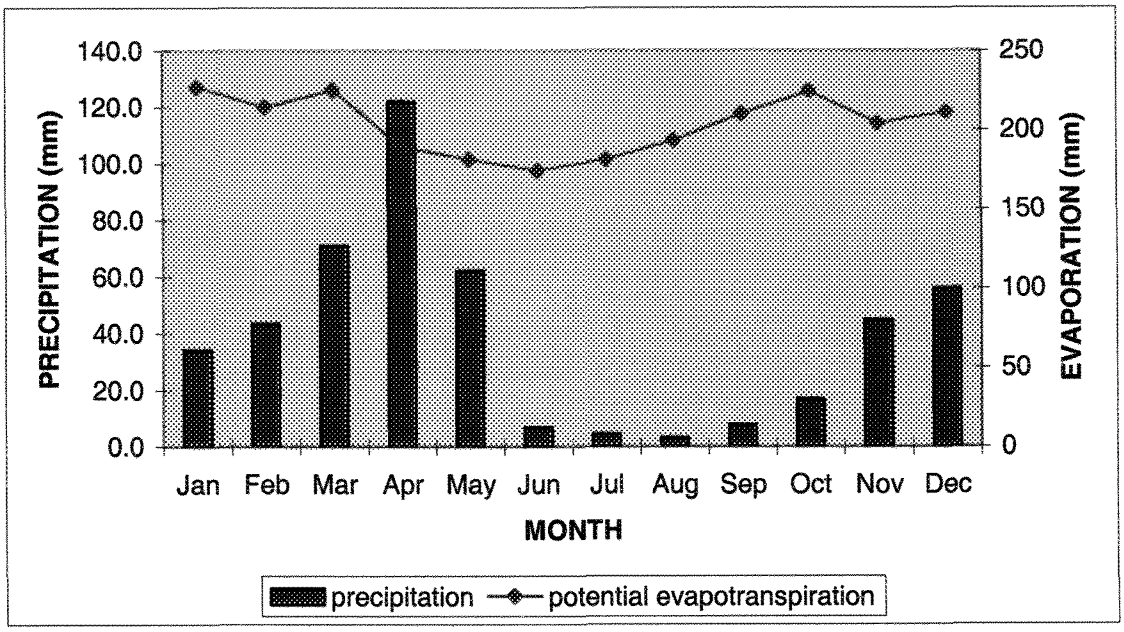


Figure 7.20: Annual rainfall and evaporation at Magadi

7.8 WATER BALANCE COMPUTATION OF LAKE MAGADI

7.8.1 INTRODUCTION

The Magadi trough is about 40 km long and has several arms, each 3-4 km wide, representing grabens in thick sequences of trachyte lava flows which filled the floor of the rift valley 1-1.9 million years ago (Baker et al., 1971). It contains a deposit of bedded trona ($NaHCO_3 .Na_2CO_3 .2H_2O$) up to 50 m thick, called the Evaporite series, which has accumulated since High Magadi time dated at 9100 years(Butzer et al., 1972). This deposits which thins towards the edges, has a high porosity and contains concentrated brine. Trona continues to form at present time.

There are no permanent rivers entering the Magadi basin and solutes are supplied mainly by a series of alkaline springs located around the perimeter of the lake. During rainy seasons, storm runoff may flood the lake to several meters deep, but during dry period the lake surface consist of a hard, porous crust of trona (Hans Eugster and Hardie Lawrence). The level of the interstitial brine never falls far below that surface. The springs feed the lagoons which are perennial waterbodies at the lake margins. The alkaline springs have been constant in composition over the last 45 years and they are assumed to be fed by a groundwater reservoir of. hot saline water. Lake Naivasha 100 km to the north, may be another important supply, as is the occasional runoff. Using Na and Cl as tracers, Eugster (1970) and Jones et el., (1977) have established that the streams which flow from the western escarpment into the rift Valley and disappear before the reach the floor could be the major recharge of this reservoir.

The combine lake Magadi-Natron drainage basin encompasses an area of about 23,207 km^2, but few of the basin's river flow directly into Lake Magadi. These two lakes are remnants for an earlier lake that began to dry up about 10000 to 12000 years B.P. (Hillaire-Marcel 1987). Lake Magadi has a semiarid climate, with about 427 mm mean annual rainfall, although its total basin may average about 750 mm. The evaporation rate is high, averaging about 200 mm per month for the year. Figure 7.20 gives additional detail of the average annual rainfall taken from the Magadi Part-time Meteorological station no. (9136167) and evapotranspiration estimated by Penman method.

PLATE 7.1 Lake Magadi salt crusts (trona). Dredging in progress in the background.

Approximately 75 km^2 of the lake's 164 km^2 total area is covered by trona deposits that are as much as 20 to 40 m thick. The central portion of the lake averages 4.4 km in width and 26 km in length, and has a permanent brine pools less than 2 to 3 m deep in several limited areas. The surface usually floods during the March-May rainy season and dries up again by June to July. No perennial river runs into it they all disappear into the basin's alluvial fan, and does the river Ewaso Ngiro which drains a very large area, flows nearby and finally reappears and continue weakly into Lake Natron, 30 km to the south. (Figure 3.3) Obviously much of its water flows into the Magadi basin aquifer.

The water balance was computed in section 7.8.2/3/4/5 as follows:

7.8.2 ESTIMATION OF EVAPORATION

The evaporation rate from an open body of water is partly a function of the degree of salinity. It is well known that the evaporation rate from a saline water surface is lower than the freshwater surface (Salhotra et al. 1985) due to vapour pressure reduction.

Several researchers (Allison et al, 1985; Ullman 1985; Jacobson and Jankowski 1989; Malek et al. 1990 Chen and Zawislanski et al. 1992) carried out measurements of evaporation rates on salt lakes in various locations in United States and Australia. They reported that the actual evaporation rates from salt-crusted surfaces are as low as a few percent to 25% of the potential or pan evaporation rate in the same area. The three mechanisms which are considered responsible are: the high shortwave reflectivity of the dry salt crust, vapor density depression due to salinity and high salt crust resistance to moisture transfer.

To estimate total evaporation from the lake based on the preceding observation, the areal extent of various types of surface conditions were estimated. The crusted surface area covers approximately 144 km^2 of the total surface area. The remaining surface was approximated to be of brine nature and covered the remaining 20 km^2 of the lake surface. 90% reduction was applied to the crusted area for 8.5 months, the season the lake was considered to be dry. The whole lake surface was assumed to remain flooded for at least 3.5 months and crusted surface dry for the remaining months in a year. During flood the lake was considered to be of brine nature and 80% evaporation reduction was applied to the whole lake surface area. Similarly, during the dry period 89 km^2 of the lake surface evaporated equivalent to the brine set up. All these estimations were then summed up to give the annual evaporation flux over the lake amounting to 97 mcm.

7.8.3 ESTIMATION OF GROUNDWATER INFLOW

After drying up of the lake, subsequent evaporation through the lake surface would cause relatively dilute groundwater to flow into the lake sediments to replace the evaporated water. Much of the groundwater inflow to normally "dry" salt lakes will replace the water which is lost by evaporation through the lake surface. Thus if a method, such as that outlined by Allison and Barnes (1983), can be used to estimate evaporation rate, this will indirectly lead to an estimate of groundwater inflow.
In periods of no surface water inflow to the lake the evaporation flux represent the groundwater inflow. It can be expressed by the equations:

$$E = GW_{in} + SW_{in}$$

where E is the evaporation flux from the lake, GW_{in} and SW_{in} is the groundwater and surface inflow respectively.

In the calculation, it was assumed that total evaporation from both encrusted and brine surfaces (144 and 20 km^2 respectively) during 8.5 of dry months represented groundwater inflow. Based on the assumption that during dry weather the rate of inflow is balanced by the rate of evaporation, the annual groundwater inflow to the lake therefore,amounts to 69 mcm.

Under steady state conditions, and assuming that the surface catchments (23,207 km^2) and the groundwater catchment are identical, this corresponds to a mean recharge flux of about 1.45 mm per year over the catchment. This value gives an order of magnitude estimate which for the climate of the area, seems reasonable.

It should be stressed that these estimates are subject to considerable error and it is difficult to assign confidence limits to them, but they do represent the first estimates for parameters which are difficult to obtain.

Cross validation (estimate total spring discharge around the lake) Page 130 Darling. Totaling all the measured spring discharges gives 159 litres per sec, which is the same as 5 mcm per year. This does not give us any close approximation of groundwater inflow as calculated above suggesting that, some springs could be seeping from the bottom of the lake.

7.8.4 ESTIMATION OF PRECIPITATION

The precipitation term was calculated from the mean annual rainfall value of 427 mm and the lakes surface area of 164 km^2 to obtain an annual estimate figure of 70 mcm representing direct rainfall into the lake.

7.8.5 ESTIMATION OF ABSTRACTION

Through evaporation from the surface the lake waters are concentrated and their solutes contribute to the main lake deposit. In the water balance of Magadi the residual that accounts to 4 mcm represents the amounts of water being accumulated as deposit. Interestingly, estimate of about 200,000 tons of trona (Mason and Theuri 1980) are commercially consumed annually, which is far less than what is accumulating. (Bradley and Eugster 1969) estimated an average rate of deposition to about 5 mm per year which is in good agreement with the rates for the Green River formation

7.9 SUMMARY OF WATER BALANCE CALCULATIONS

The monthly water budget terms of the four rift valley lakes can be summarized with annual values for the historical periods as shown in Table 7.3.

Units are in million cubic meters (mcm) per year. However, some uncertainty will always remain in evaporation and all other terms of the budget.

Hydrologic Budget Item	LAKE			
	Nakuru	Elementeita	Naivasha	Magadi
INFLOW				
Precipitation	31.8	16.4	96.5	70
Stream inflow	16.6	11	223	
Groundwater inflow	**24***	**15.7***		**69**
Total Inflow Components	72.4	43.1	319.5	139
OUTFLOW				
Lake evaporation	72.1	36	271	135
Groundwater outflow			**55****	
Abstraction		4.1***		4****
Total Outflow Components	72.1	40.1	326	139

* includes ungaged stream flow and inflow from springs.

** includes abstraction

*** the difference can be explained by change in storage.

**** represents water accumulated as deposits.

Table 7.3 Summary of the mean annual water balance of the four rift valley lakes

7.9.1 LAKE NAIVASHA

The hydrologic balance of the lake indicates that at least 55 mcm per annum infiltrates to the groundwater reservoir. The minimum supply to the lake is estimated to be 223 mcm and 97 mcm from direct precipitation. The total supply is 320 mcm, of which 271 mcm is consumed by evaporation. It is apparent that the lake is very dependent on stream inflow to maintain its level despite decline in the lake level for the past decade.

7.9.2 LAKE NAKURU

Direct rainfall into the lake is estimated to be around 32 mcm per annum. Stream flow alone appears to be inadequate to maintain lake level as it is for the case of Lake Naivasha. Stream flow and precipitation amounts to only 48 mcm. Evaporation of 72 mcm would therefore require a contribution of about 24 mcm to maintain a constant water level.

7.9.3 LAKE ELEMENTEITA

Direct rainfall into the lake is estimated to be around 16 mcm per annum and measured stream flow about 11 mcm per annum. Because the lake is closed an additional inflow of about 15.7 mcm is required to balance the annual evaporation flux of 35 mcm. This is obtained as groundwater inflow including "unmeasured surface inflow".

7.9.4 LAKE MAGADI

Penman evaporation value of 2400 mm per year for Magadi area has been used to obtain a relatively crude approximation for mean evaporation rate from the lake of 135 mcm per year. Under the assumption that this represents discharge of water from the regional groundwater system, the groundwater inflow into the lake is calculated as 69 mcm per annum.

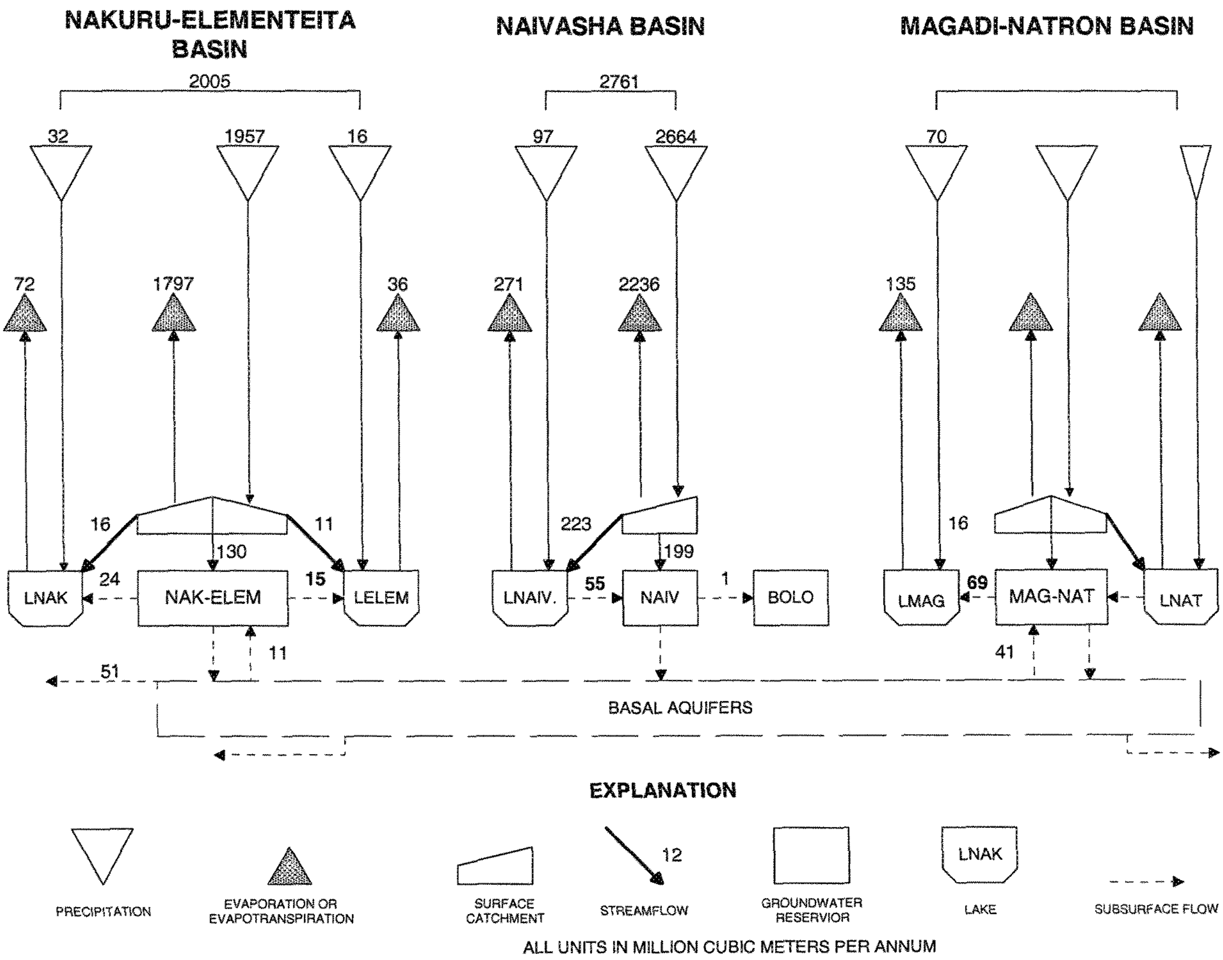


Figure 7 Hydrologic flow diagram of the southern rift valley basins (adopted from McCann 1972)

Chapter 8 Regional water balance

8.1 INTRODUCTION

The main objective of the study is to establish whether Lakes Magadi, Elementeita and Nakuru are gaining or losing groundwater and established if this could account for the 50 mcm lost annually by Lake Naivasha. To achieve this goal regional water balance is imperative. In this chapter we tackle water balance on the basis of catchments to provide a conceptual framework within which an understanding of Lake Water Balance may be achieved.

8.2 WATER BALANCE EQUATIONS

Under natural conditions (i.e. no pumping) a long term average balance for a drainage basin (catchment area) is defined by surface divides and extending to a depth where groundwater flow is negligible and can be written as:

$$P + G_{in} = G_{out} + ET + Q \pm \Delta S$$

Where P = Precipitation

G_{in} = Subsurface inflow (water entering the basin as groundwater)

G_{out}= Subsurface outflow (water leaving the basin as groundwater)

ET = Evapotranspiration and evaporation

Q = Stream flow leaving the basin

ΔS = Change in groundwater storage.

Where all quantities are long-term averages values the storage changes are assumed to be zero. On assumption that the long term averages for P, Q and ET are well known the equation can be expressed as follows:

$$\Delta S = G_{out} + G_{in} = P - ET - Q$$

8.3 WATER BALANCE OF LAKE NAIVASHA CATCHMENT

The total mean annual water supply to the catchment is 2761 mcm, which is derived entirely from precipitation (Table 8.1). Evaporation and evapotranspiration losses total 2507 mcm, leaving a residual of 254 mcm available for groundwater recharge which represents about 9.2% of total precipitation

Groundwater leaving the catchment to the Nakuru-Elementeita catchtment, within aquifers penetrated by most wells, has been estimated to be about 11 mcm, as discussed in Chapter 4. Underflow to Lake Ol Bolossat catchment area has been estimated to be 1 mcm. The total subsurface outflow is about 53 mcm leaving a much larger portion of 201 mcm of recoverable water available for groundwater recharge to deeper basal aquifers where it migrates north and southward.

8.4 WATER BALANCE OF LAKE NAKURU-ELEMENTEITA CATCHMENT

The two catchments have been merged due to the fact that they have internal drainage and therefore it's of no advantage in treating them as separate systems. The total area of the combined catchments is 2119 km^2. The total supply from precipitation amounts to 2005 mcm per annum, including 48 mcm for the lake area. Evaporation and evapotranspiration losses within the catchments amount to about 1908 mcm, leaving a residual of 97 mcm available for groundwater recharge. Subsurface ouflow northward to Lake Solai Catchment is estimated to be about 51 mcm(McCann 1972). The residual recharge of 46 mcm and 11 mcm subsurface inflow from Naivasha catchment appears available for groundwater recharge to the deeper aquifers. Recoverable water or groundwater recharge is estimated to be (57/2005) i.e.2.8% of the annual precipitation.

8.5 WATER BALANCE OF LAKE MAGADI-NATRON CATCHMENT

The total area of the combined two catchments is 23207 km^2 . The mean annual catchment precipitation is 749 mm which implies that the total supply from the precipitation is 17405 mcm/yr. Taking also the mean evapotranspiration rate of 2400 mm the total evapotranspiration has been estimated to amount to 55696 mcm/yr though this is an overestimate taking into account low evaporation flux cause by salinity and encrusted surfaces of the lakes. The residual of 38291 mcm accounts for subsurface inflow.

	LAKE		
Hydrologic Budget Item	Nakuru Elementeita	Naivasha	Magadi Natron
INFLOW			
Precipitation	2005	2761	17405
Subsurface inflow	39		38291
Total Inflow Components	2044	2761	55696
OUTFLOW			
Evapotranspiration	1804	2270	55696**
Lake evaporation	104	237	
Subsurface outflow	136	254	
Total Outflow Components	2044	2761	55696

**Overestimated Including lake evaporation.

Table 8.1 Waterbalance of the rift catchments

Chapter 9 Conclusions and recommendations

9.1 DISCUSSIONS AND CONCLUSIONS

The study attempts to improve the knowledge of the groundwater flow north and south of Lake Naivasha. The basic questions was whether the lakes are losing or gaining and if so from where and how much. Three approaches namely waterbalance, hydrological and isotopic approaches were adopted to meet the objective but it was found imperative to first develop a conceptual model of the entire region. Basing on the conceptual model and the fact that lake Naivasha is located on the culmination of the rift, the flow is expected to the south towards lake Magadi and to north towards lake Elementeita and Nakuru. Lake water balance model using spreadsheet has been used to simulate lake levels and subsequently obtained unknown term in the water balance, which in this case is groundwater

From the water balance model indicated that at least 15 mcm and 24 mcm per annum of groundwater inflow is required to maintain the levels in Lake Elementeita and Nakuru respectively. The values for groundwater inflow for Elementeita and Nakuru are in reasonable agreement with the independent estimates made on the basis of hydrological balance approach by McCann, 1974 and waterbalance model (MODFLOW) results obtained by Githae, 1998, however slight differences could be attributed to ungaged flow which was not accounted for in the model because of no data and no good estimation method could be devised.

The sensitivity analyses were performed on the variable input parameters. The most sensitive parameters to lake levels recorded were evaporation followed by rainfall and groundwater inflow. The results indicated that increase in rainfall has immediate effect on the lake levels but the offsets introduce is not retained. The results also indicated that even limited reduction of evaporation results in significant increase in lake levels. In a way it indicates how evaporation plays a big role in the lake level fluctuation and hence groundwater flow.

Due to lack of lake level and bathymetric data for Magadi and by virtue of the fact that the lake is covered by trona it proved difficult to apply the same modeling approach. However, using rather crude method, the lake was partitioned according to the different surface characteristic and the evaporation flux over the surfaces were estimated taking into account reduction in the evaporation rate by saline water and salt crusted formation. A figure of about 135 mcm per annum was obtained, close to Stevens et al, 1932 estimate of 1.06 cm per day. Further, basing on the assumption that evaporation from the lake surface in period of no surface inflow represents groundwater inflow, it was possible to estimate the annual groundwater influx to the lake. The value of approximately 69 mcm was subsequently obtained.

Examination of water borehole records shows that the piezometric surface is a replica of the topography. The subsurface flow occurs axially along the rift as if to follow the rift geometry, and laterally from the escarpments the recharge areas to the rift floor where the lakes are located.

