STUDIES OF LAKE NAIVASHA, KENYA, AND ITS DRAINAGE AREA

Per Syrén

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STUDIES OF LAKE NAIVASHA, KENYA, AND ITS DRAINAGE AREA

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FORSKNINGSRAPPORT ENGELSK TEXT

Abstract.

The paper is divided into four major parts. In the first one a general description of Lake Naivasha and its environment is given. In the second one a modern depth survey of the lake is presented and the bottom topography is discussed. The third part summarizes the water level variations of the Holocene and especially those of the last century. The final part deals with the water budget of the lake, presenting strong support for an underground outlet of the lake.

Nyckelord:
Keywords: Salvinia molesta, depth survey, water level, water budget

NOTA BENE

There is some confusion about the absolute altitude figures of Lake Naivasha, because different 0-levels have obviously been used for the various water level stations around the lake. A levelling carried out in Oct. 1985 from a bench-mark c. 1 km SSE of Naivasha railway station revealed that the lake level of 1985 10 22 was c. 1884.7 m a.s.l. Thus the lake level at the time of the depth survey (i.e. Oct. 1983), was c. 1885.8 m a.s.l. which is 3.5 m lower than the figure indicated in Chapter 2. (In all cases conversion from feet to metres has been made through multiplication by 0.3048.) For most of the discussions carried out in the paper this finding only means a change in the scale of the vertical axis of some of the diagrams, which does not alter the discussion as such. In one case, however, the difference is of some importance. The values given in Chapter 3 in connection with Fig. 3.4 must be reconsidered. Right now it is not possible to say to what extent the diagram is correct and which of the figures given from the time interval before 1910 are valid or not.

The authors

3.282 ft. = 1 m   1884.7 m = 6,185.6 ft.
1885.8 = 6,189.2 ft.

PREFACE

One of the most well-known of the lakes in Kenya's Rift Valley is Lake Naivasha. The lake is within easy reach (c. 50 kms) of Nairobi, the capital of Kenya and one of the world's most famous lakes for bird-watching. A relatively great number of investigations have been carried out concerning the lake and its surroundings, but the research studies are spread among a great number of scientific institutions. Fortunately, many of these studies were collected by the late Roger Mennell of Korongo Farm, Naivasha. I am very grateful to Roger and his widow Lucy Mennell for having been allowed to study his library.

My interest in Lake Naivasha started during my time as Head of the Geography Department at Kenya Science Teachers' College (KSTC) in 1972-1977. Together with a colleague, Dr. Nils Tarras-Wahlberg, I started some special studies in the Lake Naivasha area for the KSTC students and quite a number of interesting results appeared already at that time. Some of the results were compiled by a KSTC-student, Jane Murithii, who won a CASME award from the British Counsil for her Naivasha study.

After my return to Sweden the Naivasha research has continued, mainly through literature studies, but at two occasions, in 1980 and 1981 I had the opportunity of spending some time at Lake Naivasha through grants provided by Carl Mannerfelt's fund. In October 1983 I supervised two Swedish students, Krister Sernbo and Per Syrén, who did field work at Lake Naivasha in order to complete their degrees. Their studies were sponsored by a fund for developing international contacts ("internationaliseringsanslag") at the University of Stockholm. My own studies were, once again, sponsored by Carl Mannerfelt's fund.

The results appearing here are due to the joint efforts of Sernbo, Syrén and myself, but as is evident from the headings of each chapter, one of us takes the responsibility for the chapter in question.

We want to thank the following people for help during our stay in Kenya: Miss Belinda Rego at Kenya Science Teachers' College, Mr. S.H. Charania, Mr. J.O. Nyagua and Mr. Ndete of the Ministry of Water Development in Nairobi, Mr. Njoroge Njau at Kenya's Meteorological Department, Mr. John Kagai and Mr. Charles Ojoki at the Fisheries Department, Naivasha, who all provided valuable help for us in obtaining the necessary data for our studies. We also want to thank Mrs Lucy Mennell for her hospitality during our stay at Korongo Farm and Mr. and Mrs Hopcraft of Loldia Farm, Naivasha, who allowed us to borrow a boat for our investigations.

For valuable discussions about the manuscript, we want to thank Prof. Wibjörn Karlén at the Geography Department of the University of Stockholm. Ms Gertrud Hultblad of the same department typed parts of the manuscript, Ms Eivor Granbom of the same department improved some of the drawings, Mr. Sigvard Blom also of the same department did the printing of the paper. Mrs Jessica Karlén improved the English text.

Stockholm in December, 1985

Lars-Erik Åse

CHAPTER 1

LAKE NAIVASHA - A PRESENTATION OF AN EAST AFRICAN RIFT VALLEY LAKE AND ITS SURROUNDINGS

By Lars-Erik Åse

Geology

One of the most remarkable features of the Earth's crust is the Rift Valley of Africa. The valley, or rather the valleys, form a more or less continuous scar from Israel and Jordan in southwestern Asia all the way to Mozambique in southeastern Africa (cf. Figs. 1.1-1.3). One of the most prominent parts of the valley system is the so-called "Gregory Rift Valley" in Kenya. Flanked by scarplines like the Nyandarua Range (Aberdares) on its eastern side and the Mau Escarpment on its western side, it reaches relative altitude differences of 1000 m or more, depending on how far from the bottom of the Rift one wants to go. The evolution of the rift has been discussed very much over the years, the two most favoured ideas being the tension theory and the compression theory (cf. e.g. Buckle 1979). In connection with the breakthrough of the theory of plate tectonics, the former theory seems to be the more realistic one, supported particularly by the fact that gravity measurements (Fairhead 1976) indicate a higher position of the astenosphere under the Rift Valley than in the surroundings. It might be noted that "the dropping keystone" idea that was fundamental to Gregory (e.g. 1896, p. 220), who has given his name to this part of the Rift Valley, can be combined with both the theory of compression and the theory of tension (cf. Fig. 1.3). A relatively recent theory for the geological development of the Rift Valley built on field work in the Lake Bogoria (L. Hannington) area north of Lake Naivasha is given by McCall (1967) and appears in Fig. 1.4. The main faulting stages in the formation of the Rift Valley occurred according to McCall in the Miocene or early Pliocene (5 in Fig. 1.4), the Pliocene (7 in Fig. 1.4) and in the Pleistocene-Holocene (8 in Fig. 1.4). The faults west of Lake Baringo have a very "fresh" appearance and to the present author the faulting seems to have occurred within the last few millenia. Celia Nyamweru (1980, p. 40) writes that a fissure over 2

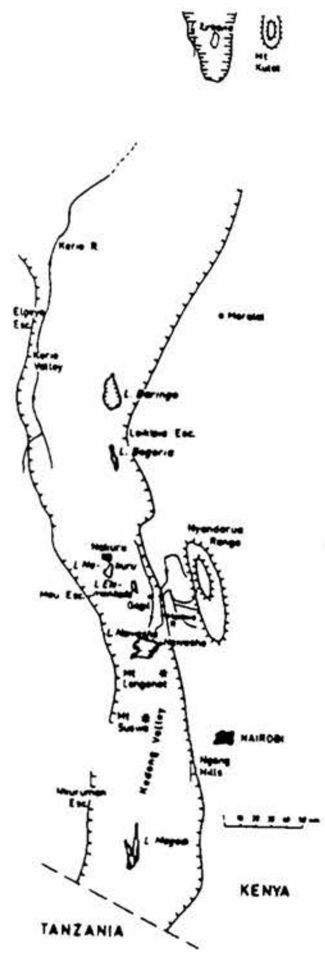


Fig. 1.1 The Kenyan part of the Rift Valley.

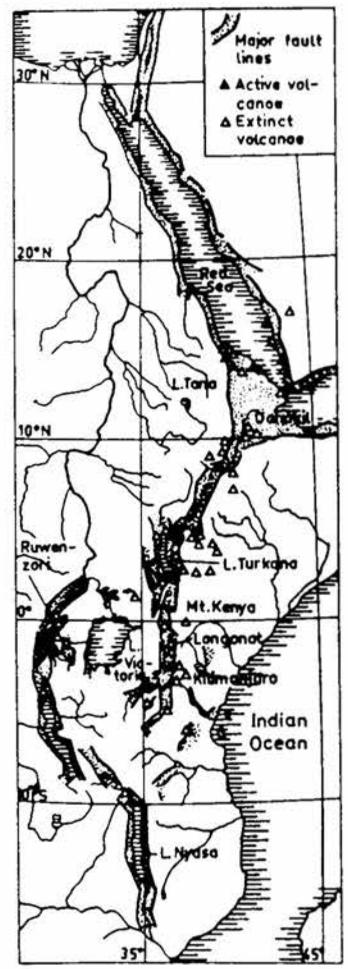


Fig. 1.2

The East African Rift Valleys and volcanoes.

metres wide was formed along the Subukia escarpment, with a downthrow on the west side, in connection with the Subukia earthquake in 1928, which had its epicentre along the Lakipia escarpment to the east of Lake Bogoria (Hannington) and a magnitude of 7.1.

During my stay in Kenya, some students drew my attention to a fresh fissure a few decimeters wide that had developed in the early 1970's at the Kikuyu Escarpment east of Lake Naivasha and passed under a house without doing much damage. So obviously, the tectonic activities of the Rift Valley are still in "full swing" and the picture drawn by

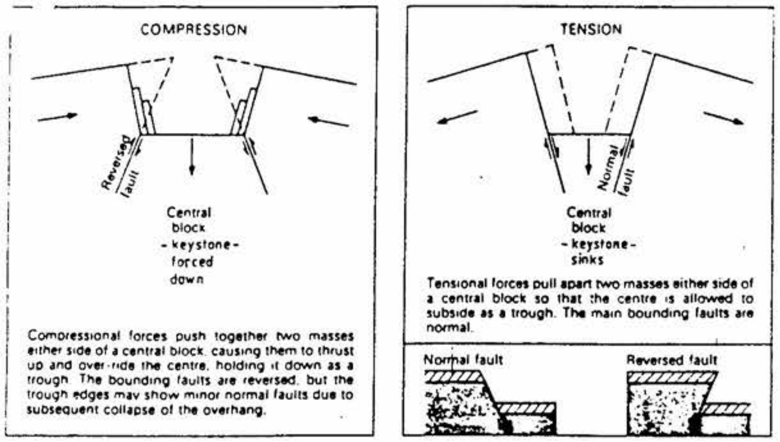


Fig. 1.3 Rift Valley formation theories. Modified from Buckle 1978.

Celia Nyamweru (1980, p. 101), in which (cf. Fig. 1.5) within 50 million years the eastern part of the African continent during a migration towards the NE, leaves the rest of the continent, seems very plausible (cf. Fig. 1.5).

The development of Gregory Rift Valley is strongly linked to the formation of volcanoes and volcanic eruptions. Volcanoes like Mt. Longonot, the Eburu Mts, Menengai and Kipipiri not only characterize the horizon around Lake Naivasha but are also responsible, through their eruptions, for the soils and lavas around the lake. Generally speaking, the volcanoes and their eruptions are geologically very young. The geological map of the Naivasha area does not include any formations older than Quaternary, in fact these are not any older than lower Pleistocene. Especially the area around Mt. Longonot has very recent features like a parasitic cone, the lava field of which is not yet tully colonized by vegetation. According to Thompson and Dodson (1958, p.22) the latest eruption of Mt. Longonot occurred "within the last hundred years". Hot springs and fumarols are frequently found both on the slopes of the volcanoes and in the bottom of the rift itself. In fact, the thermal energy from the Hell's Gate area is now being exploited for the production of electricity.

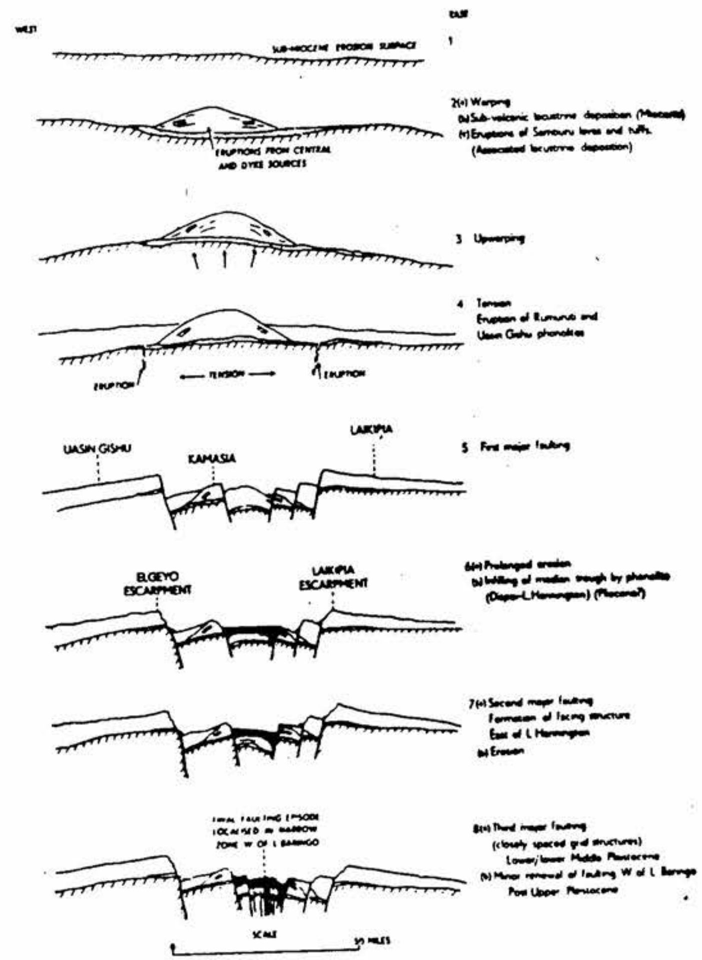


Fig. 1.4 Successive stages in the formation of the Rift Valley in the Lake Bogoria (Hannington) sector. (After McCall 1967)

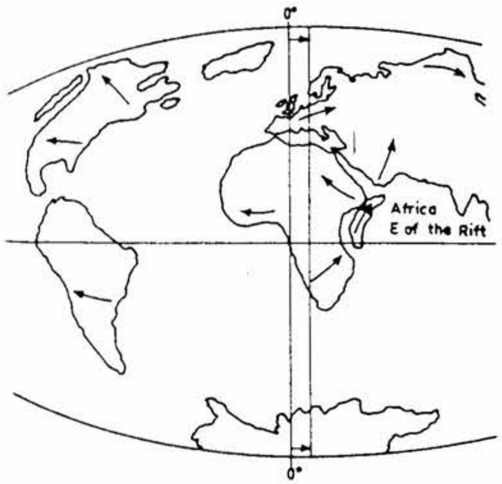


Fig. 1.5 Possible arrangement of the continents 50 million years into the future. Redrawn from Celia Nyamweru 1980.

The main rivers flowing into Lake Naivasha are the Malewa (even called (Morendat) Melawa), the Gilgil and the Karati. Especially the tributaries of the Malewa River form a very regular dendritic drainage pattern except for in the Kipipiri area, where there is a radial drainage pattern due to the conical shape of the volcanoe. The drainage area of the three rivers is covered by Tertiary and Quaternary deposits, especially pyroclastics and lacustrine deposits. Only on the slopes of the Nyandarua Range and at Kipipiri are there lavas like basalts or trachytes. The pyroclastics are mainly tefra and tuff layers deposited during eruptions of Mt. Longonot and other volcanoes in the area around the lake. The lacustrine deposits consist mainly of diatomitic silts deposited in the pluvial lakes that have existed in the Rift Valley area during the Quaternary (cf. chapter 3).

Climate and vegetation

Lake Naivasha is situated in the highest part of Rift Valley at an altitude of c. 1890 m a.s.l. In spite of this, the lake and its drainage basin (cf. Fig. 1.6) are in the rain shadow of winds coming from both the west and, more importantly, from the east. The average annual

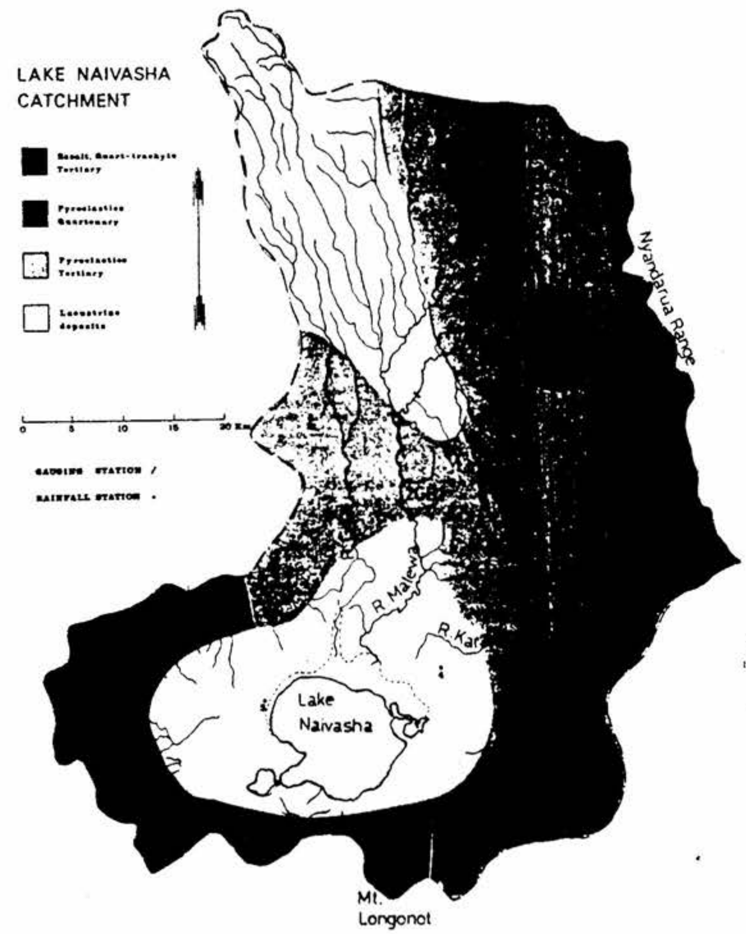


Fig. 1.6 Map showing the drainage area of Lake Naivasha and its geology. (Original, Syrén)

figure for rainfall at Naivasha D.C. for the period 1931-1960 was 608 mm (East African Meteorological Department 1966). This figure could be compared with an annual evaporation of 1865 mm, calculated for the years 1966-1982 from data from the Naivasha Water Supply (provided by Kenya's Meteorological Department). Whereas the evaporation figures show a rather small deviation of c. ±50 mm standard deviation, the precipitation figures vary greatly much strongly from one year to another. During the period 1931-1960 the highest annual precipitation, of 939 mm, was recorded in 1939, whereas the figure for 1942 was only 443 mm. Normally, most of the precipitation occurs during the "long rains" in March-May. The short rains, in October-November, are less pronounced here than in other parts of Kenya. On the other hand, during June and July it is not so dry as in other parts of Central Kenya that have the same annual precipitation. This might be due to the influence of the Zaïre monsoon from the SW that has a strong influence especially over the Lake Victoria area (cf. e.g. Ojany-Ogendo 1973, p. 59).