Applying Darcy's law on the sparse data, the subsurface flow to the south of Naivasha has been estimated to be in the range of 41 to 290 mcm/yr much of which flows in a shallow aquifer (<500 m). The higher value agrees reasonably well with McCann's estimate of 250 mcm from waterbalance which implies that about 20% is contribution from Lake Naivasha. This would also imply that less than 5% of this total would flow north and only 5% would flow at depth to the south. If the lower estimate of 41 is taken then the total estimated recharge value of 55 mcm virtually all of which could be lake recharge. Considering the lower value the northerly flow would account for about 20% of the flow from the catchment and then the southerly flow around 25% would be at significant depths.

Only 11 mcm flows towards Lake Elementeita basin i.e. approximately 20% of Naivasha average groundwater discharge. It would take some 1.4 million years for the subsurface flow to travel to Magadi and possibly emerge as a spring and on the other hand it would take 2600 years approximately to travel to Lake Elementeita. These travel times are likely to be considerably less with increased hydraulic conductivity as a result of induced temperature from geothermal fields. The age determination of these waters would help to verify these figures. It should be noted that Lake Naivasha last dried up in mid 1850s, hardly two millennium years ago for its influence to be felt today by Lake Elementeita. But this is just a matter of speculation.

Groundwater isotope provided useful information though more in a qualitative sense supporting the hypothesis that larger proportion of lake water flows more to the south than to the north. However, it was not possible to trace lakewater south of Suswa due to lack of existing boreholes. Besides, sparse data, it would still be rather difficult to trace lake water using environmental isotope due to eminent dilution as portrayed by samples around Lake Naivasha.

The majority of surface and groundwater bodies in Magadi area plot on or very close to the Local Meteoric Water line (LMWL). Thus, the isotopic signature of the springs in particular displays shallow water origin. This implies fast infiltration before considerable evaporation has taken place. Further, basing on the fact that the hot spring water does not exhibit significant $\delta^{18}O$ shift, it's enough to suggest that its water is of a local origin. This discredits the fact that Lake Naivasha groundflow ever reaches Lake Magadi. Although isotope does not provide supporting evidence, it does not rule out the possibility of groundwater flow further south. This could suggest a possible deeper regional flow system, which in a way bypasses the Magadi-Natron reservoir. A more detailed water balance of the Magadi-Natron catchment would be desirable to elucidate on this phenomenon.

Notwithstanding all the assumptions and the simplifications made the following conclusions were drawn

1. Lakes Elementeita, Nakuru and Magadi gain groundwater discharge in their water balances by 15,24 and 65 mcm per annum from their groundwater reservoirs respectively. From these estimates, 11 and 41 mcm subsurface outflow to Elementeita and Magadi from Lake Naivasha catchment can plausibly be said to be gained from the contribution from Lake Naivasha. For

Lake Elementeita isotope has provided clear evidence supporting our observation of Lake Naivasha water contribution. However, there is still little evidence to suggest that at least, of the 41 mcm a portion ever reaches Magadi in an identifiable form.

2. The flow from Lake Naivasha is directed more to the south than to the north this is supported by the proportion of groundwater deficit of the neighbouring lakes though not conclusive, further its supported by groundwater level as manifested on the piezometry and isotopic evidence.

3. The geology of the rift valley is complex and therefore aquifer is not well understood, it could take so many years for lakewater to reach Magadi and if not the case there is all the reason to believe that there is conductive cell or fracture that transmit water through regional flow system to the south bypassing the Magadi Natron sector.

4. Both water balance and isotope analyses together with hydrologic approaches had limitations, but the multiple lines of evidence gained using these approaches improved the understanding of the role of groundwater in the water budget of the lakes and how they are linked to regional flow system.

9.2 RECOMMENDATION

In calculating the model inputs, many assumptions and generalization had to be made this can be avoided if reliable data is available.

Estimates of groundwater recharge, subsurface inflow and outflow rely on the hydrologic balance of precipitation and evapotranspiration because of the complex and generally unknown subsurface geologic conditions. In view of this, it is strongly recommended that emphasis be placed on generating and collecting good quality data

Use of remote sensing is valuable in accurate estimation of evaporation and would be more useful in a situation like of Magadi, so its adoption in future studies would be very crucial.

Establishing a common zero datum for all gauges operating on the lakes would help to avoid the inconsistency of gauge readings and therefore contribute to the reliability of the water level and hence water balance.

There is need for more comprehensive studies on regional groundwater flow across national borders to help understand the fate of water from Lake Naivasha and perhaps needs for more systematic groundwater tracing.

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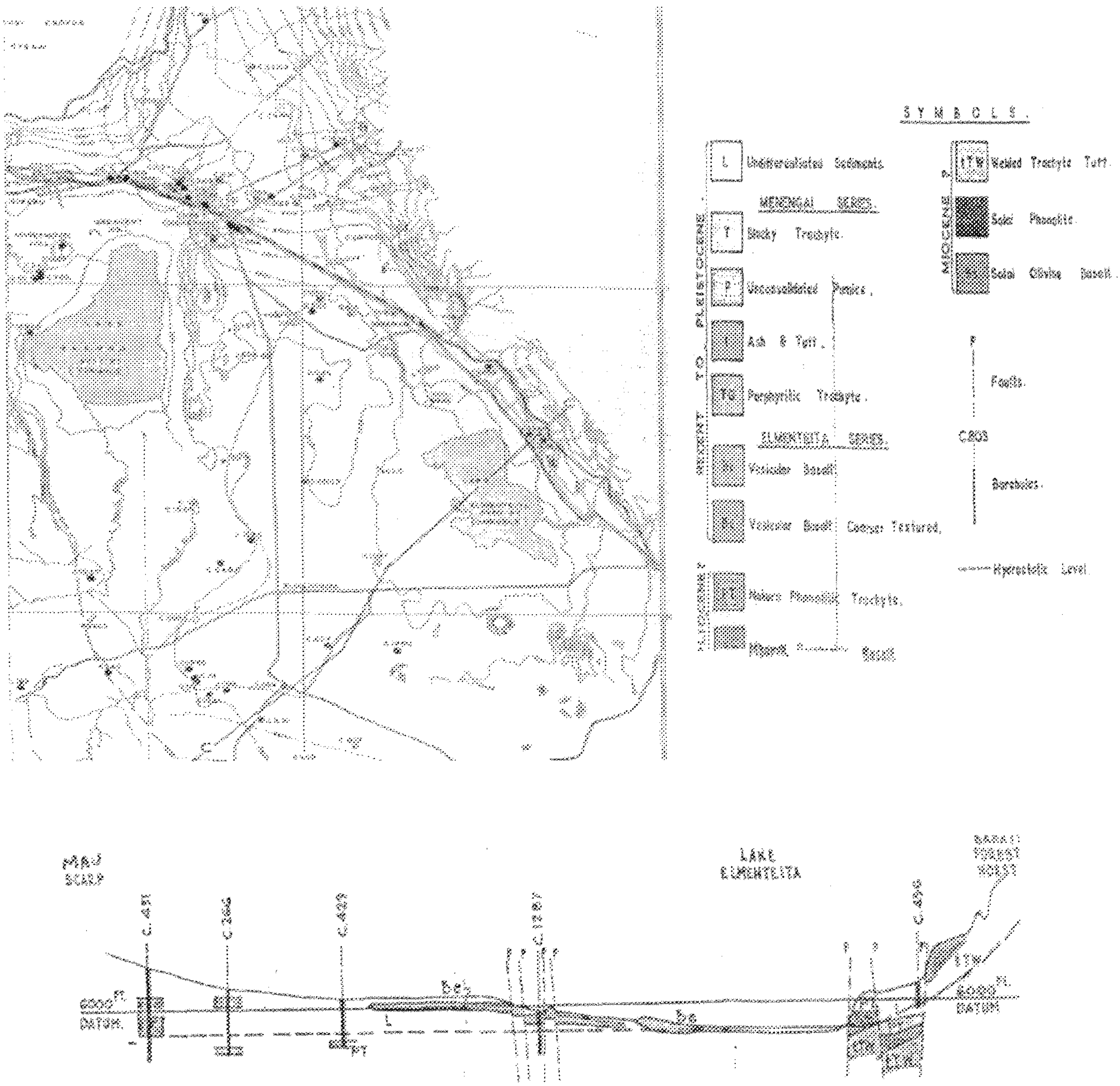
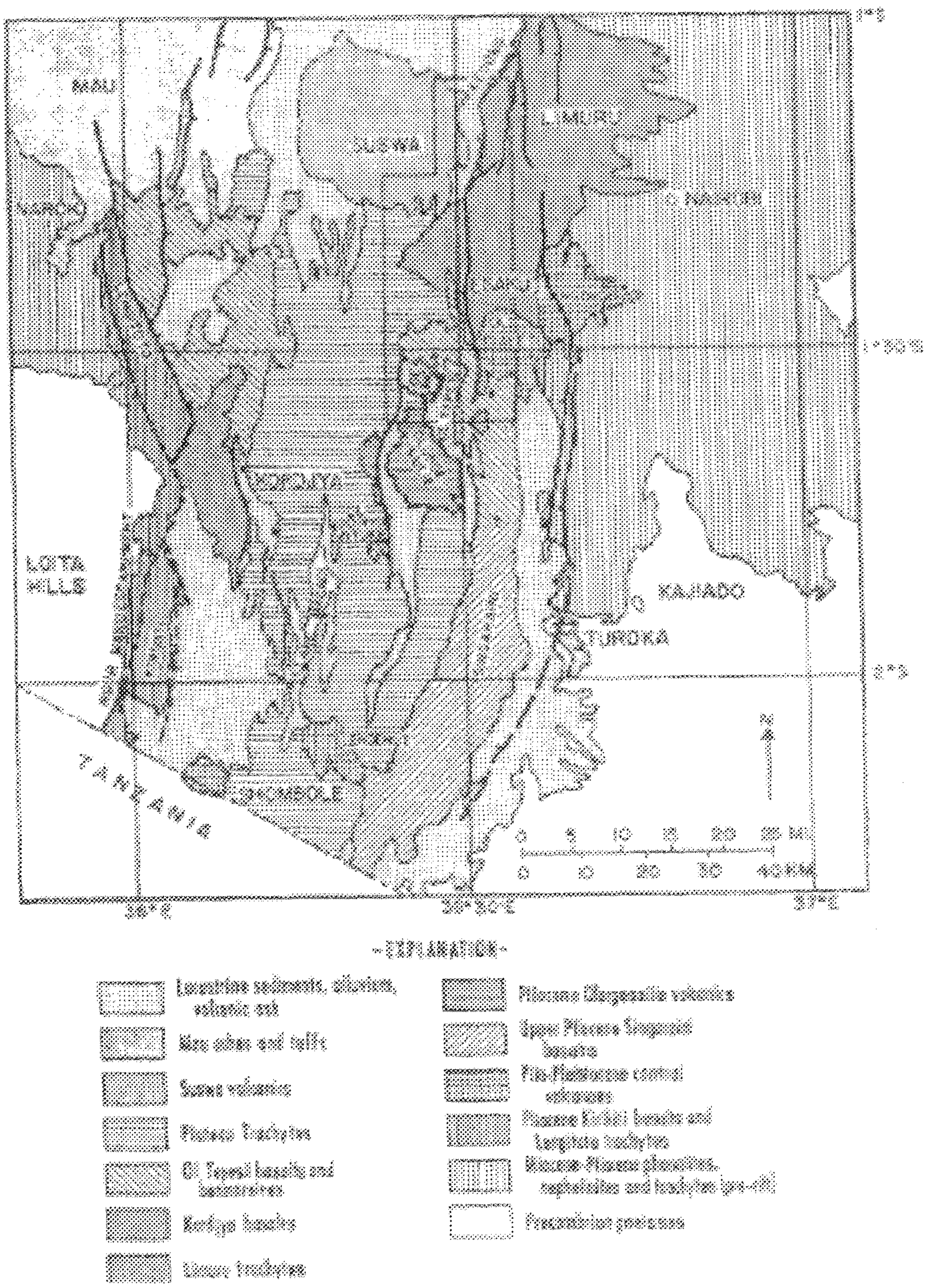
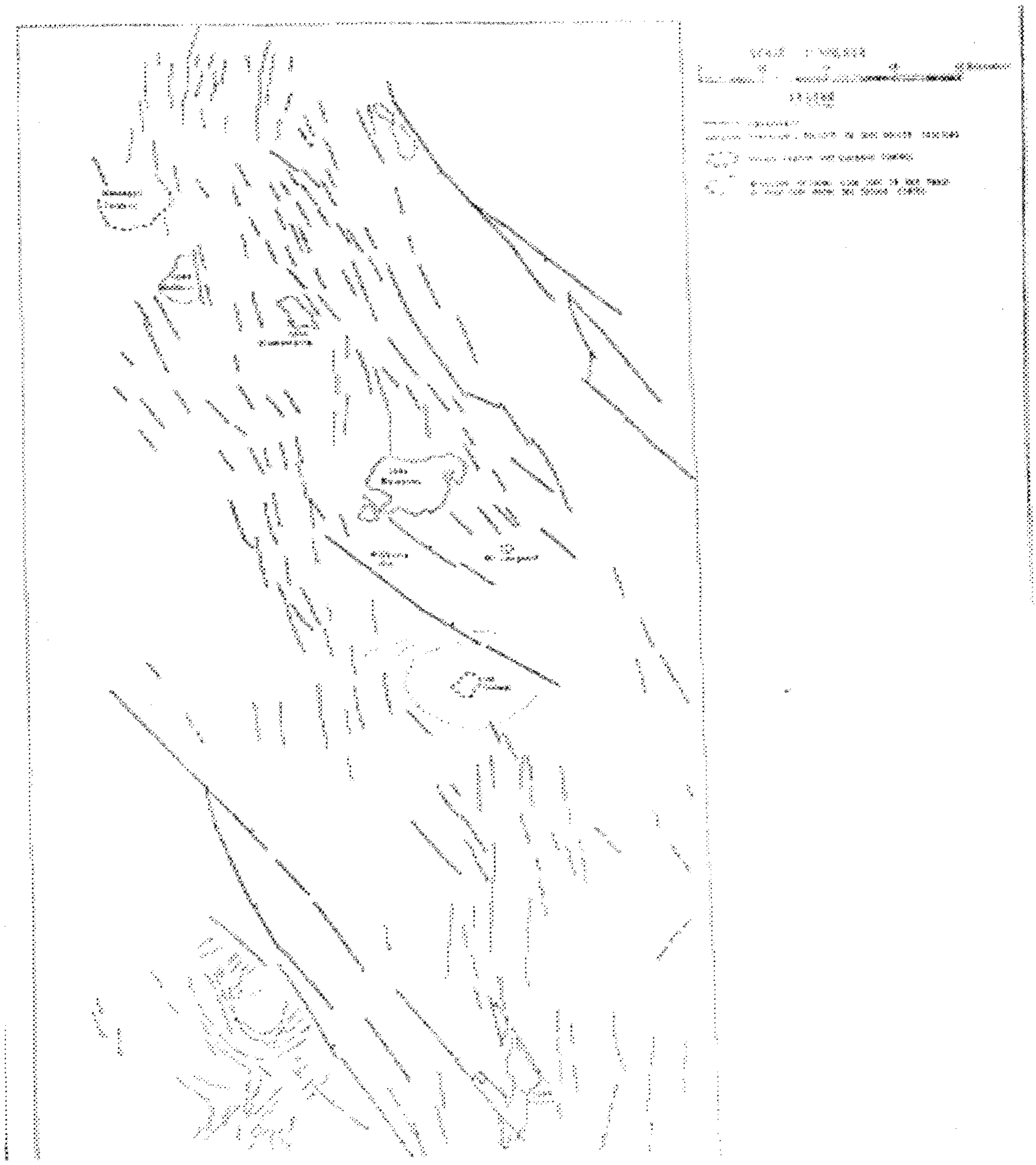
APPENDICES



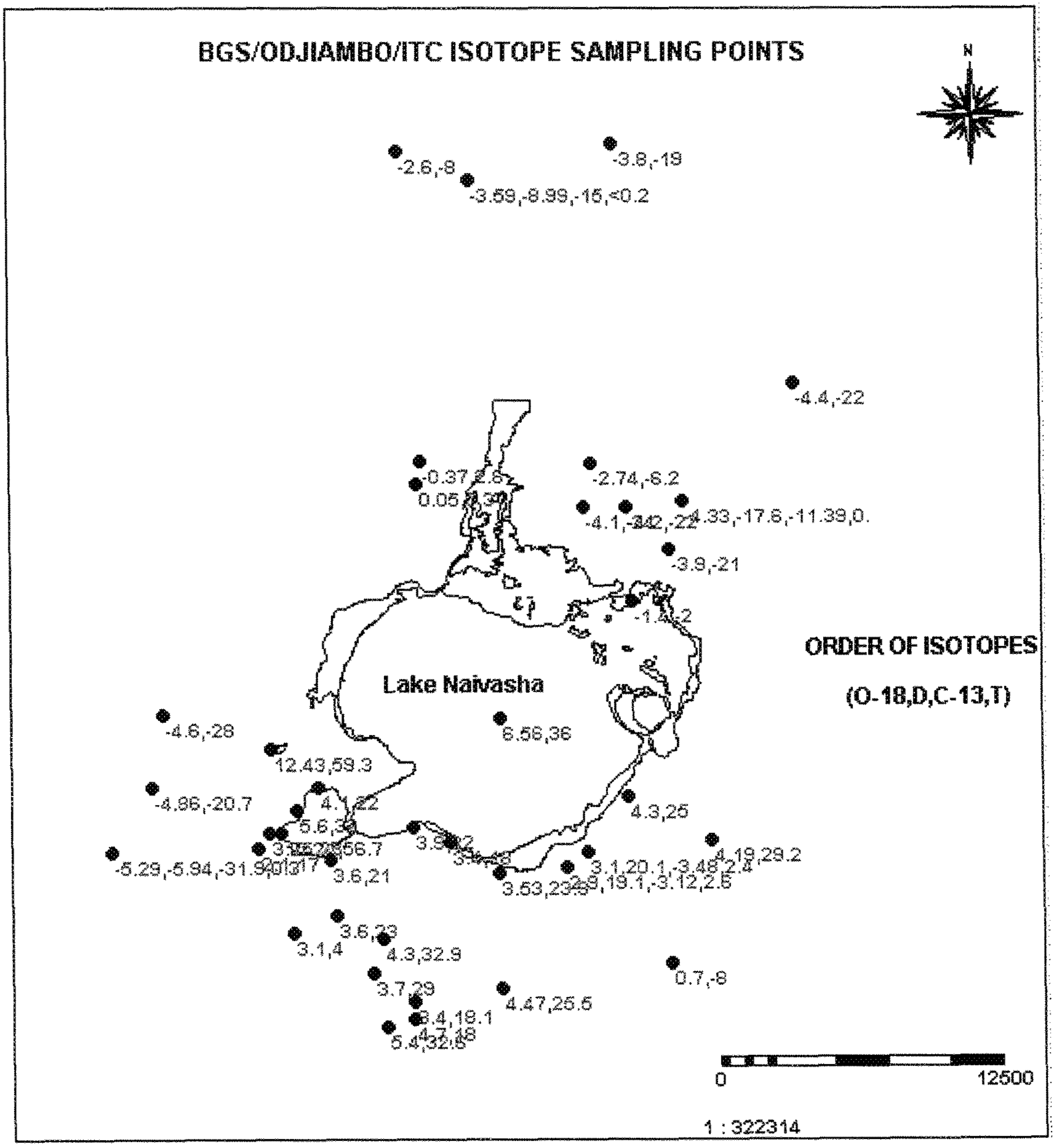
APPENDIX A-1:Geological section illustrating groundwater condition in Elementeita area



APPENDIX A-2: Geological map of the southern part of the Kenya rift valley



APPENDIX A-3: A simplified plot of lineaments and structures from LANDSAT imagery over the southern part of the Kenyan Rift Valley(By Odongo)



APPENDIX B-1: Map showing the contribution of Lake Naivasha to other waters around the lake. High dilution rate around the lake is quite evident (Source: Richard Boateng 2001)

APPENDIX C-PIEZOZOMETRIC DATA (elevation is in meters above sea level)

BHNO	EAST	SOUTH	ELEVATION
C703	231027	9909661	2611
C1551	227317	9905971	2517
C1503	223606	9904125	2008
C264	225462	9904126	2301
C1425D	221751	9902280	1884
C1161	223607	9902281	1980
C1726	221752	9900436	1849
C2172	231034	9898599	2260
C2138	231034	9898599	2267
C1524	199481	9894888	1823
P53	225469	9894908	1699
ITC001	213518	9924527	1881
ITC002	213735	9925528	1885
ITC003	213713	9924977	1886
ITC004	213459	9924929	1882
ITC007	214004	9925600	1884
ITC008	213544	9925720	1884
ITC009	211437	9921386	1886
ITC010	211914	9924455	1884
ITC011	213101	9928951	1887
ITC012	214504	9926572	1913
ITC013	212603	9923764	1883
ITC015	210473	9928944	1867
ITC020	211231	9924924	1881
ITC021	211822	9923166	1880
ITC022	212334	9922728	1885
ITC025	212267	9923041	1883
ITC026	208752	9928952	1886
ITC029	204034	9928849	1886
ITC031	211769	9924324	1882
ITC033	202866	9922388	1896
ITC035	215467	9917087	1903
ITC036	214224	9919179	1886
ITC038	203516	9924230	1886
ITC040	201591	9926461	1885
ITC042	207165	9925364	1886
ITC043	210769	9920726	1887
ITC045	209462	9928455	1889
ITC047	208988	9937384	1934
ITC048	212459	9931771	1958
ITC052	214316	9917024	1883
ITC054	197600	9929926	2333
ITC055	214375	9916225	1889
ITC056	213900	9916550	1882
ITC057	216171	9926241	2037
ITC058	218032	9922558	1999
ITC059	216171	9924404	2006
ITC060	216175	9918873	1984
ITC063	210602	9924401	1883
ITC066	199466	9920700	1877
ITC070	195752	9928078	2523
ITC071	205035	9920703	1884
ITC072	197605	9920698	1886
ITC073	199465	9922547	1903
ITC077	208741	9926237	1887
ITC080	212469	9913339	1877
ITC081	195762	9911480	1886
ITC082	206306	9931350	1886

BHNO	EAST	SOUTH	ELEVATION
ITC130	214317	9915176	1908
ITC134	210610	9911490	1920
ITC136	219659	9902553	1872
ITC140	213885	9912005	1884
ITC141	194855	9909913	1898
ITC144	213038	9914522	1891
ITC145	212664	9915091	1887
ITC146	212469	9926230	1914
ITC147	213850	9921800	1885
ITC149	217150	9918100	1929
ITC151	212675	9918025	1879
ITC152	201200	9910050	1909
ITC153	218100	9930525	2165
ITC154	211200	9912475	1886
ITC156	214009	9917763	1888
ITC158	202435	9909675	1890
ITC159	195974	9908951	1887
ITC160	196851	9915861	1888
ITC161	197660	9918954	1888
ITC162	215784	9912357	1884
ITC180	203360	9925256	1886
ITC183	208323	9931189	1884
ITC185	194375	9919316	1885
N12	215200	9913100	1907
N52	219411	9926765	2064
N54	219848	9929261	2168
N40	216441	9913361	1910
C2709	186474	9907789	2114
C0466	190189	9917009	1907
C1404	190190	9915161	1894
C2300	190500	9909750	1914
V301	193940	9902400	1774
C2557	195300	9912500	1892
EW1	196900	9930575	1852
C2586	198500	9905140	1842
V26	200130	9902275	1594
C733	202750	9940250	1819
ITC_ked1	214204	9907097	1904
ITC_ked2	208867	9909074	1883
ITC_sher	207857	9908376	1884
ITC_Heart	214281	9909564	1885
ITC_BH2	211323	9922533	1877
ITC186	194608	9918650	1885
C-1404	190188	9915164	2024
C-1798	180882	9940985	1901
C-1877	186454	9937292	1881
C-1924	208726	9957593	2154
C-1941	180882	9940985	1893
C-1947	216173	9918875	2075
C-1951	212447	9955747	2080
C-1952	212447	9957594	2064
C-2118	193876	9959425	1992
C-2160	221725	9957597	2479
C-2176	236589	9915192	2526
C-2234	190176	9935457	2003
C-2246	210600	9924403	2064
C-2269	180873	9966802	1822
C-2289	177175	9935451	2050
C-2304	197606	9917016	2063
C-2332	195734	9970491	2032

BHNO	EAST	SOUTH	ELEVATION
C-2402	180872	9968650	1867
C-2430	212464	9918873	2079
C-2493	188304	9964956	1921
C-2504	186443	9968652	1919
C-2522	193895	9918862	2044
C-2536	203173	9920704	2062
C-2537	205033	9920705	2069
C-2539	203173	9920704	2062
C-2600	192025	9935458	1918
C-2703	205033	9920705	2069
C-2705	197603	9920701	2069
C-2709	186472	9907792	2097
C-2813	197603	9920701	2045
C-2851	179035	9935451	1901
C-2883	212458	9929936	2024
C-3024	180891	9924386	2380
C-3047	179023	9966802	1778
C-3136	193878	9955741	1851
C-3164	182751	9924388	2421
C-3324	169732	9961266	1714
C-3327	166034	9933596	2759
C-3397	166035	9931748	2757
C-3431	179038	9929918	2185
C-3551	210601	9922556	2074
C-3932	180892	9922538	2299
C-3965	186442	9970488	1973
C-4155	214309	9926242	2056
C-4161	212462	9922557	2066
C-4168	212459	9928088	2062
C-4177	210599	9928088	2059
C-4178	208740	9924402	2058
C-4209	212465	9920707	2082
C-4301	212459	9928088	2043
C-4369	181650	9971650	1979
C-4491	187100	9969300	2015
C-4500	195763	9907798	2103
C-4511	181800	9971250	1977
C-4591	195700	9915200	2480
C-4924	181450	9966500	1746
C-4986	210610	9907808	2074
C-5111	188150	9965050	1903
C-5143	179022	9970487	1956

Altitude(m)	Rainfall(mm)	$\delta^{18}O(^0/_{00})$	$\delta D(^0/_{00})$
600	16.3	-7	0.8
	2.6	22	5.4
600	8.4	-8	-0.3
	11	-14	-2.1
1000	3.2	12	1.7
1800		-10	-3.2
		-64	-10.2
1900	14.3	5	-0.2
	6.6	-30	-6.8
2760	21.5	-47	-9
	22.2	-18	-4.8
2200	8.4	-39	-5.8
	7.6	-36	-5.6
2550	8.8	-4	-2.3
	49	-23	-4.9
1920	22.2	-7	-4.2
	16.1	-39	-6.4
2000	4.2	-3	-0.3
	34.7	-53	-8.2
1850	2	-4	-1.4
	11	-5	-1.3
2340	13.7	-14	-3.9
	18.4	-41	-7.2
2100	23.3	0	-2
		3	-1.9
1150	10.7	2	0.9
	39.7	-11	-0.9
1550	8	-20	-5.5
	25	-5	0.7
1000	17	-19	-4.2
	19.2	-5	-2.8
2050	10.1	-4	-1.8
	16.8	-47	-8.1
900	16.1	-1	0.1
	5.4	0	-0.4
2000	4.4	-31	-4.4
	10.2	-16	-2.4
880	32.3	-7	-2.2
	23.3	-1	-1.8
550	28.9	19	1.9
	33.4	-21	-4.6

APPENDIX D-1:Isotope Dataset: Oxygen-18 and Deuterium of rain samples.
Source: British Geological Survey Report (Darling et al., 1990)

Site No	Temp	δD(‰)	$\delta^{18}O$(‰)
1	84.6	-4	-1.2
2	80.7	-4	-1
3	85.3	-6	-0.9
4	81.3	-4	-0.5
5	78.6	-7	-1.1
6	72.4	-6	-1.1
7	82	-6	-1.2
8	82.6	-5	-1.2
9	45	-17	-3.1
10	43.5	-20	-3.2
11	66.6	-7	-1
12	60.2	-4	-6
13	39.5	-16	-2.4
14	38.5	-16	-2.5
15	34	-16	-1.3
17	40.5	-15	-2.5
18	45.3	-23	-2.5
19	0	-17	10.4
20	25.7	-6	-1.5
21	21.5	-22	-4.2
22	0	-25	-4.2
23	0	-23	0.5

APPENDIX D-2:Isotope Dataset for samples collected from the Magadi springs (Darling et al, 1990)

Site	Location	δD(‰)	$\delta^{18}O$(‰)
IS10	Elementeita Surface	0.88	-1.14
IS11	Magadi	18.48	1.06
IS17	Magadi	-1.04	-1.38
IS18	Magadi	1.68	-1.04
IS31	Elementeita Sediment pore	15.68	0.71

APPENDIX D-3:Isotope Dataset collected from spring (ITC fieldwork 2001)

Site and Type	δD(‰)	$\delta^{18}O$(‰)
Oltepesi(borehole)	-25	-4.2
Ewaso Ngiro(river)	-6	-1.5
Lake Naivasha	36	6.6
Elemementeita(spring)	-9.6	-1.5

APPENDIX D-4: Isotope dataset collected from various locations (Darling et al, 1990)

	NAKURU	NAIVASHA		NAKURU	NAIVASHA		NAKURU	NAIVASHA
May-30	1757.95		May-35	1757.00	1788.50	Mar-40	1757.00	1787.26
Jun-30	1757.97		Jun-35	1757.00	1788.44	Apr-40	1757.00	1787.47
Jul-30	1758.02		Jul-35	1757.00	1788.38	May-40	1757.00	1787.38
Aug-30	1758.05		Aug-35	1757.00	1788.32	Jun-40	1757.00	1787.25
Sep-30	1758.03		Sep-35	1757.00	1788.28	Jul-40	1757.00	1787.14
Oct-30	1758.00		Oct-35	1757.00	1788.25	Aug-40	1757.00	1786.99
Nov-30	1758.00		Nov-35	1757.00	1788.21	Sep-40	1757.00	1786.79
Dec-30	1757.92		Dec-35	1757.00	1788.19	Oct-40	1757.00	1786.69
Jan-31	1757.87		Jan-36	1757.00	1788.18	Nov-40	1757.00	1786.56
Feb-31	1757.70		Feb-36	1757.00	1788.18	Dec-40	1757.00	1786.43
Mar-31	1757.70		Mar-36	1757.00	1788.27	Jan-41	1757.00	1786.64
Apr-31	1757.72		Apr-36	1757.00	1788.67	Feb-41	1757.00	1786.89
May-31	1757.74		May-36	1757.00	1788.75	Mar-41	1757.00	1786.88
Jun-31	1757.72		Jun-36	1757.00	1788.74	Apr-41	1757.00	1786.83
Aug-31	1757.69		Jul-36	1757.00	1788.73	May-41	1757.00	1786.82
Sep-31	1757.62		Aug-36	1757.00	1788.69	Jun-41	1757.00	1786.79
Nov-31	1757.35		Sep-36	1757.00	1788.65	Jul-41	1757.00	1786.75
Dec-31	1757.38		Oct-36	1757.00	1788.60	Aug-41	1757.00	1786.71
Jan-32	1757.17	1790.98	Nov-36	1757.00	1788.51	Sep-41	1757.00	1786.66
Feb-32	1757.00	1790.98	Dec-36	1757.00	1788.42	Oct-41	1757.00	1786.60
Mar-32	1757.00	1790.98	Jan-37	1757.00	1788.31	Nov-41	1757.00	1786.55
Apr-32	1757.00	1790.98	Feb-37	1757.00	1788.15	Dec-41	1757.00	1786.50
May-32	1757.00	1790.98	Mar-37	1757.00	1788.31	Jan-42	1757.00	1786.54
Jun-32	1757.00	1790.89	Apr-37	1757.00	1788.79	Feb-42	1757.00	1786.78
Jul-32	1757.00	1790.86	May-37	1757.00	1789.15	Mar-42	1757.00	1787.03
Aug-32	1757.00	1790.83	Jun-37	1757.00	1789.55	Apr-42	1757.00	1787.26
Sep-32	1757.00	1790.86	Jul-37	1757.00	1789.95	May-42	1757.00	1787.16
Oct-32	1757.00	1790.83	Aug-37	1757.00	1789.91	Jun-42	1757.00	1787.20
Nov-32	1757.00	1790.77	Sep-37	1757.00	1789.78	Jul-42	1757.00	1787.07
Dec-32	1757.00	1790.67	Oct-37	1757.00	1789.80	Aug-42	1757.00	1786.87
Jan-33	1757.00	1790.55	Nov-37	1757.00	1789.81	Sep-42	1757.00	1786.70
Feb-33	1757.00	1790.49	Dec-37	1757.00	1789.70	Oct-42	1757.00	1786.63
Mar-33	1757.00	1790.37	Jan-38	1757.00	1789.57	Nov-42	1757.00	1786.56
Apr-33	1757.00	1790.22	Feb-38	1757.00	1789.46	Dec-42	1757.00	1786.47
May-33	1757.00	1790.16	Mar-38	1757.00	1789.34	Jan-43	1757.00	1786.34
Jun-33	1757.00	1790.06	Apr-38	1757.00	1789.24	Feb-43	1757.00	1786.24
Jul-33	1757.00	1790.06	May-38	1757.00	1789.14	Mar-43	1757.00	1786.17
Aug-33	1757.00	1790.06	Jun-38	1757.00	1789.04	Apr-43	1757.00	1786.09
Sep-33	1757.00	1790.06	Jul-38	1757.00	1788.96	May-43	1757.00	1786.12
Oct-33	1757.00	1790.06	Aug-38	1757.00	1788.92	Jun-43	1757.00	1786.15
Nov-33	1757.00	1790.10	Sep-38	1757.00	1788.88	Jul-43	1757.00	1786.12
Dec-33	1757.00	1790.10	Oct-38	1757.00	1788.82	Aug-43	1757.00	1786.05
Jan-34	1757.00	1789.82	Nov-38	1757.00	1788.69	Sep-43	1757.00	1785.94
Feb-34	1757.00	1789.59	Dec-38	1757.00	1788.55	Oct-43	1757.00	1785.82
Mar-34	1757.00	1789.52	Jan-39	1757.00	1788.43	Nov-43	1757.00	1785.64
Apr-34	1757.00	1789.44	Feb-39	1757.00	1788.35	Dec-43	1757.00	1785.53
May-34	1757.00	1789.36	Mar-39	1757.00	1788.28	Jan-44	1757.00	1785.43
Jun-34	1757.00	1789.29	Apr-39	1757.00	1788.15	Feb-44	1757.00	1785.35
Jul-34	1757.00	1789.21	May-39	1757.00	1788.01	Mar-44	1757.00	1785.30
Aug-34	1757.00	1789.13	Jun-39	1757.00	1787.92	Apr-44	1757.00	1785.25
Sep-34	1757.00	1789.06	Jul-39	1757.00	1787.85	May-44	1757.00	1785.20
Oct-34	1757.00	1788.98	Aug-39	1757.00	1787.72	Jun-44	1757.00	1785.20
Nov-34	1757.00	1788.91	Sep-39	1757.00	1787.60	Jul-44	1757.00	1785.19
Dec-34	1757.00	1788.84	Oct-39	1757.00	1787.45	Aug-44	1757.00	1785.18
Jan-35	1757.00	1788.78	Nov-39	1757.00	1787.25	Sep-44	1757.00	1785.02
Feb-35	1757.00	1788.72	Dec-39	1757.00	1787.12	Oct-44	1757.00	1784.81
Mar-35	1757.00	1788.65	Jan-40	1757.00	1787.06	Nov-44	1757.00	1784.70
Apr-35	1757.00	1788.57	Feb-40	1757.00	1787.02	Dec-44	1757.00	1784.62

APPENDIX E-1: Observed lakes levels

	NAKURU	NAIVASHA		NAKURU	NAIVASHA		NAKURU	NAIVASHA
Jan-45	1757.00	1784.59	Nov-49	1757.00	1784.94	Oct-54	1757.50	1785.37
Feb-45	1757.00	1784.61	Dec-49	1757.00	1784.74	Nov-54	1757.42	1785.27
Mar-45	1757.00	1784.61	Jan-50	1757.00	1784.79	Dec-54	1757.36	1785.17
Apr-45	1757.00	1784.63	Feb-50	1757.00	1784.77	Jan-55	1757.24	1785.12
May-45	1757.00	1784.83	Mar-50	1757.00	1784.68	Feb-55	1757.14	1785.01
Jun-45	1757.00	1785.07	Apr-50	1757.00	1784.64	Mar-55	1757.01	1784.94
Jul-45	1757.00	1785.03	May-50	1757.00	1784.69	Apr-55	1757.00	1784.90
Aug-45	1757.00	1784.97	Jun-50	1757.00	1784.82	May-55	1757.00	1784.82
Sep-45	1757.00	1784.90	Jul-50	1757.00	1784.95	Jun-55	1757.00	1784.75
Oct-45	1757.00	1784.84	Aug-50	1757.04	1784.93	Jul-55	1757.00	1784.92
Nov-45	1757.00	1784.72	Sep-50	1757.04	1784.85	Aug-55	1757.02	1785.12
Dec-45	1757.00	1784.57	Oct-50	1757.01	1784.72	Sep-55	1757.07	1785.23
Jan-46	1757.00	1784.39	Nov-50	1757.00	1784.62	Oct-55	1757.19	1785.18
Feb-46	1757.00	1784.26	Dec-50	1757.00	1784.50	Nov-55	1757.16	1785.21
Mar-46	1757.00	1784.43	Jan-51	1757.00	1784.56	Dec-55	1757.09	1785.29
Apr-46	1757.00	1784.44	Feb-51	1757.00	1785.05	Jan-56	1757.07	1785.31
May-46	1757.00	1784.46	Mar-51	1757.00	1785.28	Feb-56	1757.06	1785.27
Jun-46	1757.00	1784.62	Apr-51	1757.30	1785.47	Mar-56	1757.00	1785.28
Jul-46	1757.00	1784.86	May-51	1757.43	1785.51	Apr-56	1757.01	1785.45
Aug-46	1757.00	1784.89	Jun-51	1757.32	1785.66	May-56	1757.07	1785.53
Sep-46	1757.00	1784.91	Jul-51	1757.50	1785.82	Jun-56	1757.12	1785.61
Oct-46	1757.00	1784.85	Aug-51	1757.56	1785.88	Jul-56	1757.23	1785.82
Nov-46	1757.00	1784.79	Sep-51	1757.53	1785.99	Aug-56	1757.76	1786.13
Dec-46	1757.00	1784.78	Oct-51	1757.40	1786.15	Sep-56	1758.05	1786.24
Jan-47	1757.00	1784.97	Nov-51	1757.70	1786.19	Oct-56	1758.04	1786.23
Feb-47	1757.00	1785.58	Dec-51	1758.01	1786.09	Nov-56	1758.04	1786.13
Mar-47	1757.00	1786.29	Jan-52	1758.09	1785.98	Dec-56	1758.05	1786.03
Apr-47	1757.00	1786.48	Feb-52	1758.00	1785.85	Jan-57	1757.88	1785.92
May-47	1757.00	1786.58	Mar-52	1757.90	1785.94	Feb-57	1757.85	1785.86
Jun-47	1757.00	1786.66	Apr-52	1757.73	1786.01	Mar-57	1757.73	1785.95
Jul-47	1757.00	1786.55	May-52	1757.80	1785.93	Apr-57	1757.71	1786.13
Aug-47	1757.00	1786.48	Jun-52	1757.78	1785.87	May-57	1757.91	1786.37
Sep-47	1757.00	1786.47	Jul-52	1757.68	1785.87	Jun-57	1758.00	1786.50
Oct-47	1757.00	1786.37	Aug-52	1757.61	1785.86	Jul-57	1758.06	1786.63
Nov-47	1757.00	1786.18	Sep-52	1757.57	1785.81	Aug-57	1758.17	1786.73
Dec-47	1757.00	1786.11	Oct-52	1757.49	1785.71	Sep-57	1758.18	1786.68
Jan-48	1757.00	1786.02	Nov-52	1757.36	1785.58	Oct-57	1758.11	1786.59
Feb-48	1757.00	1785.85	Dec-52	1757.00	1785.40	Nov-57	1758.01	1786.51
Mar-48	1757.00	1785.83	Jan-53	1757.00	1785.23	Dec-57	1758.00	1786.49
Apr-48	1757.00	1785.81	Feb-53	1757.00	1785.14			
May-48	1757.00	1785.88	Mar-53	1757.00	1785.08			
Jun-48	1757.00	1785.99	Apr-53	1757.00	1785.01			
Jul-48	1757.00	1786.04	May-53	1757.00	1784.99			
Aug-48	1757.00	1785.92	Jun-53	1757.00	1784.94			
Sep-48	1757.00	1785.85	Jul-53	1757.00	1784.84			
Oct-48	1757.00	1785.76	Aug-53	1757.00	1784.74			
Nov-48	1757.00	1785.63	Sep-53	1757.00	1784.70			
Dec-48	1757.00	1785.50	Oct-53	1757.00	1784.69			
Jan-49	1757.00	1785.39	Nov-53	1757.00	1784.58			
Feb-49	1757.00	1785.31	Dec-53	1757.00	1784.42			
Mar-49	1757.00	1785.27	Jan-54	1757.00	1784.25			
Apr-49	1757.00	1785.19	Feb-54	1757.00	1784.25			
May-49	1757.00	1785.19	Mar-54	1757.00	1784.50			
Jun-49	1757.00	1785.31	Apr-54	1757.00	1784.83			
Jul-49	1757.00	1785.34	May-54	1757.10	1785.19			
Aug-49	1757.00	1785.25	Jun-54	1757.27	1785.32			
Sep-49	1757.00	1785.16	Jul-54	1757.30	1785.42			
Oct-49	1757.00	1785.10	Aug-54	1757.36	1785.48			