The winds over Lake Naivasha are generally (cf. Fig 1.7) weak and come from quite varying directions. The strongest winds (occasionally exceeding 21 knots) normally occur in August and October. In spite of the rather weak winds, the waves on the lake can rise rather high due to the uninterrupted fetches over the lake and can be disastrous for man. - The direction of the winds does not entirely correspond to those normal for Kenya. Thus, the NE-monsoon, which dominates most of Kenya during the beginning of the year (cf. e.g. Thompson and Sansom 1967, pp. 22-23) is not possible to trace in the Naivasha material. Probably the general N-S direction of the Rift Valley has a strong influence upon the weaker winds, as southerly winds seem to be more frequent than easterly winds.

The arid climate and the porous soils of most of the drainage basin of Lake Naivasha have a strong influence upon the vegetation. The Kedong valley, to the south of Lake Naivasha, has according to Trump (1967, pp. 40-43) a natural vegetation referred to as "evergreen bushland". Characteristic species for this type of vegetation are the "cactus"-shaped Euphorbia candelabrum and the fire-resistant Acocanthera schimperi. Large parts of the area have an appearance of dry savannah,

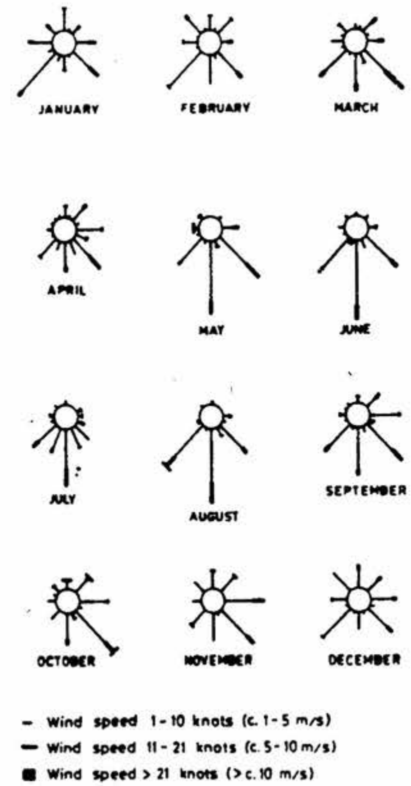


Fig. 1.7 Wind roses for Naivasha. Lat. 0°43'S Long. 36°26'E. Alt. 1900 m a.s.l. From East African Metr. Dept. 1967, p. 26.

which might partly be due to fire and downcutting of the bushes. Even grasslands frequently occur in the less arid parts of the landscape. The "whistling thorn tree" (Acacia seyal) is characteristic for this "secondary vegetation". The most characteristic tree of the shores of Lake Naivasha is the yellow fever tree (Acacia xantophloea). The lakeside zonation of the vegetation appears in Fig. 1.8 (redrawn from Gaudet 1977). Gaudet's figure shows the conditions around 1973. Since that time the water lily (Nymphea caerulea) has disappeared more or less completely from the lake. On the other hand a floating fern (Salvinia molesta) has appeared as a pest on the lake. Floating "sudds" of Salvinia-mats colonized by e.g. ~~Aotea spicata~~ are now very common at the shores of the lake (cf. Fig. 1.9).

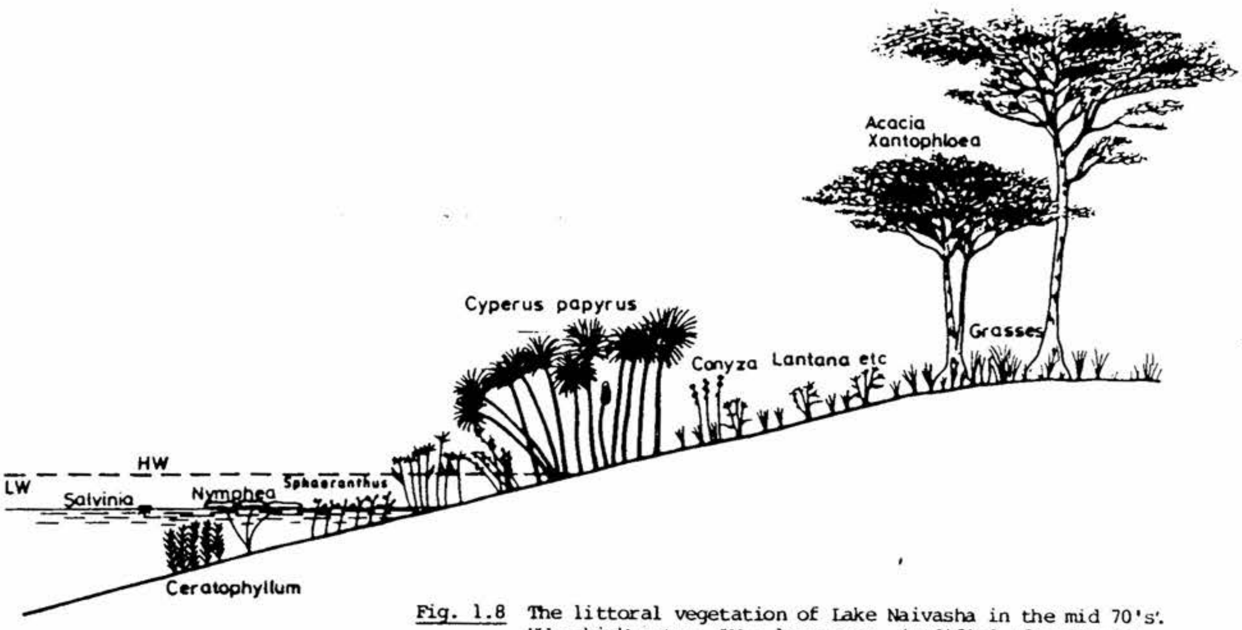


Fig. 1.8 The littoral vegetation of Lake Naivasha in the mid 70's. HW = high water, LW = low water. (Modified after Gaudet 1977)

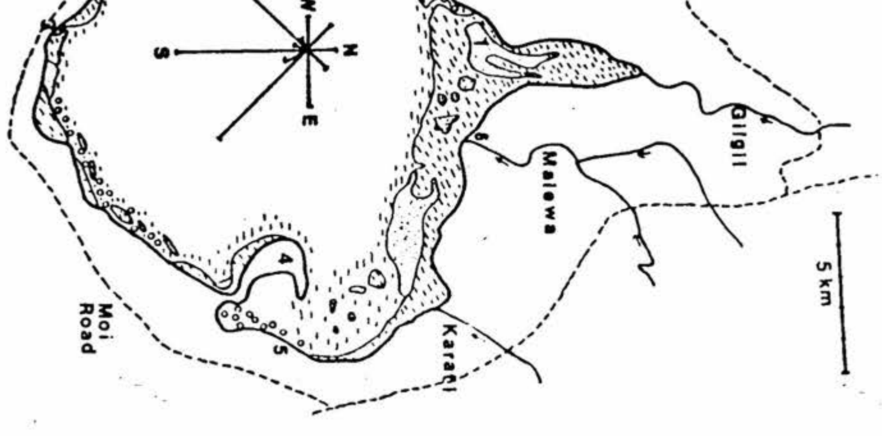


Fig. 1.9 Map showing the vegetation and prevailing winds of Lake Naivasha 1974/75. (After Jutta Diedrichs 1976 and N. Tarras-Wahlberg 1984.)

A = Water lilies
B = Salvinia
C = Papyrus
D = submerged vegetation

1 = Hopcraft's lagoon
2 = Mennell's lagoon (Korongo)
3 = Fisherman's camp
4 = Crescent Island
5 = Fisheries' Department
6 = "Lagoon of the Pelicans"

Animal life

Among the herbivores found on the floor of the Rift Valley the zebra, giraffe, Thomson's gazelle and Grant's gazelle are the most commonly seen. According to Stewart (1967, p. 52), the kongoni also occurs throughout the Rift Valley floor, whereas the gnu or wildebeest, "which formerly was found as far north as Lake Naivasha now is restricted to the plains around Lake Magadi" further to the south. Among other mammals the rock hyrax, which is particularly abundant at Fisher's tower in Hell's Gate, the porcupine, also found in Hell's Gate, and a bat, possibly the big-eared free-tailed bat that, according to Stewart (1967, p. 53), occurs in the caves of Mt. Suswa, but which also is found in small caves to the west of Korongo Farm at the western part of Lake Naivasha, can be mentioned. Large carnivores are nowadays not often seen in the Rift Valley. According to Stewart the striped hyena occurs in the Kedong Valley to the south of Lake Naivasha. The caracal is also found on the Rift floor.