APPENDIX E-2: Observed lakes levels

	NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA
Jan-58	1757.92	1775.81	1786.47	Nov-62	1758.76	1776.78	1788.59	Sep-67	1759.31	1776.57	1788.92
Feb-58	1757.91	1775.86	1786.46	Dec-62	1758.76	1776.79	1788.59	Oct-67	1758.83	1776.53	1788.94
Mar-58	1757.88	1775.81	1786.45	Jan-63	1758.73	1776.79	1788.52	Nov-67	1759.14	1776.58	1788.92
Apr-58	1757.79	1775.76	1786.53	Feb-63	1758.61	1776.76	1788.45	Dec-67	1759.19	1776.61	1788.89
May-58	1758.09	1775.89	1786.73	Mar-63	1758.57	1776.70	1788.40	Jan-68	1759.07	1776.53	1788.87
Jun-58	1758.08	1775.87	1787.07	Apr-63	1758.66	1776.70	1788.38	Feb-68	1759.02	1776.45	1788.81
Jul-58	1758.28	1776.06	1787.33	May-63	1759.07	1776.95	1788.59	Mar-68	1759.15	1776.56	1788.72
Aug-58	1758.37	1776.53	1787.40	Jun-63	1759.29	1777.10	1789.00	Apr-68	1759.58	1776.68	1788.59
Sep-58	1758.46	1776.38	1787.39	Jul-63	1759.26	1776.95	1789.36	May-68	1760.01	1776.94	1789.75
Oct-58	1758.47	1776.13	1787.36	Aug-63	1759.25	1776.80	1789.31	Jun-68	1760.02	1777.14	1789.80
Nov-58	1758.43	1776.12	1787.28	Sep-63	1759.29	1777.19	1789.19	Jul-68	1760.00	1777.18	1789.82
Dec-58	1758.41	1776.12	1787.25	Oct-63	1759.20	1777.22	1789.20	Aug-68	1760.05	1777.28	1789.75
Jan-59	1758.33	1776.09	1787.14	Nov-63	1759.13	1777.14	1789.12	Sep-68	1760.03	1777.27	1789.81
Feb-59	1758.23	1776.01	1787.02	Dec-63	1759.47	1777.25	1789.07	Oct-68	1759.95	1777.23	1789.79
Mar-59	1758.16	1775.90	1786.95	Jan-64	1759.55	1777.16	1789.43	Nov-68	1759.96	1777.25	1789.75
Apr-59	1758.10	1775.87	1786.88	Feb-64	1759.44	1777.22	1789.52	Dec-68	1760.14	1777.40	1789.75
May-59	1758.12	1775.90	1786.86	Mar-64	1759.37	1777.22	1789.39	Jan-69	1760.08	1777.33	1789.69
Jun-59	1758.15	1775.90	1786.85	Apr-64	1759.68	1777.31	1789.33	Feb-69	1760.05	1777.28	1789.61
Jul-59	1758.08	1775.89	1786.73	May-64	1759.86	1777.38	1789.52	Mar-69	1760.02	1777.29	1789.56
Aug-59	1758.08	1775.90	1786.73	Jun-64	1759.85	1777.36	1789.62	Apr-69	1760.02	1777.29	1789.48
Sep-59	1758.09	1775.90	1786.74	Jul-64	1759.95	1777.45	1789.61	May-69	1760.03	1777.30	1789.50
Oct-59	1758.02	1775.90	1786.72	Aug-64	1760.18	1777.50	1789.61	Jun-69	1759.99	1777.22	1789.45
Nov-59	1757.96	1775.93	1786.66	Sep-64	1760.36	1777.47	1789.72	Jul-69	1759.89	1777.16	1789.32
Dec-59	1757.93	1775.95	1786.63	Oct-64	1760.69	1777.88	1789.88	Aug-69	1759.87	1777.13	1789.12
Jan-60	1757.82	1775.87	1786.55	Nov-64	1760.68	1777.90	1790.07	Sep-69	1759.86	1777.23	1789.11
Feb-60	1757.74	1775.79	1786.25	Dec-64	1760.71	1777.90	1790.22	Oct-69	1759.76	1777.20	1789.01
Mar-60	1757.56	1775.70	1786.05	Jan-65	1760.63	1777.89	1790.16	Nov-69	1759.63	1776.90	1788.91
Apr-60	1757.55	1775.71	1785.99	Feb-65	1760.50	1777.79	1790.08	Dec-69	1759.62	1776.89	1788.86
May-60	1757.55	1775.69	1785.92	Mar-65	1760.38	1777.66	1790.01	Jan-70	1759.51	1776.85	1788.79
Jun-60	1757.52	1775.66	1785.84	Apr-65	1760.26	1777.46	1789.91	Feb-70	1759.50	1776.85	1788.74
Jul-60	1757.43	1775.52	1785.92	May-65	1760.28	1777.48	1789.77	Mar-70	1759.46	1776.76	1788.63
Aug-60	1757.47	1775.60	1785.87	Jun-65	1760.24	1777.42	1789.71	Apr-70	1759.68	1776.96	1788.72
Sep-60	1757.59	1775.76	1785.91	Jul-65	1760.14	1777.33	1789.76	May-70	1759.82	1777.05	1788.90
Oct-60	1757.55	1775.80	1785.92	Aug-65	1760.07	1777.26	1789.68	Jun-70	1759.91	1777.34	1788.99
Nov-60	1757.51	1775.81	1785.95	Sep-65	1760.03	1777.19	1789.60	Jul-70	1759.97	1777.35	1789.03
Dec-60	1757.43	1775.81	1785.96	Oct-65	1759.93	1777.07	1789.53	Aug-70	1760.00	1776.99	1788.99
Jan-61	1757.33	1775.74	1785.85	Nov-65	1759.86	1777.06	1789.44	Sep-70	1760.03	1777.10	1789.07
Feb-61	1757.20	1775.63	1785.73	Dec-65	1759.82	1777.04	1789.34	Oct-70	1760.45	1777.14	1789.15
Mar-61	1757.00	1775.52	1785.60	Jan-66	1759.73	1776.95	1789.24	Nov-70	1760.41	1777.15	1789.12
Apr-61	1757.00	1775.45	1785.47	Feb-66	1759.59	1776.87	1789.14	Dec-70	1760.93	1777.11	1789.03
May-61	1757.00	1775.25	1785.38	Mar-66	1759.49	1776.81	1789.04	Jan-71	1759.94	1777.01	1788.89
Jun-61	1757.00	1775.34	1785.37	Apr-66	1759.52	1776.81	1788.94	Feb-71	1759.83	1776.97	1788.78
Jul-61	1757.00	1775.28	1785.29	May-66	1759.52	1776.81	1788.86	Mar-71	1759.71	1776.80	1788.61
Aug-61	1757.00	1775.27	1785.18	Jun-66	1759.47	1776.74	1788.94	Apr-71	1759.56	1776.74	1788.50
Sep-61	1757.00	1775.29	1785.15	Jul-66	1759.42	1776.71	1788.96	May-71	1759.63	1776.79	1788.50
Oct-61	1757.00	1775.26	1785.27	Aug-66	1759.45	1776.66	1788.90	Jun-71	1759.62	1776.79	1788.61
Nov-61	1757.88	1776.28	1785.86	Sep-66	1759.54	1776.87	1788.82	Jul-71	1759.59	1776.74	1788.72
Dec-61	1758.54	1776.39	1787.16	Oct-66	1759.52	1776.85	1788.83	Aug-71	1759.83	1776.88	1788.89
Jan-62	1758.85	1776.39	1787.82	Nov-66	1759.52	1776.90	1788.90	Sep-71	1760.08	1776.98	1789.23
Feb-62	1758.79	1776.39	1788.17	Dec-66	1759.45	1776.89	1788.89	Oct-71	1760.25	1776.96	1789.21
Mar-62	1758.70	1776.39	1788.05	Jan-67	1759.31	1776.79	1788.92	Nov-71	1760.03	1776.99	1789.21
Apr-62	1758.71	1776.39	1787.89	Feb-67	1759.20	1776.70	1788.83	Dec-71	1759.95	1776.92	1789.11
May-62	1758.76	1776.61	1787.84	Mar-67	1759.06	1776.56	1788.70	Jan-72	1759.88	1776.84	1789.04
Jun-62	1758.74	1776.61	1788.15	Apr-67	1759.01	1776.53	1788.57	Feb-72	1759.89	1776.85	1788.98
Jul-62	1758.73	1776.60	1788.17	May-67	1759.08	1776.64	1788.43	Mar-72	1759.83	1776.80	1788.90
Aug-62	1758.82	1776.60	1788.15	Jun-67	1759.12	1776.61	1788.54	Apr-72	1759.69	1776.70	1788.75
Sep-62	1758.81	1776.70	1788.21	Jul-67	1759.23	1776.66	1788.75	May-72	1759.64	1776.69	1788.66
Oct-62	1758.80	1776.77	1788.42	Aug-67	1759.39	1776.63	1788.85	Jun-72	1759.64	1776.69	1788.59

APPENDIX E-3 Observed lakes levels

	NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA
Jul-72	1759.64	1776.66	1788.57	May-77	1758.40	1775.60	1787.41	Mar-82	1759.74	1776.07	1789.04
Aug-72	1759.71	1776.62	1788.52	Jun-77	1758.43	1775.68	1787.62	Apr-82	1759.65	1775.99	1788.98
Sep-72	1759.68	1776.57	1788.51	Jul-77	1758.65	1775.83	1787.81	May-82	1759.70	1776.01	1789.01
Oct-72	1759.59	1776.52	1788.44	Aug-77	1758.82	1775.96	1788.02	Jun-82	1759.68	1776.01	1789.01
Nov-72	1759.58	1776.52	1788.50	Sep-77	1758.80	1776.01	1788.06	Jul-82	1759.67	1775.96	1788.95
Dec-72	1759.54	1776.53	1788.47	Oct-77	1758.76	1775.98	1787.95	Aug-82	1759.65	1776.06	1788.95
Jan-73	1759.41	1776.47	1788.38	Nov-77	1758.89	1776.13	1788.03	Sep-82	1759.63	1776.00	1788.89
Feb-73	1759.30	1776.35	1788.27	Dec-77	1759.05	1776.19	1788.26	Oct-82	1759.73	1776.00	1788.85
Mar-73	1759.23	1776.27	1788.16	Jan-78	1759.07	1776.23	1788.31	Nov-82	1759.61	1776.06	1788.89
Apr-73	1759.05	1776.20	1788.03	Feb-78	1759.06	1776.20	1788.29	Dec-82	1759.75	1776.21	1789.41
May-73	1758.99	1776.21	1787.95	Mar-78	1759.69	1776.30	1788.45	Jan-83	1759.89	1776.20	1789.35
Jun-73	1759.03	1776.23	1787.93	Apr-78	1759.80	1776.46	1788.96	Feb-83	1759.84	1776.13	1789.25
Jul-73	1758.96	1776.16	1787.85	May-78	1759.97	1776.54	1789.28	Mar-83	1759.73	1776.04	1789.18
Aug-73	1758.96	1776.16	1787.80	Jun-78	1759.93	1776.51	1789.16	Apr-83	1759.77	1775.93	1789.09
Sep-73	1758.95	1776.20	1787.80	Jul-78	1759.99	1776.58	1789.15	May-83	1759.13	1775.94	1789.00
Oct-73	1758.94	1776.15	1787.77	Aug-78	1760.25	1776.62	1789.20	Jun-83	1759.04	1776.00	1788.93
Nov-73	1758.85	1776.11	1787.73	Sep-78	1760.45	1776.73	1789.25	Jul-83	1759.49	1775.92	1788.92
Dec-73	1758.79	1776.07	1787.63	Oct-78	1760.56	1776.88	1789.42	Aug-83	1759.50	1775.95	1788.92
Jan-74	1758.64	1775.92	1787.50	Nov-78	1760.56	1777.03	1789.47	Sep-83	1759.51	1775.98	1788.97
Feb-74	1758.49	1775.82	1787.33	Dec-78	1760.61	1777.04	1789.44	Oct-83	1759.68	1776.04	1789.08
Mar-74	1758.37	1775.76	1787.21	Jan-79	1760.62	1777.03	1789.36	Nov-83	1759.87	1776.03	1789.19
Apr-74	1758.44	1775.77	1787.25	Feb-79	1760.99	1777.10	1789.52	Dec-83	1759.62	1776.02	1789.15
May-74	1758.39	1775.81	1787.33	Mar-79	1760.98	1777.10	1789.51	Jan-84	1759.59	1775.99	1789.09
Jun-74	1758.35	1775.79	1787.32	Apr-79	1761.11	1777.02	1789.57	Feb-84	1759.47	1775.88	1788.97
Jul-74	1758.42	1775.82	1787.47	May-79	1761.18	1777.02	1789.64	Mar-84	1759.35	1777.09	1788.79
Aug-74	1759.07	1775.83	1787.55	Jun-79	1761.17	1777.00	1789.73	Apr-84	1759.37	1777.03	1788.69
Sep-74	1758.87	1775.91	1787.72	Jul-79	1761.21	1777.03	1789.79	May-84	1759.25	1776.95	1788.37
Oct-74	1758.87	1775.90	1787.82	Aug-79	1761.37	1777.01	1789.79	Jun-84	1759.15	1775.47	1788.26
Nov-74	1758.79	1775.87	1787.83	Sep-79	1761.30	1776.96	1789.73	Jul-84	1759.23	1776.38	1788.14
Dec-74	1758.73	1775.83	1787.78	Oct-79	1761.16	1776.89	1789.61	Aug-84	1759.01	1775.79	1788.02
Jan-75	1758.83	1775.76	1787.62	Nov-79	1761.04	1776.83	1789.55	Sep-84	1758.92	1775.81	1787.91
Feb-75	1758.45	1776.02	1787.47	Dec-79	1761.00	1776.83	1789.46	Oct-84	1758.97	1775.36	1787.90
Mar-75	1758.34	1775.53	1787.34	Jan-80	1760.90	1776.69	1789.32	Nov-84	1758.85	1775.34	1787.88
Apr-75	1758.19	1775.47	1787.20	Feb-80	1760.77	1776.59	1789.20	Dec-84	1758.87	1775.39	1787.87
May-75	1758.16	1775.45	1786.99	Mar-80	1760.64	1776.49	1789.09	Jan-85	1758.86	1775.28	1787.86
Jun-75	1758.18	1775.50	1787.03	Apr-80	1760.55	1776.46	1788.98	Feb-85	1758.83	1775.18	1787.81
Jul-75	1758.28	1775.56	1787.08	May-80	1760.69	1776.49	1789.13	Mar-85	1758.67	1775.47	1787.57
Aug-75	1758.64	1775.74	1787.27	Jun-80	1760.70	1776.49	1789.28	Apr-85	1758.66	1775.76	1787.56
Sep-75	1758.99	1775.95	1787.66	Jul-80	1760.68	1776.49	1789.33	May-85	1758.70	1775.91	1787.61
Oct-75	1759.07	1776.05	1787.86	Aug-80	1760.58	1776.44	1789.20	Jun-85	1758.74	1775.49	1787.67
Nov-75	1759.08	1776.08	1787.89	Sep-80	1760.50	1776.29	1789.08	Jul-85	1758.77	1775.55	1787.72
Dec-75	1759.02	1776.05	1787.79	Oct-80	1760.38	1776.23	1788.93	Aug-85	1758.81	1775.61	1787.77
Jan-76	1758.88	1775.95	1787.64	Nov-80	1760.27	1776.19	1788.88	Sep-85	1758.85	1775.71	1787.83
Feb-76	1758.74	1775.82	1787.49	Dec-80	1760.28	1776.13	1788.82	Oct-85	1758.83	1775.64	1787.81
Mar-76	1758.64	1775.71	1787.32	Jan-81	1760.14	1776.07	1788.67	Nov-85	1758.77	1775.61	1787.72
Apr-76	1758.50	1775.60	1787.16	Feb-81	1759.94	1775.93	1788.53	Dec-85	1758.72	1775.59	1787.64
May-76	1758.16	1775.54	1787.06	Mar-81	1759.90	1775.89	1788.37	Jan-86	1758.66	1776.07	1787.55
Jun-76	1758.16	1775.55	1787.00	Apr-81	1760.85	1775.97	1788.63	Feb-86	1758.60	1775.87	1787.46
Jul-76	1758.09	1775.52	1786.93	May-81	1760.20	1776.15	1789.04	Mar-86	1758.54	1775.53	1787.37
Aug-76	1758.41	1775.52	1786.82	Jun-81	1760.07	1776.21	1789.23	Apr-86	1758.48	1775.19	1787.29
Sep-76	1758.47	1775.53	1787.06	Jul-81	1760.22	1776.15	1789.25	May-86	1758.42	1775.63	1787.20
Oct-76	1758.43	1775.45	1786.87	Aug-81	1760.27	1776.30	1789.56	Jun-86	1758.54	1775.85	1787.38
Nov-76	1758.40	1775.47	1786.60	Sep-81	1760.24	1776.42	1789.64	Jul-86	1758.56	1776.25	1787.40
Dec-76	1758.25	1775.49	1786.73	Oct-81	1760.20	1776.43	1789.65	Aug-86	1758.54	1775.98	1787.38
Jan-77	1758.17	1775.51	1786.50	Nov-81	1760.16	1776.40	1789.59	Sep-86	1758.53	1775.71	1787.36
Feb-77	1758.11	1775.53	1786.34	Dec-81	1760.14	1776.36	1789.54	Oct-86	1758.52	1775.45	1787.34
Mar-77	1758.06	1775.55	1786.37	Jan-82	1759.92	1776.29	1789.53	Nov-86	1758.50	1776.15	1787.32
Apr-77	1758.00	1775.58	1786.53	Feb-82	1759.82	1776.17	1789.31	Dec-86	1758.47	1776.05	1787.28

APPENDIX E-4: Observed lakes levels

	NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA		NAKURU	ELEM	NAIVASHA
Jan-87	1758.42	1775.91	1787.19	Nov-91	1758.19	1775.94	1787.38	Sep-96	1757.81	1775.60	1786.30
Feb-87	1758.36	1775.53	1787.11	Dec-91	1758.19	1775.89	1787.34	Oct-96	1757.95	1775.61	1786.50
Mar-87	1758.30	1775.19	1787.03	Jan-92	1758.01	1775.83	1787.28	Nov-96	1757.95	1775.56	1786.50
Apr-87	1758.25	1775.43	1786.94	Feb-92	1757.67	1775.73	1787.16	Dec-96	1757.99	1775.60	1786.56
May-87	1758.16	1775.55	1786.81	Mar-92	1758.30	1775.61	1787.03	Jan-97	1757.95	1776.12	1786.50
Jun-87	1758.04	1775.66	1786.63	Apr-92	1758.22	1775.61	1786.90	Feb-97	1757.88	1776.01	1786.40
Jul-87	1758.08	1775.61	1786.70	May-92	1758.13	1775.59	1786.77	Mar-97	1757.81	1775.41	1786.30
Aug-87	1758.11	1775.53	1786.75	Jun-92	1758.04	1775.54	1786.64	Apr-97	1757.74	1775.67	1786.20
Sep-87	1758.06	1775.36	1786.66	Jul-92	1758.13	1775.58	1786.77	May-97	1757.61	1775.96	1786.00
Oct-87	1758.00	1774.98	1786.57	Aug-92	1758.22	1775.62	1786.91	Jun-97	1757.61	1775.75	1786.00
Nov-87	1757.94	1775.18	1786.49	Sep-92	1758.31	1775.73	1787.04	Jul-97	1757.61	1775.94	1786.00
Dec-87	1757.88	1775.20	1786.40	Oct-92	1758.41	1775.79	1787.18	Aug-97	1757.66	1775.91	1786.07
Jan-88	1757.82	1774.91	1786.31	Nov-92	1758.50	1775.86	1787.32	Sep-97	1757.78	1775.88	1786.25
Feb-88	1757.76	1774.93	1786.23	Dec-92	1758.59	1775.84	1787.45	Oct-97	1757.95	1775.85	1786.50
Mar-88	1757.76	1774.97	1786.22	Jan-93	1758.66	1775.92	1787.56	Nov-97	1757.95	1775.83	1786.50
Apr-88	1757.87	1775.83	1786.38	Feb-93	1758.61	1776.08	1787.48	Dec-97	1757.95	1775.96	1786.50
May-88	1757.77	1776.18	1786.23	Mar-93	1758.56	1776.04	1787.40	Jan-98	1758.87	1776.03	1787.87
Jun-88	1757.75	1776.00	1786.21	Apr-93	1758.50	1775.91	1787.32	Feb-98	1758.93	1776.11	1787.95
Jul-88	1757.95	1775.83	1786.50	May-93	1758.45	1775.84	1787.24	Mar-98	1758.91	1776.19	1787.92
Aug-88	1758.12	1775.67	1786.75	Jun-93	1758.39	1775.87	1787.16	Apr-98	1758.53	1776.12	1787.36
Sep-88	1758.26	1775.79	1786.97	Jul-93	1758.34	1775.86	1787.08	May-98	1759.13	1776.50	1788.25
Oct-88	1758.41	1775.87	1787.19	Aug-93	1758.28	1775.83	1787.00	Jun-98	1759.45	1776.56	1788.72
Nov-88	1758.41	1775.96	1787.18	Sep-93	1758.23	1775.81	1786.92	Jul-98	1759.54	1776.62	1788.85
Dec-88	1758.40	1775.97	1787.17	Oct-93	1758.18	1775.68	1786.84	Aug-98	1759.58	1776.63	1788.92
Jan-89	1758.40	1775.87	1787.17	Nov-93	1758.12	1775.63	1786.76	Sep-98	1759.58	1776.64	1788.92
Feb-89	1758.39	1775.89	1787.16	Dec-93	1757.97	1775.60	1786.54	Oct-98	1759.59	1776.69	1788.93
Mar-89	1757.82	1775.67	1787.15	Jan-94	1757.95	1775.52	1786.50	Nov-98	1758.59	1776.79	1787.45
Apr-89	1757.91	1775.71	1786.89	Feb-94	1757.88	1775.91	1786.40	Dec-98		1776.78	
May-89	1758.33	1775.82	1786.86	Mar-94	1757.76	1775.59	1786.23	May-99		1776.68	
Jun-89	1759.03	1775.83	1786.84	Apr-94	1757.68	1775.50	1786.10	Jun-99		1776.56	
Jul-89	1759.33	1775.84	1786.82	May-94	1757.68	1775.81	1786.10	Jul-99		1776.50	
Aug-89	1759.41	1775.85	1786.80	Jun-94	1757.72	1775.86	1786.16	Aug-99		1776.45	
Sep-89	1759.60	1775.88	1786.77	Jul-94	1757.88	1775.78	1786.40	Sep-99		1776.40	
Oct-89	1760.02	1775.97	1786.75	Aug-94	1757.95	1776.04	1786.50	Oct-99		1776.35	
Nov-89	1760.63	1776.06	1786.93	Sep-94	1758.01	1776.12	1786.60	Nov-99		1776.29	
Dec-89	1760.65	1776.09	1787.13	Oct-94	1757.95	1775.96	1786.50	Dec-99		1776.24	
Jan-90	1758.07	1776.21	1787.32	Nov-94	1757.95	1776.07	1786.50	Jan-00		1776.19	
Feb-90	1758.06	1776.13	1787.48	Dec-94	1758.23	1776.09	1786.92	Feb-00		1776.11	
Mar-90	1758.09	1776.22	1787.49	Jan-95	1758.15	1775.87	1786.80	Mar-00		1776.05	
Apr-90	1759.05	1776.45	1787.60	Feb-95	1758.04	1775.43	1786.64	Apr-00		1776.06	
May-90	1759.12	1776.49	1788.02	Mar-95	1757.88	1775.27	1786.40	May-00		1776.01	
Jun-90	1759.14	1776.48	1788.43	Apr-95	1757.88	1775.13	1786.40	Jun-00		1775.87	
Jul-90	1759.13	1776.41	1788.40	May-95	1757.93	1775.61	1786.47	Jul-00		1775.72	
Aug-90	1759.12	1776.36	1788.35	Jun-95	1757.95	1775.46	1786.50	Aug-00		1775.59	
Sep-90	1759.11	1776.33	1788.30	Jul-95	1757.95	1775.76	1786.51	Sep-00		1775.57	
Oct-90	1758.91	1776.25	1788.25	Aug-95	1757.81	1775.74	1786.30	Oct-00		1775.55	
Nov-90	1758.83	1776.25	1788.19	Sep-95	1757.81	1775.44	1786.30	Nov-00		1775.60	
Dec-90	1758.80	1776.20	1788.14	Oct-95	1757.88	1775.52	1786.40	Dec-00		1776.15	
Jan-91	1758.70	1776.14	1788.09	Nov-95	1757.91	1775.90	1786.45	Jan-01		1776.11	
Feb-91	1758.61	1776.07	1788.04	Dec-95	1757.99	1776.13	1786.56	Feb-01		1775.91	
Mar-91	1758.40	1775.95	1787.85	Jan-96	1757.95	1775.99	1786.50	Mar-01		1775.82	
Apr-91	1758.32	1775.94	1787.66	Feb-96	1757.88	1775.75	1786.40	Apr-01		1775.82	
May-91	1758.28	1775.94	1787.52	Mar-96	1757.81	1775.39	1786.30				
Jun-91	1758.28	1775.96	1787.44	Apr-96	1757.74	1775.21	1786.20				
Jul-91	1758.27	1775.97	1787.48	May-96	1757.66	1775.28	1786.07				
Aug-91	1758.22	1775.98	1787.53	Jun-96	1757.61	1775.64	1786.00				
Sep-91	1758.21	1775.98	1787.48	Jul-96	1757.68	1776.01	1786.10				
Oct-91	1758.28	1775.97	1787.43	Aug-96	1757.77	1775.49	1786.24				

APPENDIX E-5: Observed lakes levels (masl)

	2FC09		2FC09	2FA08		2FC09	2FA08
Jan-52	2566080	Jan-58	233280	465218	Jan-64	3913920	617242
Feb-52	181440	Feb-58	2695680	467371	Feb-64	414720	65142
Mar-52	77760	Mar-58	622080	349083	Mar-64	336960	51691
Apr-52	155520	Apr-58	285120	335851	Apr-64	11949120	338738
May-52	1062720	May-58	5469120	529821	May-64	4717440	658780
Jun-52	181440	Jun-58	699840	736717	Jun-64	1373760	146527
Jul-52	233280	Jul-58	2073600	1791925	Jul-64	4691520	2250275
Aug-52	1244160	Aug-58	3628800	2706048	Aug-64	7490880	3387976
Sep-52	1425600	Sep-58	6091200	850003	Sep-64	6065280	4455797
Oct-52	336960	Oct-58	1062720	257695	Oct-64	11093760	6451384
Nov-52	129600	Nov-58	336960	112061	Nov-64	1529280	1977948
Dec-52	103680	Dec-58	855360	5048213	Dec-64	959040	1072474
Jan-53	51840	Jan-59	570240	39047	Jan-65	466560	249739
Feb-53	25920	Feb-59	259200	6382	Feb-65	181440	2200
Mar-53	51840	Mar-59	129600	11539	Mar-65	103680	423
Apr-53	51840	Apr-59	181440	34042	Apr-65	207360	3384
May-53	233280	May-59	570240	189885	May-65	336960	2792
Jun-53	181440	Jun-59	570240	102384	Jun-65	103680	0
Jul-53	77760	Jul-59	414720	116974	Jul-65	129600	1313
Aug-53	181440	Aug-59	959040	492396	Aug-65	129600	2747
Sep-53	77760	Sep-59	1866240	1566518	Sep-65	77760	85
Oct-53	51840	Oct-59	388800	1426687	Oct-65	103680	33248
Nov-53	77760	Nov-59	285120	797386	Nov-65	77760	508108
Dec-53	77760	Dec-59	388800	825259	Dec-65	51840	1150729
Jan-54	25920	Jan-60	103680	39298	Jan-66	75168	6091
Feb-54	0	Feb-60	51840	25982	Feb-66	98496	0
Mar-54	0	Mar-60	129600	273832	Mar-66	121824	0
Apr-54	155520	Apr-60	181440	80266	Apr-66	145152	83881
May-54	2825280	May-60	311040	36957	May-66	168480	52706
Jun-54	2566080	Jun-60	155520	84672	Jun-66	191808	59051
Jul-54	2643840	Jul-60	207360	180102	Jul-66	215136	91706
Aug-54	2566080	Aug-60	1840320	1272839	Aug-66	238464	1207496
Sep-54	6402240	Sep-60	2099520	1273649	Sep-66	261792	4212826
Oct-54	829440	Oct-60	181440	1274460	Oct-66	285120	546601
Nov-54	570240	Nov-60	103680	1183939	Nov-66	1192320	1173317
Dec-54	311040	Dec-60	103680	4309499	Dec-66	181440	251177
Jan-55	233280	Jan-61	51840	65553	Jan-67	77760	846
Feb-55	155520	Feb-61	25920	35362	Feb-67	129600	338
Mar-55	51840	Mar-61	25920	15636	Mar-67	181440	0
Apr-55	77760	Apr-61	51840	16330	Apr-67	233280	1861
May-55	77760	May-61	77760	36957	May-67	1218240	3448719
Jun-55	51840	Jun-61	51840	10886	Jun-67	1088640	410648
Jul-55	77760	Jul-61	25920	11121	Jul-67	6998400	1013593
Aug-55	492480	Aug-61	285120	110871	Aug-67	1529280	1111136
Sep-55	3317760	Sep-61	155520	552528	Sep-67	570240	596853
Oct-55	1814400	Oct-61	673920	655609	Oct-67	336960	401765
Nov-55	311040	Nov-61	23587200	6358781	Nov-67	2773440	1277291
Dec-55	1321920	Dec-61	25479360	2209248	Dec-67	2514240	337131
Jan-56	1736640	Jan-62	5598720	6593296	Jan-68	155520	1946
Feb-56	1140480	Feb-62	544320	1221084	Feb-68	414720	846
Mar-56	362880	Mar-62	207360	754105	Mar-68	3240000	410902
Apr-56	699840	Apr-62	233280	651880	Apr-68	22083840	3154903
May-56	2047680	May-62	2540160	2252364	May-68	8553600	4474917
Jun-56	2099520	Jun-62	855360	1943381	Jun-68	1425600	4906039
Jul-56	7724160	Jul-62	1684800	2123517	Jul-68	1036800	2645865
Aug-56	26023680	Aug-62	3706560	1974686	Aug-68	4276800	3651928
Sep-56	8398080	Sep-62	2177280	3161549	Sep-68	596160	1282451
Oct-56	1321920	Oct-62	1244160	2719224	Oct-68	233280	661234
Nov-56	881280	Nov-62	466560	988740	Nov-68	803520	2440414
Dec-56	311040	Dec-62	803520	358214	Dec-68	5132160	299446
Jan-57	181440	Jan-63	1218240	358239	Jan-69	414720	282432
Feb-57	129600	Feb-63	362880	267844	Feb-69	622080	357985
Mar-57	129600	Mar-63	181440	146527	Mar-69	518400	269620
Apr-57	414720	Apr-63	3343680	717323	Apr-69	362880	66073
May-57	2954880	May-63	9486720	7543528	May-69	1166400	586532
Jun-57	4691520	Jun-63	6168960	3490850	Jun-69	233280	11421
Jul-57	3110400	Jul-63	751680	1096924	Jul-69	155520	38070
Aug-57	3784320	Aug-63	2255040	616226	Aug-69	181440	9560
Sep-57	2747520	Sep-63	2669760	707679	Sep-69	466560	358281
Oct-57	311040	Oct-63	440640	493641	Oct-69	155520	141959
Nov-57	362880	Nov-63	492480	629424	Nov-69	181440	100843
Dec-57	440640	Dec-63	6609600	354474	Dec-69	129600	43950

APPENDIX F-1 Stream flows at RGS 2FA08 and 2FC09 on rivers Mereroni and Njoro resply.

	2FC09	2FA08		2FC09	2FA08		2FC09	2FA08
Jan-70	414720	73729	Jan-76	103680	26057	Jan-82	142560	22588
Feb-70	207360	0	Feb-76	77760	11573	Feb-82	129600	4842
Mar-70	1529280	41285	Mar-76	51840	9315	Mar-82	194400	6634
Apr-70	5883840	786357	Apr-76	77760	13463	Apr-82	259200	12974
May-70	8735040	1985012	May-76	77760	21993	May-82	622080	1506388
Jun-70	4587840	1214348	Jun-76	77760	22842	Jun-82	622080	822143
Jul-70	1555200	882632	Jul-76	907200	45684	Jul-82	103680	303291
Aug-70	3965760	1140662	Aug-76	2255040	124277	Aug-82	1866240	1119850
Sep-70	3602880	2341982	Sep-76	2514240	763684	Sep-82	881280	882716
Oct-70	2125440	2260258	Oct-76	362880	93568	Oct-82	725760	1373650
Nov-70	1088640	976199	Nov-76	129600	19458	Nov-82	4458240	1110742
Dec-70	311040	35363	Dec-76	129600	788641	Dec-82	9927360	847833
Jan-71	207360	3807	Jan-77	181440	19669	Jan-83	570240	584924
Feb-71	103680	714	Feb-77	103680	11215	Feb-83	155520	119286
Mar-71	77760	1274	Mar-77	51840	5163	Mar-83	248832	12690
Apr-71	155520	8545	Apr-77	2799360	3513097	Apr-83	342144	90226
May-71	1944000	336877	May-77	12674880	7794946	May-83	435456	167762
Jun-71	2358720	1105299	Jun-77	1347840	1534187	Jun-83	528768	111164
Jul-71	2747520	1662728	Jul-77	4898880	3484082	Jul-83	622080	350176
Aug-71	20010240	2444009	Aug-77	6635520	5301544	Aug-83	2203200	688120
Sep-71	12337920	2461902	Sep-77	959040	1636164	Sep-83	3006720	1692592
Oct-71	907200	1592722	Oct-77	544320	789318	Oct-83	2799360	1402160
Nov-71	336960	353290	Nov-77	6972480	3450919	Nov-83	1555200	1226362
Dec-71	466560	931	Dec-77	3913920	53806	Dec-83	1192320	30794
Jan-72	362880	254	Jan-78	2540160	390767	Jan-84	440640	29356
Feb-72	1192320	0	Feb-78	3360960	110318	Feb-84	77760	2453
Mar-72	544320	0	Mar-78	4181760	756916	Mar-84	51840	0
Apr-72	103680	0	Apr-78	5002560	2872255	Apr-84	38880	0
May-72	129600	0	May-78	2799360	3781535	May-84	25920	0
Jun-72	160704	0	Jun-78	1762560	1134994	Jun-84	25920	0
Jul-72	191808	0	Jul-78	3680640	3937030	Jul-84	207360	0
Aug-72	222912	0	Aug-78	3991680	1850963	Aug-84	103680	0
Sep-72	254016	0	Sep-78	4717440	2201884	Sep-84	25920	0
Oct-72	285120	0	Oct-78	1995840	5922254	Oct-84	51840	0
Nov-72	1866240	0	Nov-78	1607040	4882435	Nov-84	77760	0
Dec-72	311040	0	Dec-78	1632960	70218	Dec-84	51840	213277
Jan-73	181440	0	Jan-79	1725531.429	307098	Jan-85	38880	0
Feb-73	77760	0	Feb-79	1818102.857	942021	Feb-85	25920	0
Mar-73	77760	0	Mar-79	1910674.286	157694	Mar-85	0	0
Apr-73	77760	0	Apr-79	2003245.714	149700	Apr-85	907200	0
May-73	77760	0	May-79	2095817.143	757762	May-85	1270080	0
Jun-73	103680	0	Jun-79	2188388.571	722484	Jun-85	1088640	0
Jul-73	129600	0	Jul-79	2280960	1237613	Jul-85	699840	0
Aug-73	699840	0	Aug-79	3628800	516398	Aug-85	577645.7143	0
Sep-73	1062720	0	Sep-79	751680	255661	Sep-85	351771.4286	0
Oct-73	362880	0	Oct-79	518400	65142	Oct-85	155520	0
Nov-73	181440	0	Nov-79	285120	39424	Nov-85	155520	0
Dec-73	0	0	Dec-79	285120	2454161	Dec-85	77760	0
Jan-74	0	0	Jan-80	181440	2068188	Jan-86	51840	0
Feb-74	0	0	Feb-80	129600	1682215	Feb-86	0	0
Mar-74	0	0	Mar-80	103680	1296241	Mar-86	25920	0
Apr-74	16247.93425	0	Apr-80	181440	910268	Apr-86	51840	0
May-74	16501.80822	0	May-80	3006720	524294	May-86	181440	894053
Jun-74	54075.15616	0	Jun-80	699840	138321	Jun-86	207360	818843
Jul-74	3706560	478921	Jul-80	622080	84346	Jul-86	207360	1902062
Aug-74	1062720	696143	Aug-80	207360	98698	Aug-86	466560	1453174
Sep-74	2436480	840193	Sep-80	155520	126507	Sep-86	1321920	697781
Oct-74	1140480	152195	Oct-80	77760	25465	Oct-86	233280	178337
Nov-74	907200	55921	Nov-80	84240	9560	Nov-86	25920	7614
Dec-74	285120	922055	Dec-80	90720	2264361	Dec-86	233280	631454
Jan-75	77760	0	Jan-81	97200	528187	Jan-87	51840	1523
Feb-75	25920	0	Feb-81	103680	622937	Feb-87	0	0
Mar-75	25920	0	Mar-81	103680	851174	Mar-87	25920	0
Apr-75	362880	0	Apr-81	103680	1041611	Apr-87	25920	0
May-75	285120	508	May-81	103680	2238008	May-87	155520	6937
Jun-75	648000	380785	Jun-81	103680	184428	Jun-87	881280	532219
Jul-75	663552	1248188	Jul-81	1166400	710217	Jul-87	207360	121570
Aug-75	679104	2033361	Aug-81	5546880	6536619	Aug-87	129600	16159
Sep-75	694656	2646457	Sep-81	3058560	1858154	Sep-87	51840	5584
Oct-75	710208	2466598	Oct-81	570240	1259609	Oct-87	0	0
Nov-75	725760	1658245	Nov-81	259200	689575	Nov-87	103680	22334
Dec-75	285120	856406	Dec-81	155520	1097600	Dec-87	25920	1051324

APPENDIX F-2 River discharges

	2FC09	2FA08		2FC09	2FA08
Jan-88	51840	0	Jan-94	25920	0
Feb-88	9080	0	Feb-94	0	0
Mar-88	18243	0	Mar-94	0	0
Apr-88	27406	1710443	Apr-94	129600	0
May-88	36569	3855730	May-94	129600	20812
Jun-88	45731	1496997	Jun-94	311040	360142
Jul-88	54894	5398834	Jul-94	2488320	688898
Aug-88	64057	11481827	Aug-94	5339520	1571022
Sep-88	73220	9607937	Sep-94	1684800	1621782
Oct-88	82383	6990413	Oct-94	1814400	162432
Nov-88	91545	2032515	Nov-94	1944000	840839
Dec-88	100708	783058	Dec-94	1192320	132484
Jan-89	109871	29525	Jan-95	155520	6345
Feb-89	119034	93145	Feb-95	25920	0
Mar-89	128197	8122	Mar-95	25920	0
Apr-89	2462400	103635	Apr-95	0	0
May-89	1296000	3809453	May-95	77760	82993
Jun-89	570240	813429	Jun-95	25920	427738
Jul-89	1814400	1041934	Jul-95	492480	1423818
Aug-89	1658880	2949664	Aug-95	181440	312174
Sep-89	3525120	2571079	Sep-95	155520	407941
Oct-89	1503360	2386735	Oct-95	155520	776713
Nov-89	2721600	2127521	Nov-95	570240	6341362
Dec-89	5196960	217507	Dec-95	440640	2191225
Jan-90	7672320	3840925	Jan-96	51840	
Feb-90	466560	248978	Feb-96	0	
Mar-90	984960	945743	Mar-96	25920	
Apr-90	13633920	7824654	Apr-96	51840	
May-90	3654720	2601196	May-96	181440	
Jun-90	933120	923578	Jun-96	207360	
Jul-90	440640	228843	Jul-96	207360	
Aug-90	285120	775697	Aug-96	466560	
Sep-90	285120	511830	Sep-96	1321920	
Oct-90	259200	84600	Oct-96	233280	
Nov-90	181440	129523	Nov-96	25920	
Dec-90	207360	113872	Dec-96	233280	
Jan-91	3888000	0	Jan-97	51840	
Feb-91	77760	0	Feb-97	0	
Mar-91	25920	0	Mar-97	25920	
Apr-91	103680	0	Apr-97	25920	
May-91	103680	0	May-97	155520	
Jun-91	155520	0	Jun-97	881280	
Jul-91	181440	0	Jul-97	207360	
Aug-91	1036800	0	Aug-97	129600	
Sep-91	1036800	0	Sep-97	51840	
Oct-91	311040	0	Oct-97	0	
Nov-91	129600	0	Nov-97	103680	
Dec-91	103680	0	Dec-97	25920	
Jan-92	25920	0	Jan-98	51840	
Feb-92	25920	0	Feb-98	9080	
Mar-92	0	0	Mar-98	18243	
Apr-92	0	0	Apr-98	27406	
May-92	77760	49576	May-98	36569	
Jun-92	129600	381969	Jun-98	45731	
Jul-92	155520	3871973	Jul-98	54894	
Aug-92	155520	2149686	Aug-98	64057	
Sep-92	725760	3557515	Sep-98	73220	
Oct-92	492480	3160910	Oct-98	82383	
Nov-92	777600	1720510	Nov-98	91545	
Dec-92	285120	565382	Dec-98	100708	
Jan-93	984960	1508080	Jan-99	109871	
Feb-93	3810240	2426413	Feb-99	119034	
Mar-93	207360	49322	Mar-99	128197	
Apr-93	25920	14805	Apr-99	2462400	
May-93	207360	237049	May-99	1296000	
Jun-93	518400	2164068	Jun-99	570240	
Jul-93	596160	959956	Jul-99	1814400	
Aug-93	673920	494402	Aug-99	1658880	
Sep-93	129600	148811	Sep-99	3525120	
Oct-93	25920	10744	Oct-99	1503360	
Nov-93	25920	19627	Nov-99	2721600	
Dec-93	25920	208962	Dec-99	5196960	

APPENDIX F-3 River discharges (cubic meters)