The puff-adder is the most commonly seen snake; among birds seed-eating weavers, bee-eaters, superb starlings and hoopoes are among the most frequently observed. Secretary birds, ostriches, Verraux eagle and the famous lammegeyr (cf. Carnelley 1972) are among the birds of Hell's Gate.

Characteristic mammals of the lake itself are the hippo and the coypus. The former, which has become a problem for the farmers around the lake, has been carefully studied by Jutta Dietrichs (1976). During the 1970's the coypus spread from fur farms to the north of the lake and is now quite common in spite of some hunting. According to Gibson (1973) the coypus used to feed on Nymphea stalks and Papyrus, which might be a reason for the disappearance of the blue water lily (Nymphea). However, in the view of the present author (Åse 1982, p. 167) the rising water level from 1977 onwards could have been a reason for the disappearance of the water lilies. There were water lillies in the '30s.

As was mentioned in the preface of this paper, Lake Naivasha is virtually a paradise for bird-watchers. Among the most common species are the cormorant, which is often seen on drowned Acacia stumps, various herons, such as the Goliath heron and egrets, kingfishers and pelicans. The sacred ibis and the bronze winged ibis are both very common. The red knobbed coot, which was extremely abundant in the 1970's, has now decreased tremendously, possibly due to the disappearance of water lilies and submerged vegetation. Among the predators the fish-eagle must be mentioned. In contrast to the coot, the fisheagle seems to have increased in number, possibly due to the introduction of a crayfish, Louisiana swampy red crayfish, in 1969-1970. As can be deducted from studying the "vomiting balls" emanating from the fish-eagle, crayfish is now a very common food for the fish-eagle.

Among articles dealing with the bird-life of Lake Naivasha the following might be mentioned: Stewart 1967, Carnelley 1972, Lundberg and Tallmark 1973, and Tarras-Wahlberg 1981.

A very common frog in and around the lake is the tree frog and at dawn and dusk, especially during the long rains, a cacaphony of sounds emanating from frogs and toads can be heard from the lake shore. very rare

The most common fish in Lake Naivasha is Tilapia. According to Stewart (1967, p. 55) there are three different species of Tilapia; nigra, zillii and leucosticta. According to Malvestuto (1975), Tilapia leucosticta was introduced to Lake Naivasha in 1954. He also found that the average size of Tilapia leucosticta was smaller in Oloidien bay, which was isolated from the main lake from 1939 to 1961, than in the other parts of Lake Naivasha. It was also found that the fish was heavily infected by a worm (Contracaecum sp. or spp.). However, the decrease in the fishing of Tilapia that occurred during the 1970's was probably due to the appearance of Salvinia, which so to say blocked the hatching grounds for Tilapia. Now, fishing of Tilapia has increased again after the rise in lake level that started in 1977. Another very common fish in Lake Naivasha is the large-mouthed black bass, which has also been introduced to the lake. The black bass is a predator, nowadays probably mainly on crayfish, whereas Tilapia feeds on littoral vegetation and plankton.

Land use around Lake Naivasha

Before the arrival of the "wazungu" (white people) the land around Lake Naivasha was mainly grazed by Maasai cattle. (von Höhnel, who reported about the Teleki expedition that visited the area around Lake Naivasha in August 1888 describes (1892, p. 791) a meeting with Maasai women who were on their way to the Kikuyos to exchange soda for tobacco.) Grazing of cattle is still very common around the lake and European breeds have also been imported to replace or interbreed with the zebu. Even Friesian dairy cattle are found around the lake. Where irrigation can be provided cultivation of vegetables and other crops can occur. Often cited (e.g. by Jutta Diedrichs 1976) is the harvesting of seven crops of lucern from the same field during one single year. In addition to vegetables, maize is now the most common crop around the lake. Attempts have been made to cultivate flowers, e.g. carnations for export to Europe, and for the processing of perfumes. The industrial development of the Naivasha area is otherwise very limited. Exceptions are the creamery at Morendat, and the vegetable processing factory just west of Naivasha town. Naivasha town also has some hotels, shops and a market-place. The tourist industry is concentrated to Lake Naivasha Hotel and Safariland Lodge on the eastern shore of the lake.

The landowners around the lake are still mainly Europeans. The workers on the farms are mainly Africans who often live in small villages on the farms. The fishermen at the lake are often people from the area around Lake Victoria belonging to the Luo tribe, who have migrated to Lake Naivasha. The main tribes of the area, the Kikuyos and the Maasai, normally do not eat fish. Many people from Nairobi visit the lake for fishing and bird-watching during holidays and weekends.

CHAPTER 2

DEPTH-SURVEY OF LAKE NAIVASHA

by Krister Sernbo

Introduction

One of the most important tools for the study of a lake is of course, a depth-map. In the case of Lake Naivasha a depth-survey was made as early as 1927 (cf. Thompson and Dodson 1963, Fig. 2.3). However, the quality of the survey was obviously not very good, especially as the echosounding technique was not practiced at that time. Thus, a major task for the studies carried out at Lake Naivasha in 1983 was to make echosoundings of the lake, which could form the basis for a depth-survey. A depth-survey is of particular interest for the description and explanation of the bottom topography of the lake and, to some extent, also allows for comparison with the survey of 1927. Moreover, a depth-survey could serve as a basis for limnological studies of the lake, some of which have already been carried out by e.g. J.J. Gaudet, N. Tarras-Wahlberg and L-E. Åse (cf. reference list).

Methods

Echosounding

Lake depths were surveyed using a Lowrence X-15^{M} echosounding instrument. The equipment has an operating frequency of 192 KHz, accuracy within 0.6 percent.

The soundings were carried out from a small motorboat, running at constant speed and direction between two defined positions. The recording echosounding-equipment could then give a depth profile to the appropriate scale between the two positions (cf. Fig. 2.1).

Compass bearings were taken to determine the positions of the starting and stopping points (except sections No. 8-13, where positions were determined by theodolite measurements), and 38 sounding-sections of varying length were echosounded. Their positions are shown in Fig. 2.2. As a basis for navigation and map-drawing, the topographical maps 1:50 000 Naivasha 133-2 and Longonot 133-4 (Survey of Kenya 1967-1969) were used.

Shortage of time (and to a certain extent, the high petrol rates) limited the number of sections sounded. Because it soon became evident that the bottom topography in the middle of the lake was quite even, the survey was concentrated to areas close to the shore, and especially to the northern part of the lake, where the major inflows enter Lake Naivasha. Crescent Lake, which according to the map of 1927 (Thompson and Dodson 1963) forms the deepest area of the lake, has also been sounded more thoroughly.

The distribution of the sections also had to be adapted to the great Papyrus-belts and the floating islands of Papyrus, which together cover large parts of the lake. Belts consisting of the floating fern, Salvinia, could sometimes also be quite difficult to pass through with the small motorboat.

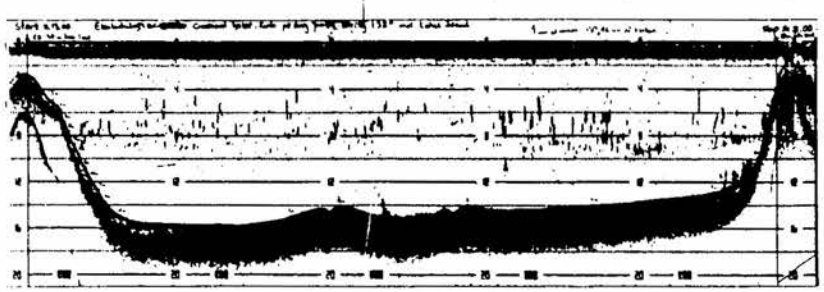


Fig. 2.1 Example of a depth-profile (sounding-section No. 21), as registered by the echosounding instrument. This particular sounding-section above shows the bottom topography of Crescent Lake, with its character of a volcanic crater.

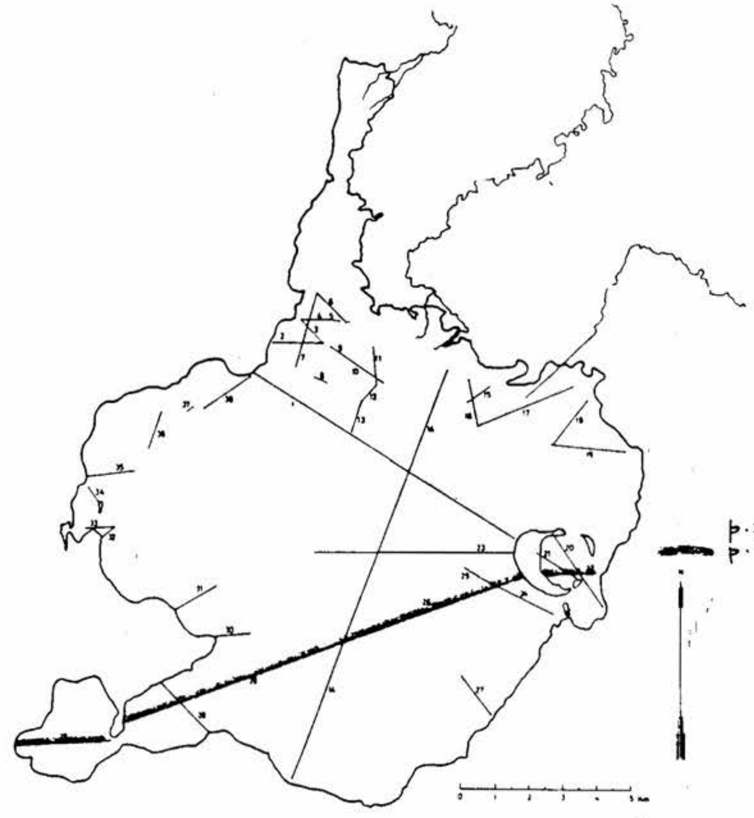


Fig. 2.2 Sections sounded during the depth-survey. The irregular pattern is due to the concentration of effort to the most interesting parts, namely, the parts close to the shores, the delta area and Crescent Lake.

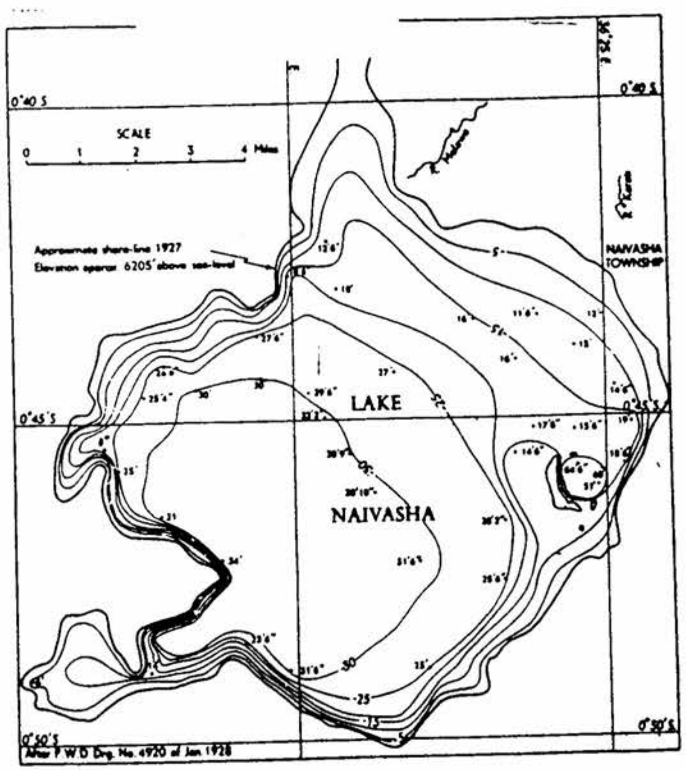


Fig. 2.3 Depth-map of Lake Naivasha, based on data from 1927. The contours are shown relative to the water surface in November 1927, when the altitude of the lake was approximately 1892.0 m a.s.l. (Note that this is 3 m higher than the 0-level of the map from 1983.) (From Thompson and Dodson 1963.)

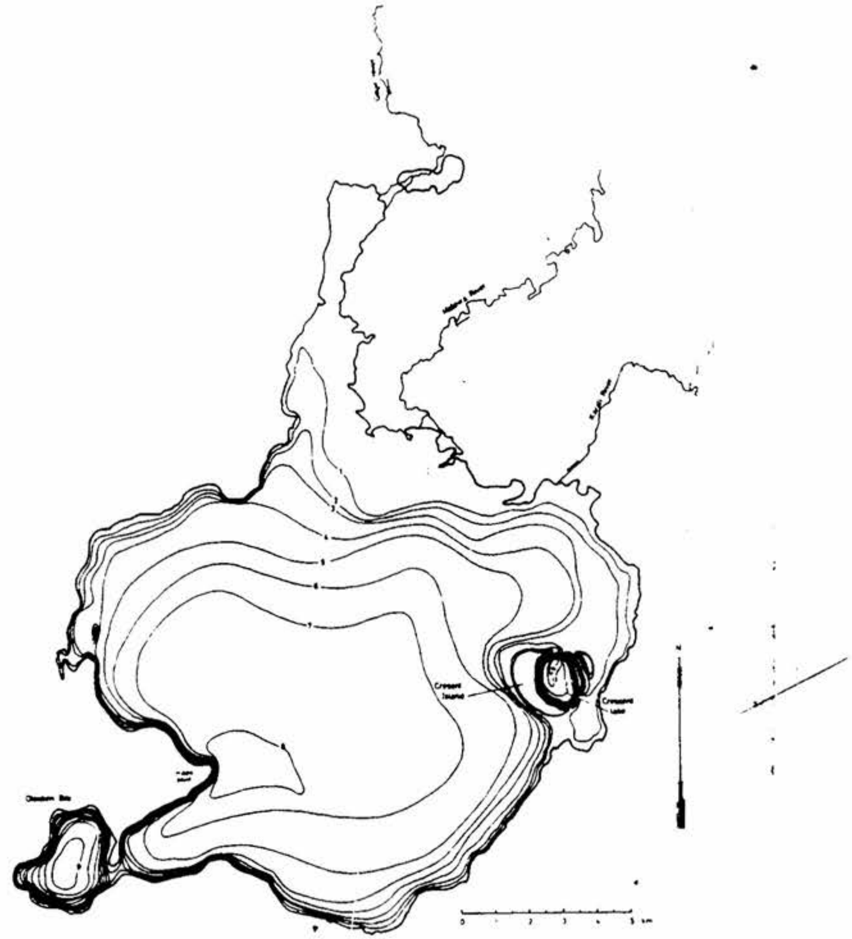


Fig 2.4 Depth-map of Lake Naivasha, based on soundings made in 1983. The map is drawn referring to a lake-surface level of 1889 m a.s.l.

uction of the map

Every point along the sounded sections that corresponds to a position with a depth of an even metre, was indicated on the map. Contour lines were drawn between points with the same value for depth.

The depth-map (cf. Fig. 2.4) was drawn referring to a lake-surface level of 1889 m a.s.l., which corresponds to the surface level of Lake Naivasha during the depth-survey (October 1983) minus the depth of the echosounding instrument. The lake-surface level during the time of echosounding was indicated to be 1889.3 m a.s.l. on a gauge at Korongo Farm.

Discussion of errors

Compass bearings were taken to determine the start- and stop-positions of the sounded sections. On those occasions when useful aiming-points were distant, the method could have lead to errors (approximately ±100-200 metres). Even the measurements made with the theodolite were inclined to be affected by error, because of the long distances between the instrument and the boat.

To achieve a picture of the sounded section that was in the correct scale it was important to maintain a constant speed and direction. In areas with dense floating vegetation of Salvinia and other types of floating vegetation it was occasionally difficult to maintain constant speed. Efforts were made to compensate for loss of speed, and therefore errors in this connection are probably of minor importance. Fortunately, the soundings were mostly carried out under very calm conditions, which simplified maintaining of a constant direction.

The limited quantity of sections sounded leads to some uncertainty in the drawing of contour lines. Thus, the contour for eight metres is not well-covered by sounding-sections. Another sparsely sounded area is the western part of the lake, where the drawing of the contour lines is based mainly on the topography of the adjacent lake-bottom and the surrounding land.

Sounding-section No.14, crossing the lake in direction SSW to NNE, suggests a contour pattern which does not completely correspond to the surrounding sections No. 9-13 and 15-19. On the other hand, there is good correspondence to section No. 1. Papyrus, which does not seem to grow in deep water (deeper than about two metres below average lake level, cf. Figs. 2.8 and 2.11) in Lake Naivasha, appears from section No. 14 to be growing in much deeper water. This suggests that there might be an error in the drawing of the contours in this area.

The bottom morphology of Lake Naivasha

General features

The depth-map of Lake Naivasha, shown in Fig. 2.4, has been drawn using a lake-surface level of 1889 m a.s.l., and all depth-figures in the following text refer to that level. The map indicates a very flat bottom with major decrease in depth only close to the shores. The flat bottom topography is also clearly shown in the two cross-section figures, 2.5 and 2.6. Fig. 2.6 also shows two areas that topographically differ greatly from the dominating flat pattern, namely Crescent Lake and Oloidien Bay. These areas form the deepest parts of the lake. Crescent Lake has a maximum depth of 17 m, which is the deepest spot in the lake, and Oloidien Bay has a maximum depth of 9 m. The deepest registered spot in the main lake is 9 m, registered just outside Hippo point. The mean depth is 4.7 m. The volume of the lake is calculated to 9.0 x 10^8 m^3 at a lake level of 1889 m a.s.l.

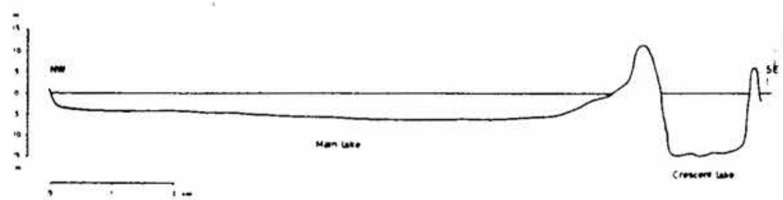


Fig. 2.5 Cross-section from NW to SE, based on sounded sections No. 1 and 21. The flat bottom of the main lake and the volcanic character of Crescent Lake are clearly visible.