	9036310		9036310	9036147		9036310	9036147		9036310	9036147
Jan-52	19.0	Nov-56	37.5		Sep-61	132.8	39.6	Jul-66	81.5	81.3
Feb-52	26.4	Dec-56	42.0		Oct-61	282.5	68.8	Aug-66	46.0	76.9
Mar-52	17.7	Jan-57	12.9		Nov-61	109.7	344.2	Sep-66	93.9	81.5
Apr-52	106.8	Feb-57	30.6		Dec-61	18.6	185.2	Oct-66	19.3	46.0
May-52	107.8	Mar-57	89.1		Jan-62	67.5	41.4	Nov-66	13.2	93.9
Jun-52	24.4	Apr-57	119.0		Feb-62	92.5	1.5	Dec-66	13.4	19.3
Jul-52	51.7	May-57	116.5		Mar-62	100.4	67.0	Jan-67	31.3	13.2
Aug-52	68.1	Jun-57	33.8		Apr-62	78.3	109.3	Feb-67	71.5	13.4
Sep-52	47.6	Jul-57	121.1		May-62	99.9	75.8	Mar-67	103.7	31.3
Oct-52	38.5	Aug-57	34.5		Jun-62	69.9	80.3	Apr-67	89.7	71.5
Nov-52	48.9	Sep-57	24.7		Jul-62	71.7	7.1	May-67	73.5	103.7
Dec-52	20.0	Oct-57	81.7		Aug-62	70.9	29.7	Jun-67	38.4	89.7
Jan-53	13.2	Nov-57	41.5		Sep-62	89.2	142.3	Jul-67	31.1	73.5
Feb-53	18.0	Dec-57	26.7		Oct-62	51.3	58.6	Aug-67	47.7	38.4
Mar-53	51.4	Jan-58	80.2	41.4	Nov-62	14.2	39.3	Sep-67	74.4	31.1
Apr-53	68.4	Feb-58	50.7	53.3	Dec-62	56.9	58.8	Oct-67	14.0	47.7
May-53	13.2	Mar-58	46.1	38.0	Jan-63	65.9	14.2	Nov-67	26.7	74.4
Jun-53	13.2	Apr-58	150.2	40.5	Feb-63	124.1	56.9	Dec-67	114.7	14.0
Jul-53	41.1	May-58	46.0	139.0	Mar-63	116.0	65.9	Jan-68	126.8	26.7
Aug-53	70.7	Jun-58	110.0	45.0	Apr-63	45.3	124.1	Feb-68	199.6	114.7
Sep-53	34.3	Jul-58	62.3	186.0	May-63	30.4	116.0	Mar-68	77.9	126.8
Oct-53	43.3	Aug-58	50.5	73.4	Jun-63	88.9	45.3	Apr-68	35.5	199.6
Nov-53	66.2	Sep-58	64.2	25.4	Jul-63	21.5	30.4	May-68	95.3	77.9
Dec-53	34.3	Oct-58	38.1	86.7	Aug-63	22.0	88.9	Jun-68	56.4	35.5
Jan-54	36.1	Nov-58	30.0	22.3	Sep-63	73.7	21.5	Jul-68	30.0	95.3
Feb-54	24.7	Dec-58	19.8	45.6	Oct-63	137.7	22.0	Aug-68	32.4	56.4
Mar-54	17.2	Jan-59	34.8	43.1	Nov-63	37.3	73.7	Sep-68	78.7	30.0
Apr-54	139.6	Feb-59	62.2	36.8	Dec-63	41.5	137.7	Oct-68	54.3	32.4
May-54	172.6	Mar-59	62.7	50.7	Jan-64	44.2	37.3	Nov-68	110.8	78.7
Jun-54	115.3	Apr-59	151.8	68.7	Feb-64	175.1	41.5	Dec-68	52.9	54.3
Jul-54	113.2	May-59	58.4	76.6	Mar-64	92.3	44.2	Jan-69	83.7	110.8
Aug-54	63.6	Jun-59	75.3	46.2	Apr-64	40.4	175.1	Feb-69	42.4	52.9
Sep-54	45.3	Jul-59	38.7	88.1	May-64	128.4	92.3	Mar-69	120.6	83.7
Oct-54	63.5	Aug-59	54.3	68.5	Jun-64	85.6	40.4	Apr-69	29.4	42.4
Nov-54	42.8	Sep-59	35.4	37.0	Jul-64	67.1	128.4	May-69	54.7	120.6
Dec-54	24.2	Oct-59	72.2	56.2	Aug-64	61.4	85.6	Jun-69	54.6	29.4
Jan-55	88.8	Nov-59	27.0	99.5	Sep-64	59.6	67.1	Jul-69	83.2	54.7
Feb-55	93.6	Dec-59	26.7	20.8	Oct-64	39.0	61.4	Aug-69	45.6	54.6
Mar-55	20.7	Jan-60	24.6	41.4	Nov-64	15.5	59.6	Sep-69	47.4	83.2
Apr-55	89.5	Feb-60	88.9	25.1	Dec-64	14.0	39.0	Oct-69	21.3	45.6
May-55	75.4	Mar-60	56.8	79.6	Jan-65	24.1	15.5	Nov-69	22.3	47.4
Jun-55	43.3	Apr-60	89.6	35.1	Feb-65	88.4	14.0	Dec-69	105.9	21.3
Jul-55	55.0	May-60	24.2	17.5	Mar-65	61.5	24.1	Jan-70	128.9	26.7
Aug-55	123.0	Jun-60	33.3	29.2	Apr-65	32.7	88.4	Feb-70	117.4	22.3
Sep-55	119.4	Jul-60	161.2	17.7	May-65	39.1	61.5	Mar-70	55.2	105.9
Oct-55	54.9	Aug-60	74.6	94.2	Jun-65	46.6	32.7	Apr-70	66.9	128.9
Nov-55	61.0	Sep-60	52.0	52.6	Jul-65	21.3	39.1	May-70	104.3	117.4
Dec-55	57.4	Oct-60	42.0	28.2	Aug-65	64.9	46.6	Jun-70	57.3	55.2
Jan-56	45.3	Nov-60	29.7	13.5	Sep-65	56.1	21.3	Jul-70	55.8	66.9
Feb-56	67.7	Dec-60	67.3	9.6	Oct-65	32.2	64.9	Aug-70	84.1	104.3
Mar-56	80.7	Jan-61	34.8	24.7	Nov-65	15.5	56.1	Sep-70	30.9	57.3
Apr-56	57.4	Feb-61	25.9	23.4	Dec-65	43.3	32.2	Oct-70	24.8	55.8
May-56	87.7	Mar-61	70.3	11.1	Jan-66	51.8	15.5	Nov-70	13.2	84.1
Jun-56	82.9	Apr-61	62.9	60.9	Feb-66	144.0	43.3	Dec-70	27.3	30.9
Jul-56	192.1	May-61	45.1	79.3	Mar-66	49.9	51.8	Jan-71	105.1	24.8
Aug-56	70.0	Jun-61	47.7	66.6	Apr-66	73.6	144.0	Feb-71	96.1	13.2
Sep-56	63.7	Jul-61	118.3	13.4	May-66	81.3	49.9	Mar-71	108.7	27.3
Oct-56	62.3	Aug-61	37.9	118.9	Jun-66	76.9	73.6	Apr-71	49.2	105.1

APPENDIX G-1: Monthly Rainfall (mm) at derives from readings taken at Bwami Daniel Farm (9036310) and Elem, Soysambu Estate (9036147)

	9036310	9036147		9036310	9036147		9036310	9036147		9036310	9036147
May-71	126.4	96.1	Mar-76	18.4	20.3	Jan-81	113.2	26.7	Nov-85	110.2	59.1
Jun-71	63.7	108.7	Apr-76	27.5	84.9	Feb-81	90.3	27.6	Dec-85	87.1	26.5
Jul-71	22.4	49.2	May-76	29.9	63.4	Mar-81	28.3	86.7	Jan-86	113.9	22.4
Aug-71	49.1	126.4	Jun-76	22.5	33.7	Apr-81	32.3	151.0	Feb-86	13.2	16.7
Sep-71	53.1	63.7	Jul-76	8.3	67.6	May-81	35.9	83.9	Mar-86	42.0	31.0
Oct-71	103.3	22.4	Aug-76	16.0	43.7	Jun-81	28.9	37.0	Apr-86	44.7	108.0
Nov-71	22.6	49.1	Sep-76	16.7	18.4	Jul-81	26.9	70.5	May-86	25.8	73.3
Dec-71	27.2	53.1	Oct-76	123.4	27.5	Aug-81	16.4	113.2	Jun-86	36.9	115.3
Jan-72	112.6	26.7	Nov-76	50.5	29.9	Sep-81	107.0	90.3	Jul-86	68.3	110.2
Feb-72	53.7	103.3	Dec-76	42.7	22.5	Oct-81	113.8	28.3	Aug-86	98.5	87.1
Mar-72	68.4	22.6	Jan-77	81.9	8.3	Nov-81	29.8	32.3	Sep-86	88.4	113.9
Apr-72	97.0	27.2	Feb-77	36.9	16.0	Dec-81	41.0	35.9	Oct-86	13.2	13.2
May-72	27.1	112.6	Mar-77	45.1	16.7	Jan-82	163.6	28.9	Nov-86	77.8	42.0
Jun-72	67.3	53.7	Apr-77	92.2	123.4	Feb-82	31.8	26.9	Dec-86	36.0	44.7
Jul-72	87.7	68.4	May-77	149.0	50.5	Mar-82	75.0	16.4	Jan-87	23.5	26.7
Aug-72	25.0	97.0	Jun-77	45.0	42.7	Apr-82	104.3	107.0	Feb-87	94.1	25.8
Sep-72	11.4	27.1	Jul-77	49.1	81.9	May-82	53.7	113.8	Mar-87	20.9	36.9
Oct-72	20.4	67.3	Aug-77	78.2	36.9	Jun-82	31.3	29.8	Apr-87	75.4	68.3
Nov-72	4.5	87.7	Sep-77	139.8	45.1	Jul-82	22.6	41.0	May-87	18.7	98.5
Dec-72	27.2	25.0	Oct-77	121.1	92.2	Aug-82	90.7	163.6	Jun-87	42.7	88.4
Jan-73	58.5	11.4	Nov-77	48.7	149.0	Sep-82	76.9	31.8	Jul-87	191.5	13.2
Feb-73	62.2	20.4	Dec-77	50.8	45.0	Oct-82	37.9	75.0	Aug-87	115.0	77.8
Mar-73	60.6	4.5	Jan-78	102.9	49.1	Nov-82	60.7	104.3	Sep-87	89.3	36.0
Apr-73	152.0	27.2	Feb-78	114.0	78.2	Dec-82	124.2	53.7	Oct-87	77.0	23.5
May-73	122.3	58.5	Mar-78	63.5	139.8	Jan-83	93.6	26.7	Nov-87	105.9	94.1
Jun-73	52.7	62.2	Apr-78	80.8	121.1	Feb-83	53.7	31.3	Dec-87	81.6	20.9
Jul-73	48.8	60.6	May-78	28.3	48.7	Mar-83	66.4	22.6	Jan-88	68.8	75.4
Aug-73	1.8	152.0	Jun-78	88.4	50.8	Apr-83	90.1	90.7	Feb-88	37.1	18.7
Sep-73	27.2	122.3	Jul-78	48.5	102.9	May-83	12.0	76.9	Mar-88	50.1	42.7
Oct-73	55.7	52.7	Aug-78	121.1	114.0	Jun-83	11.0	37.9	Apr-88	70.5	191.5
Nov-73	135.5	48.8	Sep-78	71.2	63.5	Jul-83	17.6	60.7	May-88	61.4	115.0
Dec-73	55.1	1.8	Oct-78	116.6	80.8	Aug-83	82.5	124.2	Jun-88	49.5	89.3
Jan-74	72.3	26.7	Nov-78	69.1	28.3	Sep-83	32.1	93.6	Jul-88	156.2	77.0
Feb-74	121.9	27.2	Dec-78	54.4	88.4	Oct-83	35.5	53.7	Aug-88	111.7	105.9
Mar-74	146.5	55.7	Jan-79	52.8	48.5	Nov-83	54.3	66.4	Sep-88	15.2	81.6
Apr-74	43.3	135.5	Feb-79	65.3	121.1	Dec-83	55.8	90.1	Oct-88	84.9	68.8
May-74	64.2	55.1	Mar-79	38.0	71.2	Jan-84	52.2	12.0	Nov-88	89.9	37.1
Jun-74	0.0	72.3	Apr-79	23.4	116.6	Feb-84	65.5	11.0	Dec-88	109.0	50.1
Jul-74	3.0	121.9	May-79	56.4	69.1	Mar-84	72.7	17.6	Jan-89	79.3	70.5
Aug-74	0.0	146.5	Jun-79	34.2	54.4	Apr-84	35.9	82.5	Feb-89	75.2	61.4
Sep-74	2.2	43.3	Jul-79	13.7	52.8	May-84	13.2	32.1	Mar-89	98.5	49.5
Oct-74	20.2	64.2	Aug-79	16.4	65.3	Jun-84	42.4	35.5	Apr-89	156.0	156.2
Nov-74	118.1	0.0	Sep-79	64.4	38.0	Jul-84	92.5	54.3	May-89	107.1	111.7
Dec-74	149.2	3.0	Oct-79	94.7	23.4	Aug-84	236.3	55.8	Jun-89	108.2	15.2
Jan-75	117.6	0.0	Nov-79	157.3	56.4	Sep-84	81.3	52.2	Jul-89	36.4	87.8
Feb-75	45.2	2.2	Dec-79	39.0	34.2	Oct-84	98.1	65.5	Aug-89	27.6	84.9
Mar-75	65.1	20.2	Jan-80	108.0	13.7	Nov-84	44.2	72.7	Sep-89	48.4	89.9
Apr-75	24.2	118.1	Feb-80	47.6	16.4	Dec-84	55.2	35.9	Oct-89	37.7	109.0
May-75	34.6	149.2	Mar-80	99.0	64.4	Jan-85	27.6	13.2	Nov-89	54.1	79.3
Jun-75	12.0	117.6	Apr-80	50.9	94.7	Feb-85	33.2	42.4	Dec-89	40.9	75.2
Jul-75	44.5	45.2	May-80	190.0	157.3	Mar-85	59.1	92.5	Jan-90	69.3	26.7
Aug-75	37.6	65.1	Jun-80	0.0	39.0	Apr-85	26.5	236.3	Feb-90	35.6	98.5
Sep-75	20.3	24.2	Jul-80	27.6	108.0	May-85	22.4	81.3	Mar-90	12.5	156.0
Oct-75	84.9	34.6	Aug-80	86.7	47.6	Jun-85	16.7	98.1	Apr-90	55.3	107.1
Nov-75	63.4	12.0	Sep-80	151.0	99.0	Jul-85	31.0	44.2	May-90	99.3	108.2
Dec-75	33.7	44.5	Oct-80	83.9	50.9	Aug-85	108.0	55.2	Jun-90	84.3	36.4
Jan-76	67.6	26.7	Nov-80	37.0	190.0	Sep-85	73.3	27.6	Jul-90	48.8	27.6
Feb-76	43.7	37.6	Dec-80	70.5	0.0	Oct-85	115.3	33.2	Aug-90	94.1	48.4

APPENDIX G-2: Monthly Rainfall (mm) derives from readings taken at Bwami Daniel Farm (9036310) and Elem, Soysambu Estate (9036147)

	9036310	9036147
Sep-90	190.1	37.7
Oct-90	32.5	54.1
Nov-90	64.7	40.9
Dec-90	76.0	69.3
Jan-91	29.5	35.6
Feb-91	14.0	12.5
Mar-91	18.6	55.3
Apr-91	24.9	99.3
May-91	118.8	84.3
Jun-91	163.7	48.8
Jul-91	128.5	94.1
Aug-91	149.2	190.1
Sep-91	156.0	32.5
Oct-91	38.5	64.7
Nov-91	24.3	76.0
Dec-91	42.3	29.5
Jan-92	45.1	14.0
Feb-92	61.9	18.6
Mar-92	206.8	24.9
Apr-92	16.4	118.8
May-92	53.0	163.7
Jun-92	126.0	128.5
Jul-92	156.5	149.2
Aug-92	53.1	156.0
Sep-92	82.3	38.5
Oct-92	32.8	24.3
Nov-92	26.2	42.3
Dec-92	53.3	45.1
Jan-93	25.9	61.9
Feb-93	0.9	206.8
Mar-93	23.6	16.4
Apr-93	73.5	53.0
May-93	109.5	126.0
Jun-93	79.5	156.5
Jul-93	60.1	53.1
Aug-93	94.5	82.3
Sep-93	115.6	32.8
Oct-93	50.3	26.2
Nov-93	24.8	53.3
Dec-93	110.3	25.9
Jan-94	10.0	0.9
Feb-94	0.0	23.6
Mar-94	44.8	73.5
Apr-94	59.5	109.5
May-94	45.5	79.5
Jun-94	71.8	60.1
Jul-94	148.1	94.5
Aug-94	92.0	115.6
Sep-94	101.8	50.3
Oct-94	65.1	24.8
Nov-94	27.4	110.3
Dec-94	0.0	10.0
Jan-95	38.8	0.0
Feb-95	89.3	44.8
Mar-95	39.8	59.5
Apr-95	74.4	45.5
May-95	108.9	71.8
Jun-95	178.8	148.1
Jul-95	103.3	92.0
Aug-95	109.0	101.0
Sep-95	11.0	101.8
Oct-95	103.1	49.9
Nov-95	4.5	65.1
Dec-95	11.2	27.4

APPENDIX G-3: Monthly Rainfall (mm)

EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)	EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)
178440	9964500	1.6	NC1	1758.25	175280	9959500	2.6	NN6	1757.25
177940	9964500	2.6	NC2	1757.25	174780	9959500	2.6	NN7	1757.25
177440	9964500	2.6	NC3	1757.25	174280	9959500	2.6	NN8	1757.25
176940	9964500	2.5	NC4	1757.35	175780	9959500	2.6	NN9	1757.25
176440	9964500	2.5	NC5	1757.35	173280	9959500	2.6	NN10	1757.25
175960	9964500	1.1	NC6	1758.75	172780	9959500	2.4	NN11	1757.45
175576	9964000	0.6	NDI	1759.25	172420	9959500	2.4	NN12	1757.45
176076	9964000	2	ND2	1757.85	172180	9959500	1.1	NN13	1758.75
176570	9964000	2.5	ND3	1757.35	178720	9959000	2.1	N01	1757.75
177075	9964000	2.6	ND4	1757.25	178220	9959000	2.8	N02	1757.05
177575	9964000	2.7	ND5	1757.15	177720	9959000	2.8	N03	1757.05
178075	9964000	2.6	ND6	1757.25	177220	9959000	2.7	N04	1757.15
178370	9964000	1.7	ND7	1758.15	176720	9959000	2.7	N05	1757.15
173260	9961000	0.5	NK1	1759.35	176220	9959000	2.6	N06	1757.25
173760	9961000	2.5	NK2	1757.35	175770	9959000	2.6	N07	1757.25
174260	9961000	2.6	NK3	1757.25	175220	9959000	2.6	N08	1757.25
174760	9961000	2.7	NK4	1757.15	174720	9959000	2.6	N09	1757.25
175260	9961000	2.7	NK5	1757.15	174220	9959000	2.6	N10	1757.25
175760	9961000	2.7	NK6	1757.15	173720	9959000	2.6	N11	1757.25
176260	9961000	2.8	NK7	1757.05	173220	9959000	2.6	N12	1757.25
176760	9961000	2.8	NK8	1757.05	172720	9959000	2.4	N13	1757.45
177260	9961000	2.8	NK9	1757.05	172350	9959000	1	N14	1758.85
177760	9961000	7.8	NK10	1757.05	172550	9958500	0.7	NP1	1759.15
178260	9961000	2.6	NK11	1757.25	172850	9958500	1.8	NP2	1758.05
178670	9961000	1.2	NK12	1758.65	173350	9958500	2.1	NP3	1757.75
178630	9960500	1.2	NLI	1758.65	173850	9958500	2.4	NP4	1757.45
178130	9960500	2.7	NL2	1757.15	174350	9958500	2.4	NP5	1757.45
177630	9960500	2.8	NL3	1757.05	174850	9958500	2.5	NP6	1757.35
177130	9960500	2.8	NL4	1757.05	175350	9958500	2.6	NP7	1757.25
176630	9960500	2.7	NL5	1757.15	175850	9958500	2.6	NP8	1757.25
176130	9960500	2.7	NL6	1757.15	176350	9958500	2.7	NP9	1757.15
175630	9960500	2.6	NL7	1757.25	176850	9958500	2.7	NP10	1757.15
176130	9960500	2.6	NL8	1757.25	177350	9958500	2.7	NP11	1757.15
174630	9960500	2.6	NL9	1757.25	177850	9958500	2.1	NP12	1757.75
174130	9960500	7.6	NL10	1757.25	173600	9958000	1	NQ1	1758.85
173630	9960500	7.6	NL11	1757.25	174100	9958000	2.4	NQ2	1757.45
173130	9960500	7.6	NL12	1757.25	174600	9958000	2.4	NQ3	1757.45
172630	9960500	2.6	NL13	1757.25	175100	9958000	2.4	NQ4	1757.45
172520	9960500	1.3	NL14	1758.55	175600	9958000	2.5	NQ5	1757.35
178620	9960000	1.3	NM1	1758.55	176100	9958000	2.6	NQ6	1757.25
178120	9960000	2.7	NM2	1757.15	176600	9958000	2.6	NQ7	1757.25
177620	9960000	2.7	NM3	1757.15	177100	9958000	2.6	NO8	1757.25
177120	9960000	2.8	NM4	1757.05	177600	9958000	2.4	NO9	1757.45
176620	9960000	2.8	NM5	1757.05	178100	9958000	2	NQ10	1757.85
176120	9960000	2.7	NM6	1757.15	178580	9958000	1.2	NQ11	1758.65
175620	9960000	2.7	NM7	1757.15	173910	9957500	1.3	NRI	1758.55
175120	9960000	2.7	NM8	1757.15	174400	9957500	1.3	NR2	1758.55
174620	9960000	2.6	NM9	1757.25	174910	9957500	2.3	NR3	1757.55
174120	9960000	2.6	NM10	1757.25	175410	9957500	2.4	NR4	1757.45
173620	9960000	2.6	NM11	1757.25	175910	9957500	2.5	NR5	1757.35
173120	9960000	2.6	NM12	1757.25	176410	9957500	2.4	NR6	1757.45
172620	9960000	2.4	NM13	1757.45	176910	9957500	2.4	NR7	1757.45
172405	9960000	1.2	NM14	1758.65	177410	9957500	2.4	NR8	1757.45
178280	9959500	2.1	NN1	1757.75	177910	9957500	2	NR9	1757.85
177780	9959500	2.8	NN2	1757.05	178410	9957500	1.7	NR10	1758.15
177280	9959500	2.8	NN3	1757.05	178580	9957500	1.1	NR11	1758.75
176780	9959500	2.8	NN4	1757.05	174100	9957000	0.9	N51	1758.95
175780	9959500	2.6	NN5	1757.25	174600	9957000	1.3	N52	1758.55