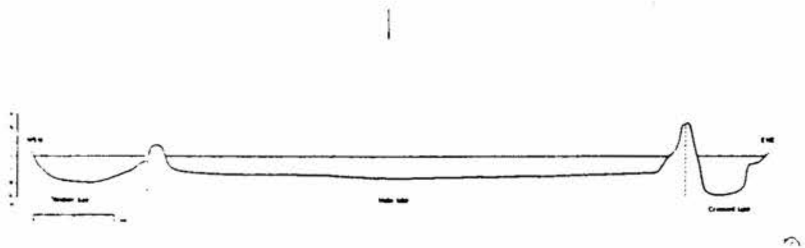


Fig. 2.6 Cross-section from WSW to ENE, based on sounded sections [redacted] and 22. The figure shows the flat bottom of the main lake and the two areas of divergent character and deeper water, namely Oloidien Bay and Crescent Lake.

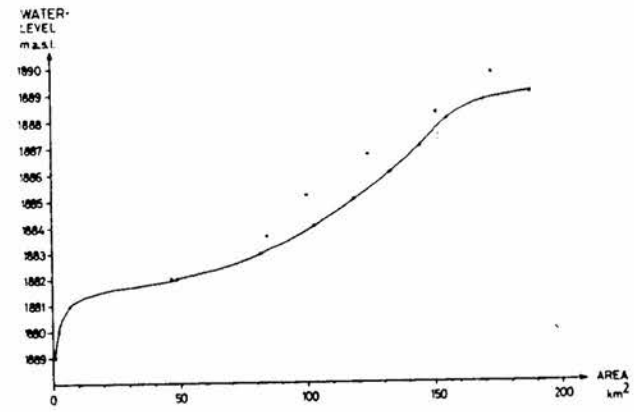
The flat bottom topography of the lake contrasts with the hilly topography of the surroundings. The most probable way to explain the difference is that the lake basin has filled up with large amounts of sediments, resulting in an even bottom topography.

The depth-map clearly shows a more shallow area in the northern part of the lake. This feature has been interpreted as a delta, built up by sediment loads deposited by the main inflows, namely the rivers Malewa, Gilgil and Karati, which all enter the lake in this area.

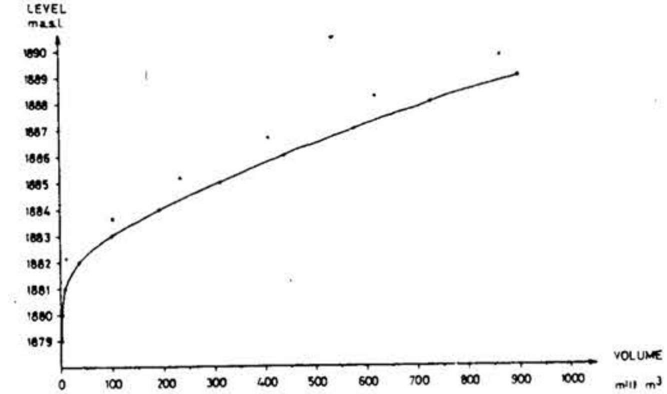
Comparison with the depth-map of 1927

As mentioned earlier, it is not clear what kind of material the depth-map of 1927 (Thompson & Dodson 1963, cf. Fig. 2.3) is based on, and therefore we do not know the degree of accuracy of the map. Some notes can be made:

- The deepest spots in the main lake and in Crescent Lake are the same on both the 1927 map and the current map, and the figures for depth in these places also correspond. It is also possible to find



A



B

Fig. 2.7 Relationship between the water level of the lake and A: the area, B: the volume. Figures are based on calculations from the depth-map of 1983 (Fig. 2.4). Crosses not connected by curves are derived from the survey of 1927 (Brind and Robertson 1958).

in both of the maps an indistinct slope from the northeastern part of the lake towards the southwest.

- On the other hand, there are many major differences. For example, on the 1927 map Oloidien Bay is drawn completely differently as compared to the present map, and Thompson and Dodson (1963) note that probably sufficient readings were not taken in the south-western part of the lake. The deepest spot in the bay is noted to be approximately one and a half metre (referring to a lake-surface level of 1889 m a.s.l.). During the soundings of 1983, a depth of 9 m was recorded in the bay.

- The map from 1927 does not show the presence of a delta as clearly as the map from 1983 does, although the northern part of the lake is shown as rather shallow. Furthermore, the 0-contour (i.e. the shoreline) shows a lakeward bending on the map from 1927.

Between 1927 and 1983 changes in the bottom topography might have occurred. For instance, it is possible that the delta has been built up and enlarged during this period. But it is hard to believe that Oloidien Bay has become more than seven metres deeper in 55 years. Thus, a comparison between the two maps is not very fruitful, and would probably not be so even if the original map-drawings were found.

Volcanic bottom structures

As mentioned earlier, Lake Naivasha is situated in the Gregory Rift Valley, and thus one should not be surprised to find volcanic features in the bottom morphology of the lake.

Crescent Lake The most prominent volcanic features in the lake are Crescent Island and Crescent Lake, which together form an old volcanic crater, which has been described already by von Höhnel (1892). The form of the crater is shown well by the depth-map (Fig. 2.4), which indicates a rounded shape and steep slopes. The steep crater walls are also clearly shown in the cross-section in Fig. 2.5, and in the sounded section in Fig. 2.1. A more detailed study of Fig. 2.1 reveals a pair of small irregularities on the bottom of the crater. These features are difficult to explain, but they might be small underwater springs or steam-jets. Taking into consideration the thick layers of sediments in Crescent Lake (at least 10 metres thick, according to the Richardsons 1972), a theory suggesting some sort of gas leakage is the most probable. As a support for this theory, there are earlier reports of upwelling water or gas in the area (Åse and Tarras-Wahlberg, pers. comm.).

Oloidien Bay The sounded section through Oloidien Bay has given a completely different picture of the depth-conditions in the bay than that based on the old map (cf. Fig. 2.6). The bay forms a clearly defined area where the average depth is deeper than that of the main lake, and obviously it also constitutes the remains of an old crater. Oloidien Bay's origin as a volcanic crater is an important though not unexpected finding of this study.

Morphology of the delta

In the northern part of the lake, a delta has been built up by sediments from the main inflows to the lake. Judging from the form of the delta, most of the sediment-load has been brought by the rivers Gilgil and Malewa.

The sounded section in Fig. 2.8 gives an indication of a small delta front in the southern part of the delta (probably accentuated by the edge of the *Papyrus*-clumps). In other parts of the delta there seems to be a more gradual, smoother slope towards deeper water (cf. Fig. 2.9). Sediment samples collected from the delta contained material in the clay-silt fractions, and that kind of material seldom forms steep delta fronts (cf. e.g. Axelsson 1967). The shifting lake level probably also prevents the formation of a marked delta front.

The sounded sections in the delta area very often show an irregular bottom topography. Some of the irregularities could be old *Papyrus* roots lying at the bottom, but many are probably furrows, formed through erosion by running water from the inflows during periods of lower water-level (cf. Fig. 2.10).

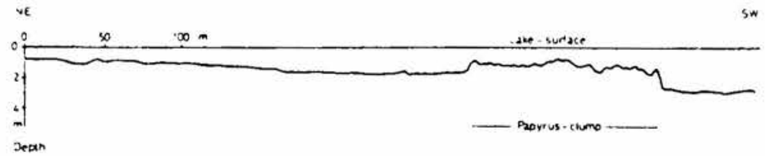


Fig. 2.8 This sounding-section (part of section No. 12) indicates a small delta front, probably accentuated by clumps of Papyrus.

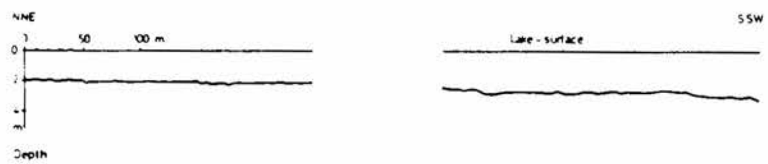


Fig. 2.9 This sounding-section (part of section No. 7) exemplifies an area where the depth of the delta gradually increases towards deeper water.

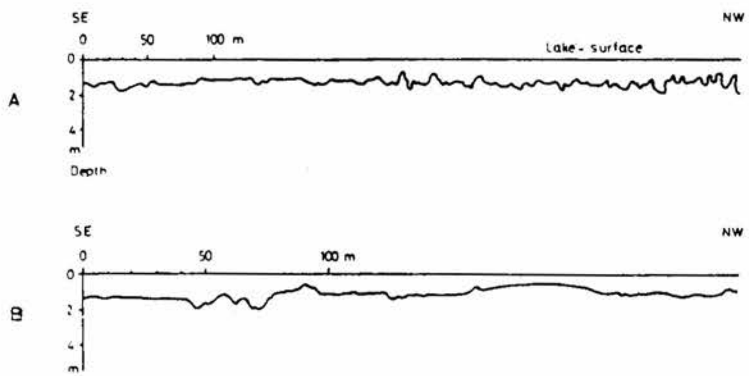


Fig. 2.10 Irregular bottom topography. Many of the irregularities are probably furrows, formed through erosion by running water from the inflows. The figures are parts of sections No. 6 (A) and 9 (B).

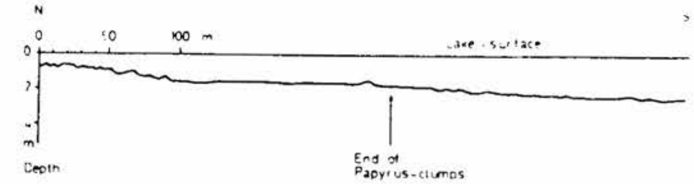


Fig. 2.11 An example from the delta area (section No. 16) where the outermost Papyrus-clump is found in water less than two metres deep.

On the topographical map of 1967, the distribution of Papyrus in Lake Naivasha is marked. Comparison with the depth-map shows that the delta area corresponds well to the area where Papyrus is distributed in the northern part of the lake (there are also large Papyrus-belts in the western part of the lake). The shallow water of the delta promotes colonization and spreading of Papyrus (Gaudet 1977). The sounded sections from the delta do not show any presence of Papyrus in water deeper than two metres (cf. Figs. 2.8 and 2.11). On the other hand, dense vegetation like that of a Papyrus-belt must surely capture large amounts of sediments, and thus the Papyrus should accentuate the growing of the delta.

There is a need for more detailed studies in order to find out to what extent Papyrus is limited by water depth in its distribution in Lake Naivasha. If it were limited by certain water depth (for example 2 m) it would be very interesting to compare the distribution of Papyrus today with older aerial photos, and maybe learn something about the earlier extent of the delta.

Small bottom structures

The fine accuracy of the echo-sounding instrument made it possible to detect even quite small irregularities on the lake bottom, some of which might be of importance to the small-scale geomorphology of the lake. Several of the sounding-sections made close to the shore showed

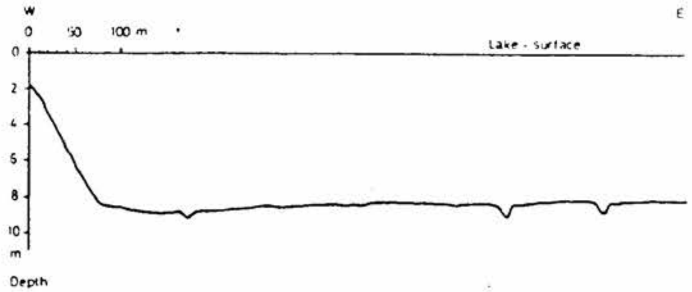


Fig. 2.12 Depressions in the lake bottom at great depth (part of section No. 30). A possible interpretation might be that these are underwater springs or steam-jets.

small, distinct depressions, about 0.3-0.8 metres deep (cf. Fig. 2.10). The depressions have been found at depths between 2 and 4 metres. These depressions have been interpreted as ditches, dug by farmers cultivating new land during periods of low lake-surface level, e.g. the low water levels of the 1940's and 1950's (Åse 1982).

The unexpected irregularities at the bottom of Crescent Lake, which might be underwater springs, have previously been described. The sounded section made eastwards from Hippo point (section No. 30), across the deepest part of the main lake, showed a number of small (about 0.3 m), less distinct depressions in the lake bottom (cf. Fig. 2.12). The depressions were registred at a depth of about 8 metres, implying that the hypothesis of manmade ditches is not plausible in this case. A depression of this size, originating from a structure in the bedrock underlying the lake would most likely soon be filled up with sediments (compare with the normally completely flat bottom, e.g. Fig. 2.1). At this time the only reasonable hypothesis is that even these depressions are underwater springs or steam-jets, continuously kept open by upwelling water or gas.

CHAPTER 3

LAKE NAIVASHA - THE WATER LEVEL VARIATIONS FROM EARLY HOLOCENE TO 1980 A.D.

By Lars-Erik Åse

The climate of the Rift Valley has not always been as arid as it is today. Periods of wet weather have alternated with periods of dry weather. The wetter periods are called pluvials, the drier interpluvials, just as we talk about ice ages as glacials and of the periods between the glacials as interglacials. However, the tempting idea about synchronity between ice ages in Europe and pluvials in Africa does not seem valid from what we know today. This was otherwise the idea that influenced geologists and archaelogists for a number of decades. In fact, the four ice ages commonly talked about in Europe i.e. Günz, Mindel, Riss and Würm were thought to each have a corresponding pluvial age in East Africa and these were even named.

Thus, the last pluvial epoch was called Gamblian after a cave to the south of Lake Elementaita, Gamble's cave, which was excavated by L.S.B. Leakey between 1926 and 1929 (cf. Sonia Cole 1970, p. 49). The idea of a correspondence between pluvial ages in Africa and ice-ages in Europe was very much favoured by E. Nilsson, both in his gradual dissertation in 1932 and later (e.g. 1938). Nilsson did a great number of levellings of old shorelines and presented (1932, p.43) a map showing the maximal extent of the "Gamblian" lake, here reproduced as Fig. 3.1. According to Nilsson (1939, p. 432) the highest shore of the Gamblian lake developed during the latter part of the Gotiglacial epoch, i.e. c. 10 000 B.C. or c. 12 000 B.P. according to the "traditional" Swedish time scale (cf. e.g. G. Lundqvist 1963). According to Nilsson the altitude was c. 1930 m a.s.l. Later studies by e.g. Bishop (1971), Richardsons (1972) and Celia Wasbourne-Kamau-Nyamweru (1967 and 1974) have given a rather different picture of the "Gamblian Lake" or the last Pluvial. Thus, Bishop (1971, p. 521) shows that from c. 8000-10 000 years ago there seemed to have been two lakes in the Naivasha-Nakuru area. The northern one ("Great-Nakuru") with a level c. 600 feet (e.g. 180 m) higher than the present Lake Nakuru seems to

GAMBLIAN LAKE.

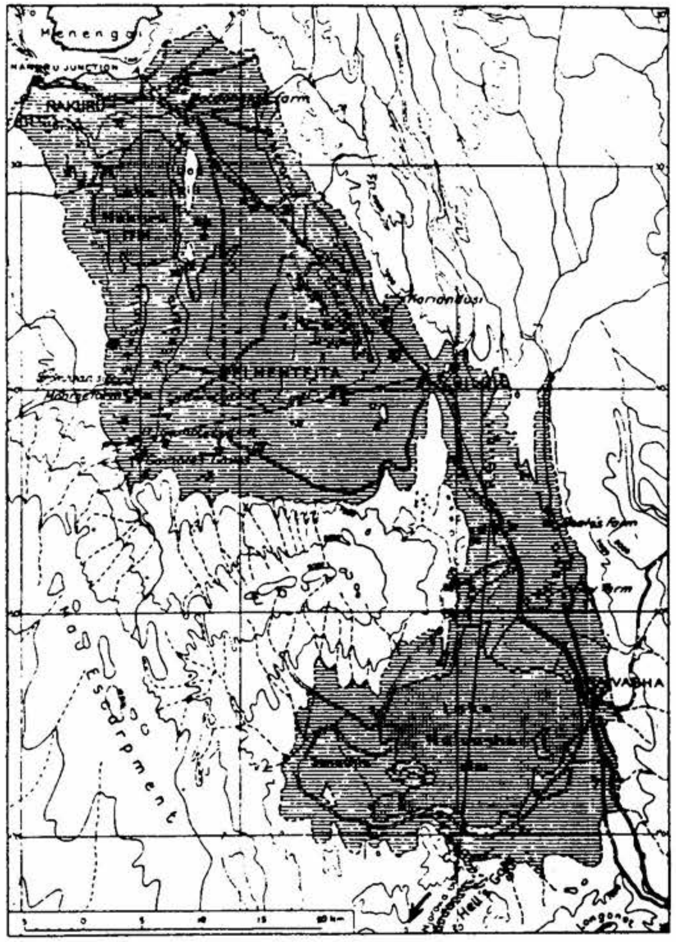


Fig. 3.1 The Nakuru-Naivasha Basin, Eastern Rift Valley. The highest ancient lake of the basin (No. I) is marked with horizontal lines and its shore-line is dotted where it has not been followed and levelled. Shore-lines of lower ancient lakes are designated by the same numbers (II-VII) as the corresponding lakes. Present lakes are checkered. The figures of the contour-lines are in feet. (E. Nilsson 1932)