APPENDIX H-1A Bathymetric data of Lake Nakuru

EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)	EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)
175100	9957000	2.3	N53	1757.55	178200	9962500	2.6	NF2	1757.25
175600	9957000	2.5	N54	1757.35	177700	9962500	2.8	NF3	1757.05
176100	9957000	2.5	N55	1757.35	177200	9962500	2.8	NF4	1757.05
176600	9957000	2.5	N56	1757.35	176700	9962500	2.8	NF5	1757.05
177100	9957000	2.4	N57	1757.45	176200	9962500	2.7	NF6	1757.15
177600	9957000	2.3	N58	1757.55	175700	9962500	2.7	NF7	1757.15
178100	9957000	2.1	N59	1757.75	175200	9962500	1.8	NF8	1758.05
178600	9957000	1	N60	1758.85	174820	9962500	1.2	NF9	1758.65
178020	9957000	1.3	N61	1758.55	178640	9963000	1.2	NE1	1758.65
177350	9956500	1	NJ1	1758.65	178140	9963000	2.6	NE2	1757.25
176850	9956500	1.8	NJ2	1758.05	177640	9963000	2.8	NE3	1757.05
176350	9956500	1.9	NJ3	1757.95	177140	9963000	2.8	NE4	1757.05
175850	9956500	1.7	NJ4	1758.15	176640	9963000	2.7	NE5	1757.15
175350	9956500	1.4	NJ5	1758.45	176140	9963000	2.6	NE6	1757.25
174850	9956500	1.3	NJ6	1758.55	175640	9963000	1.9	NE7	1757.95
174350	9956500	0.5	NJ7	1759.35	175340	9963000	0.5	NE8	1759.35
173770	9961500	1.2	NH1	1758.65	175600	9963500	0.6	NO1	1759.25
174270	9961500	2.4	NH2	1757.45	176100	9963500	2.5	NO2	1757.35
174770	9961500	2.6	NH3	1757.25	176600	9963500	2.8	NO3	1757.05
175270	9961500	2.7	NH4	1757.15	177100	9963500	2.8	NO4	1757.05
175770	9961500	2.7	NH5	1757.15	177600	9963500	2.8	NO5	1757.05
176270	9961500	2.8	NH6	1757.05	178100	9963500	2.6	NO6	1757.25
176770	9961500	2.8	NH7	1757.05	178450	9963500	1	NO7	1758.85
177270	9961500	2.8	NH8	1757.05	175960	9964500	1.1	NO8	1758.75
177770	9961500	2.8	NH9	1757.05	175880	9965000	0.9	NB1	1758.95
178270	9961500	2.6	NH!O	1757.25	176380	9965000	2.4	NB2	1757.45
178550	9961500	1.3	NH11	1758.55	176880	9965000	2.5	NB3	1757.35
174600	9962000	1.2	N62	1758.65	177380	9965000	2.4	NB4	1757.45
175100	9962000	1.6	N63	1758.25	177880	9965000	2.4	N85	1757.45
175600	9962000	2.7	N64	1757.15	178380	9965000	1.9	NB6	1757.95
176100	9962000	2.7	N65	1757.15	178580	9965000	1.1	NB7	1758.75
176600	9962000	2.8	N66	1757.05	178195	9965500	0.9	NA1	1758.95
177100	9962000	2.8	N67	1757.05	177680	9965500	2	NA2	1757.85
177600	9962000	2.7	N68	1757.15	177180	9965500	2.4	NA3	1757.45
178100	9962000	2.7	N69	1757.15	176680	9965500	1.9	NA4	1757.95
178600	9962000	1.6	N70	1758.25	176050	9965500	0.8	NA5	1759.05
178700	9962500	1.2	NFI	1758.65	176700	9965500	1.2	SS2	1758.65
					177200	9965500	1.2	SS3	1758.65

APPENDIX H-1B Bathymetric data of Lake Nakuru

EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)	EAST	NORTH	DEPTH	DESCRIP.	ELEV(m)
195005	9950786	1.0	E201	1775.83	192998	9950207	1.7	E611	1775.13
194847	9950429	0.6	SP	1776.23	193004	9949712	1.6	E612	1775.23
194695	9950322	0.8	SP	1776.03	193007	9949181	1.2	E613	1775.63
194470	9950167	1.0	SP	1775.83	192505	9948810	1.0	E701	1775.83
194472	9949738	0.6	SP	1776.23	192500	9949310	1.2	E702	1775.63
195003	9949043	1.2	E202	1775.63	192498	9949800	1.2	E703	1775.63
195003	9949243	0.2	E203	1776.63	192500	9950810	1.6	E704	1775.23
195012	9948563	1.5	E204	1775.33	192500	9951300	1.7	E705	1775.13
195002	9948048	1.2	E205	1775.63	192500	9951850	1.8	E706	1775.03
195410	9947774	0.9	SP	1775.93	192506	9952320	1.8	E707	1775.03
195500	9947685	0.8	E101	1776.03	192503	9952800	1.7	E708	1775.13
195498	9948190	1.3	E102	1775.53	192505	9953300	1.7	E709	1775.13
195507	9948492	1.3	E103	1775.53	192500	9953810	1.7	E710	1775.13
194500	9948749	0.4	E301	1776.43	192499	9954300	1.3	E711	1775.53
194501	9948849	1.4	E302	1775.43	192506	9954810	1.2	E712	1775.63
194500	9949354	1.3	E303	1775.53	192500	9955180	1.1	E713	1775.73
194498	9949637	0.6	E304	1776.23	192005	9949400	1.3	E801	1775.53
199500	9950137	1.0	E305	1775.83	192007	9949500	1.4	E802	1775.43
194500	9950770	1.6	E306	1775.23	191600	9949506	1.2	SP	1775.63
194500	9951200	1.7	E307	1775.13	191052	9950000	0.7	SP	1776.13
194500	9951770	1.2	E308	1775.63	191818	9950215	1.5	SP	1775.33
194500	9951980	1.2	E309	1775.63	192000	9950360	0.6	E803	1776.23
194000	9948700	0.2	E401	1776.63	191999	9950868	1.5	E804	1775.33
194000	9948752	0.8	E402	1766.03	192004	9951360	1.6	E805	1775.23
194000	9949254	1.4	E403	1775.43	191999	9951862	1.7	E806	1775.13
194002	9949760	1.5	E404	1775.33	192002	9952363	1.8	E807	1775.03
194002	9950255	1.7	E405	1775.13	192002	9952862	1.8	E808	1775.03
194006	9950754	1.7	E406	1775.13	192009	9953370	1.7	E809	1775.13
194005	9951238	1.7	E407	1775.13	192003	9953859	1.3	E810	1775.13
194008	9951760	1.7	E408	1775.13	192008	9952361	1.7	E811	1775.13
194008	9952181	1.1	E409	1775.73	192000	9954877	0.8	E812	1776.03
193595	9952215	1.0	SP	1775.83	191500	9954591	1.0	E901	1775.83
193370	9953221	1.2	SP	1775.63	191508	9954088	1.8	E902	1775.03
193228	9954697	1.2	SP	1775.63	191508	9953589	1.7	E903	1775.13
193502	9952297	1.3	E501	1775.53	191497	9953086	1.7	E904	1775.13
193503	9951797	1.2	E502	1775.63	191499	9952591	1.7	E905	1775.13
193500	9951297	1.7	E503	1775.13	191448	9952175	1.8	E906	1775.03
193500	9950797	1.7	E504	1775.13	191005	9952997	1.5	E1001	1775.33
193500	9950297	1.7	E505	1775.13	191006	9953492	1.0	E1002	1775.83
193500	9949797	1.6	E506	1775.23	191000	9954000	1.6	E1003	1775.23
193500	9949290	1.1	E507	1775.73	191002	9954455	1.0	E1004	1775.33
192995	9955213	0.7	E601	1776.13	191000	9954552	0.6	E1005	1775.83
193005	9954705	1.6	E602	1775.23	190500	9954334	0.7	E1101	1775.23
193012	9954208	1.6	E603	1775.23	190500	9953860	1.3	E1102	1775.83
193010	9953703	1.7	E604	1775.13	190500	9953358	1.2	E1103	1776.23
193008	9953211	1.7	E605	1775.13	190500	9954334	0.7	E1104	1776.13
193011	9952709	1.7	E606	1775.13	190500	9953458	1.3	E1105	1775.53
193006	9952210	1.7	E607	1775.13	190500	9953358	1.2	E1106	1775.63
193011	9951702	1.8	E608	1775.03	190880	9953508	1.5	E1107	1775.33
193005	9951208	1.7	E609	1775.13	190000	9953871	0.8	E1201	1776.03
192998	9950711	1.7	E610	1775.13	190000	9953338	0.4	E1202	1776.43
					194098	9950988	1.5	SP	1775.33
					194935	9950775	1.3	SP	1775.53

APPENDIX H-1C: Bathymetric data of Lake Elementeita

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (m)	EAST	NORTH	DEPTH	DESCRIPN.	ELEV (m)
203381	9909009	2.9	NA01	1882.6	206950	9919000	4.2	N1912	1881.3
203885	9909002	3.5	NA02	1882.0	206250	9919000	4.3	N1913	1881.2
204390	9909008	4.2	NA03	1881.3	205750	9919000	4.8	N1914	1880.7
204885	9908996	4.0	NA04	1881.5	205250	9919000	4.8	N1915	1880.7
205386	9909002	3.7	NA05	1881.8	202250	9919000	5.6	N1921	1879.9
199686	9909893	3.1	SP1	1882.4	201750	9919000	5.7	N1922	1879.8
205062	9908825	3.3	SP2	1882.4	201250	9919000	5.4	N1923	1880.1
211540	9914590	9.8	SP3	1875.7	200750	9919000	5.3	N1924	1880.2
217965	9914195	1.1	SP4	1884.4	200460	9919000	5.1	N1925	1880.4
199065	9914275	3.7	SP5	1881.8	202430	9919500	5.1	N2006	1880.4
202450	9920785	2.8	SP11	1882.7	202930	9919500	4.9	N2007	1880.6
202865	9921250	3.1	SP12	1882.4	203430	9919500	4.8	N2008	1880.7
201490	9920711	3.1	2SP13	1882.4	203930	9919500	4.6	N2009	1880.9
213600	9918835	2.6	SP14	1882.9	204430	9919500	4.4	N2010	1881.1
200310	9920500	3.2	N2201	1882.3	207960	9919500	2.1	N2016	1883.4
200810	9920500	1.6	N2202	1881.9	208220	9919500	2.0	N2017	1883.5
201310	9920500	3.7	N2203	1881.8	202080	9920000	4.7	N2106	1880.8
201810	9920500	3.8	N2204	1881.7	201580	9920000	4.6	N2107	1880.9
202310	9920500	4.1	N2205	1881.4	201080	9920000	4.5	N2108	1881.0
199580	9920000	3.3	N2111	1882.2	200580	9920000	4.2	N2109	1881.3
208900	9920000	1.1	N2112	1884.4	200080	9920000	3.8	N2110	1881.7
209010	9920000	1.9	N2113	1883.6	202810	9920500	3.9	N2206	1881.6
208710	9920000	1.6	N2114	1883.9	203310	9920500	3.6	N2207	1881.9
208210	9920000	1.3	N2115	1884.2	203810	9920500	3.4	N2208	1882.1
204580	9920000	3.0	N2101	1882.5	204060	9920500	2.6	N2209	1882.9
204080	9920000	3.5	N2102	1882.0	203830	9921000	3.2	N2301	1882.3
203580	9920000	4.0	N2103	1881.5	203330	9921000	1.9	N2302	1881.6
203080	9920000	4.5	N2104	1881.0	202830	9921000	3.5	N2303	1882.0
202580	9920000	4.5	N2105	1881.0	202710	9921000	3.1	N2304	1882.4
204930	9919500	3.9	N2011	1881.6	202865	9921250	3.1	N2305	1882.4
205430	9919500	3.6	N2012	1881.9	200730	9919370	2.4	SP6	1883.1
205930	9919500	3.5	N2013	1882.0	205970	9919680	2.9	SP7	1882.6
206375	9919500	2.5	N2014	1883.0	205530	9919785	2.5	SP8	1883.0
207570	9919460	2.5	N2015	1883.0	204806	9919850	3.1	SP9	1882.4
199930	9919500	4.4	N2001	1881.1	203850	9920940	3.1	SP10	1882.4
200430	9919500	4.8	N2002	1880.7	205893	9909000	1.9	NA06	1882.6
200930	9919500	5.0	N2003	1880.5	205067	9908825	3.3	SS3	1882.2
201400	9919500	5.3	N2004	1880.2	202950	9918500	6.0	N1821	1879.5
201930	9919500	5.1	N2005	1880.4	202450	9918500	5.9	N1822	1879.6
204750	9919000	5.0	N1916	1880.5	201950	9918500	5.9	N1823	1879.6
204250	9919000	5.2	N1917	1880.3	201450	9918500	5.8	N1824	1879.7
203750	9919000	5.4	N1918	1880.1	200950	9918500	5.8	N1825	1879.7
203250	9919000	5.5	N1919	1880.0	205450	9918500	5.7	N1816	1879.8
202750	9919000	5.5	N1920	1880.0	204950	9918500	5.7	N1817	1879.8
209750	9919000	3.1	N1906	1882.4	204450	9918500	5.7	N1818	1879.8
209250	9919000	2.8	N1907	1882.7	203950	9918500	5.8	N1819	1879.7
208750	9919000	3.1	N1908	1882.4	203450	9918500	5.9	N1822	1879.6
208250	9919000	3.4	N1909	1882.1	207950	9918500	4.7	N1811	1880.8
207750	9919000	3.9	N1910	1881.6	207460	9918500	5.2	N1812	1880.3
200450	9918500	5.7	N1826	1879.8	206950	9918500	5.3	N1813	1880.2
199950	9918500	5.2	N1827	1880.3	206450	9918500	5.5	N1814	1880.0
211750	9919000	2.7	N1901	1882.8	205950	9918500	5.6	N1815	1879.9
211500	9919000	3.2	N1902	1882.3	210450	9918500	3.7	N1806	1881.8
211250	9919000	3.3	N1903	1882.2	209950	9918500	3.4	N1807	1882.1
210750	9919000	3.4	N1904	1882.1	209450	9918500	3.6	N1808	1881.9
210250	9919000	3.4	N1905	1882.1	208950	9918500	4.2	N1809	1881.3
207250	9919000	4.6	N1911	1880.9	208450	9918500	4.5	N1810	1881.0

APPENDIX H-3A: Bathymetric data of Lake Naivasha

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)	EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)
212818	9918500	2.4	N1801	1883.1	206500	9917500	6.0	N1615	1879.5
212320	9918500	3.0	N1802	1882.5	211000	9917500	4.5	N1606	1881.0
211820	9918500	3.5	N1803	1882.0	210500	9917500	4.0	N1607	1881.5
211450	9918500	3.6	N1804	1881.9	210000	9917500	4.1	N1608	1881.4
210950	9918500	3.8	N1805	1881.7	209500	9917500	3.9	N1609	1881.6
213000	9918000	3.0	N1731	1882.5	209000	9917500	4.3	N1610	1881.2
213130	9918000	2.2	N1732	1883.3	213128	9917500	2.8	N1601	1882.7
210500	9918000	3.7	N1726	1881.8	213000	9917498	3.4	N1602	1882.1
211000	9918000	3.8	N1727	1881.7	212500	9917502	4.1	N1603	1881.4
211500	9918000	4.0	N1728	1881.5	212000	9917498	4.1	N1604	1881.4
212000	9918000	3.7	N1729	1881.8	211560	9917501	4.1	N1605	1881.4
212500	9918000	3.4	N1730	1882.1	212860	9917000	3.7	N1531	1881.8
208000	9918000	5.2	N1721	1880.3	213350	9917000	2.4	N1532	1883.1
208500	9918000	4.9	N1722	1880.6	210355	9917000	3.4	N1526	1882.1
209000	9918000	4.4	N1723	1881.1	210855	9916998	4.0	N1527	1881.5
209500	9918000	3.9	N1724	1881.6	211350	9917000	4.2	N1528	1881.3
210000	9918000	3.8	N1725	1881.7	211850	9917000	4.1	N1529	1881.4
205500	9918000	6.1	N1716	1879.4	212350	9916995	3.9	N1530	1881.6
206000	9918000	5.9	N1717	1879.6	207960	9917000	6.2	N1521	1879.3
206500	9918000	5.9	N1718	1879.6	208460	9917000	5.9	N1522	1879.6
207000	9918000	5.8	N1719	1879.7	208960	9917000	5.7	N1523	1879.8
207500	9918000	5.5	N1720	1880.0	209460	9917000	4.7	N1524	1880.8
203000	9918000	6.1	N1711	1879.3	209960	9917000	3.5	N1525	1882.0
203500	9918000	6.1	N1712	1879.4	205460	9917000	6.6	N1516	1878.9
204000	9918000	6.2	N1713	1879.3	205960	9917000	6.4	N1517	1879.1
204500	9918000	6.1	N1714	1879.4	206460	9917000	6.5	N1518	1879.0
205000	9918000	6.0	N1715	1879.5	206960	9916998	6.4	N1519	1879.1
200500	9918000	5.9	N1706	1879.6	207460	9917000	6.3	N1520	1879.2
201000	9918000	6.0	N1707	1879.5	202960	9917001	6.6	N1511	1878.9
201500	9918000	6.0	N1708	1879.5	203460	9917000	6.8	N1512	1878.7
202000	9918000	6.1	N1709	1879.4	203960	9917000	6.8	N1513	1878.7
202500	9918000	6.2	N1710	1879.3	204460	9917000	6.7	N1514	1878.8
198215	9918000	3.4	N1701	1882.1	204960	9917000	6.6	N1515	1878.9
198500	9918000	4.1	N1702	1881.4	200460	9917000	6.2	N1506	1879.3
199000	9918000	5.0	N1703	1880.5	200960	9917000	6.2	N1507	1879.3
199500	9918000	5.5	N1704	1880.0	201460	9917000	6.3	N1508	1879.2
200000	9918000	5.8	N1705	1879.7	201960	9917001	6.3	N1509	1879.2
198300	9917500	4.3	N1631	1881.2	202460	9917000	6.3	N1510	1879.2
197800	9917500	3.2	N1632	1882.3	197960	9917000	3.6	N1501	1881.9
201300	9917500	6.2	N1626	1879.3	198460	9917000	5.1	N1502	1880.4
200800	9917500	6.0	N1627	1879.5	198955	9917000	5.6	N1503	1879.9
200300	9917500	6.2	N1628	1879.3	199460	9917000	5.9	N1504	1879.6
199800	9917500	6.0	N1629	1879.5	199960	9917000	6.2	N1505	1879.3
199300	9917500	5.7	N1630	1879.8	198500	9916500	5.6	N1431	1879.9
203680	9917500	6.3	N1621	1879.2	198000	9916500	4.3	N1432	1881.2
203300	9917500	6.3	N1622	1879.2	197690	9916500	3.2	N1433	1882.3
202800	9917500	6.3	N1623	1879.2	201000	9916500	6.3	N1426	1879.2
201300	9917500	6.3	N1624	1879.2	200500	9916500	6.4	N1427	1879.1
201800	9917500	6.2	N1625	1879.3	200000	9916500	6.3	N1428	1879.2
206000	9917500	6.1	N1616	1879.4	199500	9916500	6.3	N1429	1879.2
205500	9917500	6.1	N1617	1879.4	199000	9916500	5.9	N1430	1879.6
205000	9917500	6.3	N1618	1879.2	203500	9916500	6.4	N1421	1879.1
204500	9917500	6.2	N1619	1879.3	203000	9916500	6.6	N1422	1878.9
204000	9917500	6.4	N1620	1879.1	202500	9916500	6.6	N1423	1878.9
208500	9917500	5.0	N1611	1880.5	202000	9916501	6.4	N1424	1879.1
207990	9917500	5.8	N1612	1879.7	201500	9916500	6.4	N1425	1879.1
207500	9917500	5.8	N1613	1879.7	206000	9916500	6.7	N1416	1878.8
207000	9917500	6.0	N1614	1879.5	205500	9916500	7.0	N1417	1878.5

APPENDIX H-3B: bathymetric data of Lake Naivasha

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)	EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)
205000	9916501	6.6	N1418	1878.9	209340	9915500	5.2	N1224	1880.3
204500	9916500	6.5	N1419	1879.0	209840	9915000	1.5	N1225	1884.0
204000	9916500	6.5	N1420	1879.0	205340	9915501	6.8	N1216	1878.7
208500	9916500	6.0	N1411	1879.5	205840	9915500	6.7	N1217	1878.8
208000	9916499	6.5	N1412	1879.0	206340	9915500	6.7	N1218	1878.6
207500	9916500	6.6	N1413	1878.9	206840	9915500	6.7	N1219	1878.8
207000	9916500	6.7	N1414	1878.8	207340	9915498	6.6	N1220	1878.9
206500	9916500	6.7	N1415	1878.8	202840	9915500	6.8	N1211	1878.7
210999	9916500	3.4	N1406	1882.1	203340	9915500	6.9	N1212	1878.6
210505	9916501	1.9	N1407	1882.6	203840	9915500	6.9	N1213	1878.6
210001	9916500	2.7	N1406	1882.8	204340	9915498	6.9	N1214	1878.6
209500	9916500	4.3	N1409	1881.2	204840	9915501	6.8	N1215	1878.7
209000	9916500	5.4	N1410	1880.1	200340	9915500	6.7	N1206	1878.8
213270	9916500	2.8	N1401	1882.7	200840	9915500	6.8	N1207	1878.7
213000	9916500	3.8	N1402	1881.7	201340	9915500	6.8	N1208	1878.7
212498	9916500	3.8	N1403	1881.7	201840	9915500	6.7	N1209	1878.8
212000	9916501	4.2	N1404	1881.3	202340	9915500	6.7	N1210	1878.8
211500	9916500	3.6	N1405	1881.9	197840	9915500	3.4	N1201	1882.1
210040	9916000	0.5	N1326	1885.0	198330	9915498	5.4	N1202	1880.1
211010	9916000	2.6	N1327	1882.9	198830	9915500	5.8	N1203	1879.7
211520	9916000	13.9	N1328	1871.6	199340	9915506	6.2	N1204	1879.3
212010	9916000	6.0	N1329	1879.5	199830	9915501	6.5	N1205	1879.0
212515	9915998	3.9	N1330	1881.6	199160	9915000	5.9	N1126	1879.6
212893	9916000	1.8	N1331	1882.7	198585	9915000	4.5	N1127	1881.0
207760	9916000	6.5	N1321	1879.0	198030	9915000	3.4	N1128	1882.1
208000	9916000	6.7	N1322	1878.8	201660	9914998	7.0	N1121	1878.5
208500	9916000	6.1	N1323	1879.4	201160	9915000	6.9	N1122	1878.6
209000	9916000	5.5	N1324	1880.0	200660	9915000	6.9	N1123	1878.6
209500	9916000	3.5	N1325	1882.0	200160	9951000	6.8	N1124	1878.7
205260	9916000	6.7	N1316	1878.8	199660	9915000	6.4	N1125	1879.1
205760	9916000	6.7	N1317	1878.8	204160	9915000	7.0	N1116	1878.5
206260	9916000	6.8	N1318	1878.7	203670	9915000	7.2	N1117	1878.3
206760	9916000	6.8	N1319	1878.7	203170	9915000	7.2	N1118	1878.3
207260	9916000	6.6	N1320	1878.9	202660	9915000	7.0	N1119	1878.5
202760	9916000	6.5	N1311	1879.0	202160	9915000	7.0	N1120	1878.5
203260	9916000	6.5	N1312	1879.0	206660	9915000	6.9	N1111	1878.6
203760	9916000	6.5	N1313	1879.0	206165	9915001	6.9	N1112	1878.6
204260	9916000	6.7	N1314	1878.8	205655	9915000	6.8	N1113	1878.7
204760	9916000	6.6	N1315	1878.9	205162	9915000	6.8	N1114	1878.7
200260	9916000	6.5	N1306	1879.0	204660	9915003	6.9	N1115	1878.6
200760	9916000	6.4	N1307	1879.1	209170	9915004	5.7	N1106	1879.8
201260	9916000	6.5	N1308	1879.0	208670	9915000	6.3	N1107	1879.2
201760	9916000	6.5	N1309	1879.0	208170	9915000	6.6	N1108	1878.9
202260	9916000	6.5	N1310	1879.0	207660	9915005	6.7	N1109	1878.8
197760	9916000	3.4	N1301	1882.1	207160	9915000	6.7	N1110	1878.8
198260	9916000	5.3	N1302	1880.2	212485	9915000	1.3	N1101	1884.2
198760	9916000	5.6	N1303	1879.9	211915	9914995	12.6	N1102	1872.9
199260	9916000	6.2	N1304	1879.3	211415	9914998	14.2	N1103	1871.3
199760	9916000	6.4	N1305	1879.1	210160	9915000	0.7	N1104	1884.8
210880	9915500	3.8	N1226	1881.7	209660	9915000	5.4	N1105	1880.1
211340	9915500	15.5	N1227	1870.0	199265	9914500	5.9	N1026	1879.6
211845	9915500	14.5	N1228	1871.0	198770	9914500	3.7	N1027	1881.8
212340	9915501	6.6	N1229	1878.9	201770	9914500	7.4	N1021	1878.1
212840	9915500	2.5	N1230	1881.0	201270	9914500	7.4	N1022	1878.1
207840	9915500	6.5	N1221	1879.0	200765	9914500	7.3	N1023	1878.2
208340	9915500	6.2	N1222	1879.3	200265	9914500	7.1	N1024	1878.4
208840	9915500	6.0	N1223	1879.5	199765	9914501	6.1	N1025	1879.4

APPENDIX H-3C: Bathymetric data of Lake Naivasha

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)	EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)
204270	9914500	7.5	N1016	1878.0	208255	9913495	6.2	N817	1879.3
203270	9914500	7.5	N1018	1878.0	208755	9913499	6.0	N818	1879.5
202770	9914500	7.4	N1019	1878.1	209265	9913503	5.8	N819	1879.7
202270	9914500	7.4	N1020	1878.1	209745	9913500	5.7	N820	1879.8
206770	9914500	7.0	N1011	1878.5	202749	9913495	7.6	N806	1877.9
206270	9914500	7.1	N1012	1878.4	203260	9913500	7.6	N807	1877.9
205770	9914500	7.1	N1013	1878.4	203755	9913501	7.6	N808	1877.9
205270	9914501	7.3	N1014	1878.2	204265	9913502	7.4	N809	1878.1
204770	9914499	7.3	N1015	1878.2	204760	9913500	7.3	N810	1878.2
209270	9914500	6.2	N1006	1879.3	200260	9913500	4.0	N801	1881.5
208770	9914500	6.2	N1007	1879.3	200760	9913498	6.3	N802	1879.2
208270	9914500	6.4	N1008	1879.1	201260	9913501	7.1	N803	1878.4
207770	9914500	6.8	N1009	1878.7	201764	9913499	7.5	N804	1878.0
207270	9914501	7.0	N1010	1878.5	202260	9913499	7.6	N805	1877.9
212025	9914500	1.3	N1001	1884.2	203090	9912998	7.6	N716	1877.9
211505	9914510	1.4	N1002	1884.1	202586	9913004	7.7	N717	1877.8
210625	9914500	1.1	N1003	1884.4	202085	9912999	7.6	N718	1877.9
210150	9914500	5.2	N1004	1880.3	201582	9913001	7.5	N719	1878.0
209770	9914500	5.7	N1005	1879.8	201185	9913000	2.4	N720	1883.1
209960	9914000	6.0	N921	1879.5	205586	9913004	7.1	N711	1878.4
210460	9913998	5.6	N922	1879.9	205090	9913008	7.2	N712	1878.3
210954	9914006	3.8	N923	1881.7	204586	9913002	7.2	N713	1878.3
211065	9914008	3.2	N924	1882.3	204090	9913000	7.4	N714	1878.1
207460	9914000	7.0	N916	1878.5	203584	9913002	7.4	N715	1878.1
207962	9914000	6.9	N917	1878.6	208088	9913002	6.3	N706	1879.2
208460	9913997	6.7	N918	1878.8	207587	9912998	6.6	N707	1878.9
208960	9914000	6.5	N919	1879.0	207083	9913000	6.9	N708	1878.6
209462	9913998	6.1	N920	1879.4	206585	9913002	6.9	N709	1878.6
204962	9914000	7.3	N91 1	1878.2	206090	9912999	7.0	N710	1878.5
205461	9913997	7.3	N912	1878.2	210585	9913000	2.8	N701	1882.7
205962	9914000	7.2	N913	1878.3	210060	9913015	4.6	N702	1880.9
206462	9914000	7.1	N914	1878.4	210575	9913000	5.5	N703	1880.0
206962	9913998	7.1	N915	1878.4	209088	9913003	5.8	N704	1879.7
202458	9913999	7.5	N906	1878.0	208595	9912998	6.0	N705	1879.5
202960	9913997	7.6	N907	1877.9	208366	9912503	6.1	N616	1879.4
203460	9914000	7.6	N908	1877.9	208869	9912497	5.8	N617	1879.7
203962	9914001	7.6	N909	1877.9	209370	9912496	5.1	N618	1880.4
204460	9914000	7.5	N910	1878.0	209860	9912495	4.1	N619	1881.4
199962	9914000	3.4	N901	1882.1	210145	9912500	2.8	N620	1882.7
200460	9914001	6.5	N902	1879.0	205865	9912504	6.9	N611	1878.6
200965	9914002	7.1	N903	1878.4	206365	9912498	6.9	N612	1878.6
201465	9914001	7.4	N904	1878.1	206865	9912500	6.7	N613	1878.8
201965	9913998	7.4	N905	1878.1	207365	9912498	6.5	N614	1879.0
210259	9913501	4.9	N821	1880.6	207872	9912499	6.4	N615	1879.1
210760	9913503	4.0	N822	1881.5	203369	9912498	7.4	N606	1878.1
210930	9913500	3.0	N823	1882.5	203870	9912503	7.3	N607	1878.2
207759	9913500	6.5	N816	1879.0	204369	9912506	7.2	N608	1878.3
208255	9913495	6.2	N817	1879.3	204868	9912500	7.1	N609	1878.4
208755	9913499	6.0	N818	1879.5	205369	9912499	7.1	N61 0	1878.4
209265	9913503	5.8	N819	1879.7	200868	9912500	3.7	N601	1881.8
209745	9913500	5.7	N820	1879.8	201380	9912505	6.7	N602	1878.8
205260	9913510	7.2	N811	1878.3	201870	9912502	7.0	N603	1878.5
205760	9913504	7.0	N812	1878.5	202375	9912506	7.5	N604	1878.0
206260	9913506	6.9	N813	1878.6	202864	9912505	7.6	N605	1877.9
206757	9913498	6.7	N814	1878.8	207665	9912013	6.2	N516	1879.3
207258	9913497	6.7	N815	1878.8	208170	9912012	6.0	N517	1879.5
207759	9913500	6.5	N816	1879.0	208671	9912008	5.5	N518	1880.0

APPENDIX H-3D: Bathymetric data of Lake Naivasha

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)	EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)
209117	9912995	4.7	N519	1880.8	209437	9911510	3.0	N401	1882.5
209685	9912010	3.0	N520	1882.5	208955	9911510	4.2	N402	1881.3
205171	9912002	6.9	N511	1878.6	208435	9911499	5.5	N403	1880.0
205665	9911998	6.7	N512	1878.8	207950	9911504	5.7	N404	1879.8
206171	9911980	6.7	N513	1878.8	207452	9911498	6.1	N405	1879.4
206660	9911997	6.5	N514	1879.0	208640	9910994	4.1	N321	1881.4
207176	9912001	6.3	N515	1879.2	209009	9911001	2.8	N322	1882.7
207665	9912013	6.2	N516	1879.3	206139	9911005	6.4	N316	1879.1
208170	9912012	6.0	N517	1879.5	206648	9910985	6.2	N317	1879.3
208671	9912008	5.5	N518	1880.0	207140	9911004	5.9	N318	1879.6
209170	9912995	4.7	N519	1880.8	207680	9911006	5.7	N319	1879.8
209685	9912010	3.0	N520	1882.5	208145	9910998	5.2	N320	1880.3
202608	9912000	7.0	N506	1878.5	203641	9910996	6.7	N311	1876.8
203169	9912001	7.2	N507	1878.3	204138	9911001	6.8	N312	1878.7
203672	9912001	7.2	N508	1878.3	204643	9910995	6.7	N313	1878.8
204168	9911993	7.0	N509	1878.5	205146	9911000	6.5	N314	1879.0
204671	9912004	6.8	N510	1878.7	205641	9910992	6.5	N315	1879.0
202749	9913495	7.6	N806	1877.9	201138	9910994	5.9	N306	1879.6
203260	9913500	7.6	N807	1877.9	201638	9911000	6.0	N307	1879.5
203755	9913501	7.6	N808	1877.9	202138	9911004	6.2	N308	1879.3
204265	9913502	7.4	N809	1878.1	202660	9910996	6.4	N309	1879.1
204760	9913500	7.3	N810	1878.2	203140	9910997	6.6	N310	1878.9
205260	9913510	7.2	N811	1878.3	198642	9910997	3.2	N301	1882.3
205760	9913504	7.0	N812	1878.5	199143	9911004	5.5	N302	1880.0
206260	9913506	6.9	N813	1878.6	199634	9910992	5.9	N303	1879.6
206757	9913498	6.7	N814	1878.8	200134	9911004	6.0	N304	1879.5
207258	9913497	6.7	N815	1878.8	200634	9911000	5.9	N305	1879.6
207759	9913500	6.5	N816	1879.0	208826	9910537	3.1	N221	1882.4
208255	9913495	6.2	N817	1879.3	206671	9910499	5.8	N216	1879.7
208755	9913499	6.0	N818	1879.5	207079	9910502	5.6	N217	1879.9
209265	9913503	5.8	N819	1879.7	207600	9910499	5.0	N218	1880.5
209745	9913500	5.7	N820	1879.8	208185	9910492	4.5	N219	1881.0
210259	9913501	4.9	N821	1880.6	208676	9910501	3.7	N220	1881.8
210760	9913503	4.0	N822	1881.5	204127	9910506	6.5	N211	1879.0
210930	9934500	3.0	N822	1882.5	204605	9910510	6.5	N212	1879.0
200147	9912020	3.6	N501	1881.9	205128	9910501	6.2	N213	1879.3
200666	9912005	6.2	N502	1879.3	205656	9910505	6.2	N214	1879.3
201150	9912004	6.4	N503	1879.1	206142	9910510	6.1	N215	1879.4
201670	9912010	6.5	N504	1879.0	201632	9910471	4.7	N206	1880.8
202176	9911999	6.7	N505	1878.8	202155	9910500	5.7	N207	1879.8
199449	9911510	5.2	N421	1880.3	202678	9910560	6.2	N208	1879.3
199188	9911500	3.4	N422	1882.1	203144	9910544	6.4	N209	1879.1
201947	9911501	6.4	N416	1879.1	203621	9910480	6.5	N210	1879.0
201449	9911502	6.3	N417	1879.2	198748	9910500	3.3	N201	1882.2
200955	9911503	6.2	N418	1879.3	199395	9910575	5.4	N202	1880.1
200450	9911500	6.3	N419	1879.2	200028	9910647	5.7	N203	1879.8
199950	9911505	6.2	N420	1879.3	200638	9910632	5.5	N204	1880.0
204452	9911500	6.8	N411	1878.7	201172	9910543	4.8	N205	1880.7
203950	9911497	7.0	N412	1878.5	204074	9909997	6.0	N112	1879.5
203453	9911502	7.0	N413	1878.5	203551	9910011	6.1	N113	1879.4
202951	9911502	6.9	N414	1878.6	203089	9909996	5.9	N114	1879.6
202452	9911500	6.6	N415	1878.9	202561	9910007	3.2	N115	1882.3
206953	9911504	6.4	N406	1879.1	206623	9909995	4.9	N107	1880.6
206450	9911500	6.4	N407	1879.1	206112	9910001	5.4	N108	1880.1
205948	9911504	6.5	N408	1879.0	205608	9909997	5.7	N109	1879.8
205446	9911500	6.7	N409	1878.8	205067	9909997	5.8	N110	1879.7
204949	9911498	6.7	N410	1878.8	204585	9910015	6.0	N111	1879.5

APPENDIX H-3E: Bathymetric data of Lake Naivasha

EAST	NORTH	DEPTH	DESCRIPN.	ELEV (M)
199296	9909945	1.8	N101	1883.7
199675	9910024	4.7	N102	1880.8
208136	9910015	2.8	N104	1882.7
207640	9910010	3.5	N105	1882.0
207127	9910012	4.2	N106	1881.3
200164	9909893	3.1	N103	1882.4
207085	9909502	1.3	NB01	1884.2
206515	9909524	3.6	NB02	1881.9
206020	9909502	4.3	NB03	1881.2
205521	9909502	4.9	NB04	1880.6
205020	9909502	5.2	NB05	1880.3
204530	9909504	5.4	NB06	1880.1
204025	9909500	5.3	NB07	1880.2
203520	9909506	5.2	NB08	1880.3
203051	9909498	3.2	NB09	1882.3

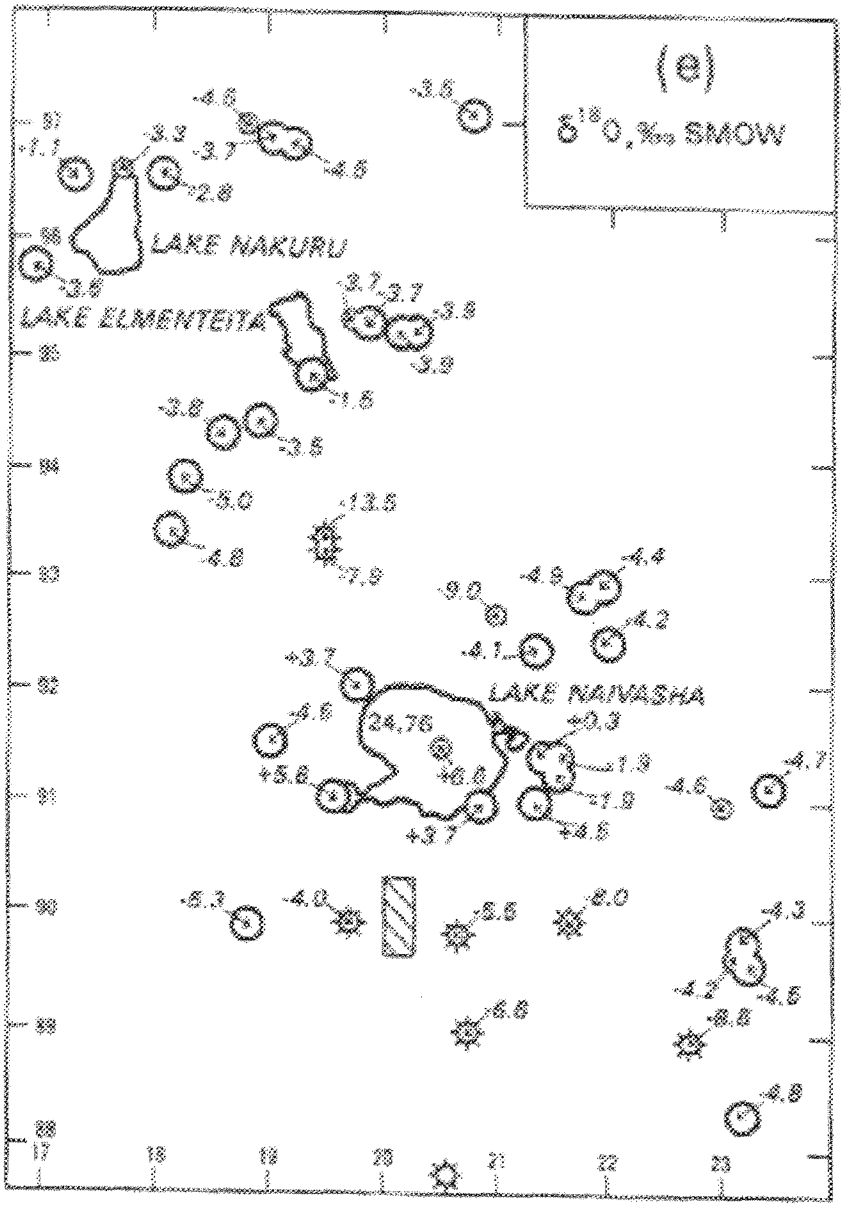
APPENDIX H-3F: Bathymetric data of Lake Naivasha

MONTH	PET	AVMTEV	Factor
JAN	193.00	185.00	1.04
FEB	179.00	182.00	0.98
MAR	195.00	188.00	1.04
APR	151.00	132.00	1.14
MAY	145.00	132.00	1.10
JUN	140.00	122.00	1.15
JUL	139.00	124.00	1.12
AUG	142.00	130.00	1.09
SEP	153.00	139.00	1.10
OCT	157.00	131.00	1.20
NOV	134.00	117.00	1.15
DEC	175.00	154.00	1.14
		Average	1.10

APPENDIX I-A:Comparision between Penman Potential evaporation and Average Monthly Pan Evaporation

ID	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	annual total(mm)
26	1963												1194	
26	1964	1928	1651.5	1375	2011	888	1200.5	1513	968	1055	1142	1323.25	1504.5	1655.975
26	1965	2079.5	1760.25	1624	1654.5	1150	1511	1514	1568	1718	1577	1168	1815	1913.925
26	1966	2231	1869	1873	1298	1412	1316	1340	1274	1159	1183	1108	1721	1778.4
26	1967	2111	2334	2384	1495	1402	1241	1193	1403	1485	1323	1099	1760	1923
26	1968	2206	1441	1463	956	1159	1199	1086	1085	1374	1049	950	1631	1559.9
26	1969	1779	1267	1469	1695	1450	1460	1433	1633	1557	1613	1324	2058	1873.8
26	1970	1654	2330	1789	1330	1651	1154	1247	1139	1214	1340	1236	1834.5	1791.85
26	1971	1798	2365	2396	1483	1316	1213	1207	1189	1538	1417	1269	1611	1880.2
26	1972	1818	1451	1737	1795	1201	1425	1447	1449	2175	1384	1262	1850	1899.4
26	1973	2081	1907	2887	1903	1592	1271	1542	1586	1346	1470	1214	1698	2049.7
26	1974	1772	2340	1824	1614	1373	1251	1137	1195	1340	1311	1080	1546	1778.3
26	1975	2079	2121	2161	1469	1554	1182	1112	1083	1289	1122	1015	1400	1758.7
26	1976	1843	1559	2134	1324	1305	1263	1087	1260	1299	1399	1307	1357	1713.7
26	1977	1461	1590	1677	1119	1273	1136	1076	1221	1110	1380	1002	1155	1520
26	1978	1456	1383	1242	888	1254	1070	994	1109	1088	1075	1077	1180	1381.6
26	1979	1103	1188	1609	1300	1073	1096	1185	1209	1198	1326	1182	1476	1494.5
26	1980	1934	1930	1834	1404	1121	1017	1268	1376	1471	1469	1179	1633	1763.6
26	1981	2008	1835	1529	1111	1086	1203	980	1091	1152	1135	1163	1412	1570.5
26	1982	1886	1800	2284	1056	1039	1189	1264	1173	1280	1019	1020	1297	1630.7
26	1983	1593	1621	1972	1328	1268	1204	1126	1168	1244	1057	1146	1202	1592.9
26	1984	1805	1992	2112	1391	1590	1400	1136	1250	1464	1135	1233	1300	1780.8
26	1985	1802	1689	1793	1265	1111	779	1065	1225	1414	1451	1320	1595	1650.9
26	1986	1950	1996	1895	1199	1228	1103	1190	1196	1217	1214	1233	1366	1678.7
26	1987	1874	2080.5	2137	1244	1136	1190.5	1171	1219.5	1170	1283	1235	1469	1721
26	1988	1798	2165	2058	1289	1541	1278	1152	1243	1123	1352	1237	1573	1780.9
26	1989	1985	1930	2020	1255	1329	1419	1414	1378	1532	1208	1345	1470	1828.5
26	1990	1617	1536	1401	1260	1814	1318	1308	1467	1648	1404	1276	1596	1764.5
26	1991	2151	2195	2159	1277	1225	1260	1202	1469	1572	1387	1239	1901	1903.7
26	1992	2198	2272	2428	1489	1269	1204	1307	1430	1384	1256	1364	1478	1907.9
26	1993	1403	1402	2296.5	1506	1419	1021	1287	1349.5	1768	1686	1398	1766	1830.2
26	1994	2530	2304	2165	1565	1328	1151	1090	1269	1486	1256	950	1722	1881.6
26	1995	2443	2110											
		1887	1857	1927	1386	1308	1217	1228	1280	1383	1304	1192	1549	1750
26	mean	189	186	193	139	131	122	123	128	138	130	119	155	

APPENDIX I-B: Nakuru Show Evaporation monthly data (mm)



APPENDIX Isotopic data from Suswa- nakuru sector (Darling 1990)