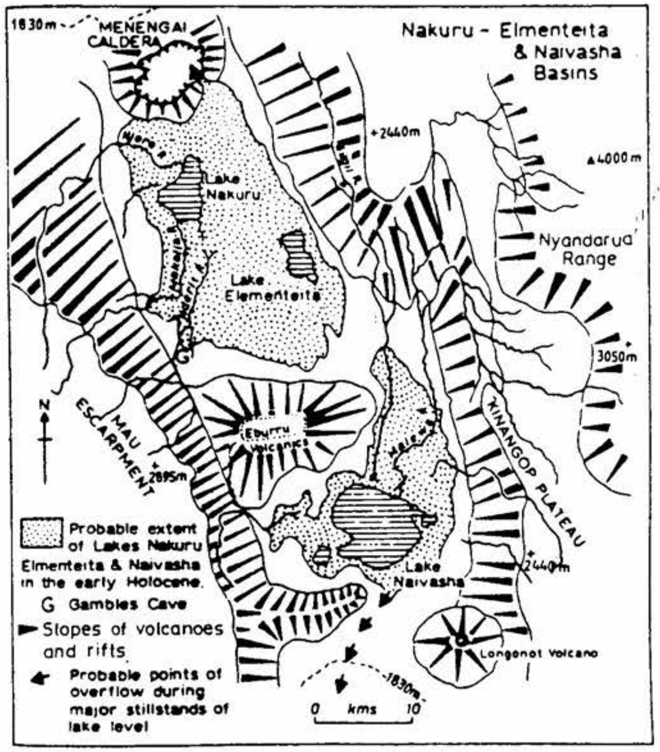


Fig. 3.2 Major relief features and extent of former lakes in the Nakuru-Elmenteita and Naivasha basins. (Modified after Bishop 1971)

have had its outlet towards the north, i.e. towards the Menengai Caldera, whereas the southern one ("Great-Naivasha") in the present Lake Naivasha area was drained towards the south. The level of the southern lake was at least 350 feet, i.e. 105 m higher than that of the present Lake Naivasha (Celia Kamau 1974). As the present Lake Nakuru has an altitude of 5767 feet (e.g. 1758 m a.s.l.) and Lake Naivasha an altitude of c. 1890 m a.s.l. the former "Great-Naivasha" had a lake level c. 60 m higher than "Great-Nakuru". Analyses by the Richardsons (1972) indicate high water level of Lake Naivasha from c. 9200 up to 5700 years B.P., during which time planktonic genera of diatoms dominate samples in a core taken from the crater east of Crescent Island.

Even for the "post-pluvial epoch" (Nilsson's terminology) there is poor relationship between Nilsson's studies and the data appearing in Richardsons' study. Thus, whereas Nilsson talks about two wet phases, the Makalian and the Nakuran, occurring between c. 6000-4500 and 4000-2000 B.C. (Nilsson 1938, p. 432) and two dry phases just before 6000 and 4000 B.C., Richardsons' study indicates high water levels up to c. 5700 years B.P. and decreasing water level up to 3040 years B.P, when the lake was almost dry even in the deepest part of the crater east of Crescent Island which now has a depth of c. 20 m. Since then, Richardsons believe that the water level seems to have varied considerably, in agreement with Nilsson's idea. However, whereas Nilsson thinks that the present water level is an extremely low one for the last 3000 years, Richardsons favour the idea that fluctuations have occurred mainly below rather than above the present surface. It must be admitted that there are very few ^{14}C-determinations to verify the modern ideas about the variations of the water level of L. Naivasha and, in a way, one must also give credit to Nilsson for having realized the tremendous Holocene (and late Pleistocene) variations of the lake levels in the Naivasha-Nakuru area. Taking into consideration the complete lack of absolute datings available at the time of Nilsson's studies, the tentative datings in his diagrams were not bad, although he seems to have overestimated the number of raised shorelines in the area.

Unfortunately, due to the absence of a written indigenous language, there are no records of the water levels of Lake Naivasha before the arrival of the first "wazungu" (= white people) c. 100 years ago. There is an indication (Edmondson 1977) that around the middle of the 19th century Maasai were herding their cattle on dry land where the centre of Lake Naivasha is now. There is also a Maasai tradition about a very dry period immediately before the arrival of white men, during which cattle grazed in Crescent Island (Sikes 1936, p. 82) which obviously was at the time a peninsula. When Fischer, the first European, arrived in June 1883 water level had started to rise, but (according to a Maasai) it was still possible to get across to Crescent Island. The level of the mud between Crescent Island and the mainland is according to Sikes 6193 feet which means the lake level would normally be at least six inches lower or 6192.50 feet. With a correction of +2 feet this equals to 1880.1 m a.s.l.

Fig. 3.3 Drawing of Lake Naivasha in Aug. 1888. From von Höhnel, 1892.

Teleki and von Höhnel visited the Naivasha area in August 1888. von Höhnel presented (1892) both a small-scaled map over the area and a drawing (1892, p. 793). The map shows that at that time Crescent Island was clearly isolated from the lake-shore. In the area where the Gilgil River now enters L. Naivasha there was an incised deep bay up to approximately the 6200 feet contour of the topographical map or in other words c. 20 feet or 6 m higher than the lake level of 1959 (which is unfortunately given a wrong altitude on the map). The drawing (here reproduced as Fig. 3.3) also indicates a rising lake level. Even during Gregory's visit in 1893 the lake level was very high (Sikes 1936, p. 83), which was also the case in 1894. Hobley (cited from Sikes) mentioned "the lake level was so high that we were unable to pass between the cliff, where the railway now runs, so we clambered over the bluff". Sikes arrives at the conclusion "that lake level cannot have been less than 6228 feet above sea level - that is about three feet below present rail level at the point - and may well have been a few feet higher". As the rainfall at Machakos was well above normal in 1895, Sikes arrives at the conclusion of a high water level even in 1895.

There then followed four years of severe drought culminating in "the famine years" of 1898 and 1899. During this period the lake must, according to Sikes, "have dropped rapidly until 1900. The Railway Survey of 1898 shows that the lake level on September 14th, 1898, was 6,214.72 and on November 19th, 6,214.56. Continous records were commenced at the end of 1908, when the level stood at 6,210.90." In 1982 a curve for the water level variations of L. Naivasha between 1911 and 1980 was published (Åse 1982, p. 162). The lake levels prior to 1935 were according to the original, a diagram kept at Korongo Farm, "weekly observations but frequent interpolations. Between 1936 and April 1964 levels were taken from Naivasha Staff Gauge Records. These records seem at least able to provide reasonable monthly records." From May 1964 the material consists of R. Mennell's daily water level observations. Unfortunately, these observations were stopped at the death of Mr. Mennell in 1983.

The levels have been converted from feet to metres by multiplication with 0.3048. In 1958 a change of Datum took place so that 6210' of the old system corresponds to 6212' in the new one. Thus, a correction of +2 feet should be added to the figures cited from Sikes. From the diagram at Korongo Farm monthly and annual average figures were calculated. The table below summarizes the observations before 1910.

Water level records from Lake Naivasha before 1910

Source	Date	Original figure	Correction	Water level m a.s.l.
Fisher through Sikes	June 1883	Below 6192.5'	+2 feet	1888.1
von Höhnel	Aug. 1888	c. 6 m higher than the water level of 1959	None	1893.1
Hobley through Sikes	1894	Above 6228'	+2 feet	1898.9
Railway Record through Sikes	Sept. 1898	6214.74'	+2 feet	1894.9
	Nov. 1898	6214.56'	+2 feet	1894.8
Water level record through Sikes	End of 1908	6210.90'	+2 feet	1893.7

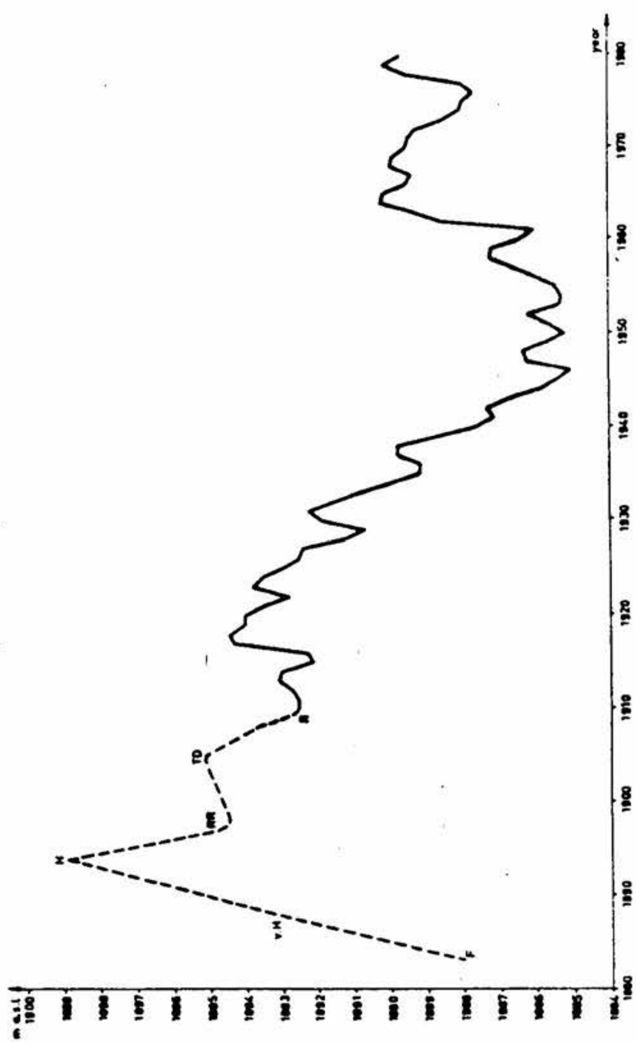
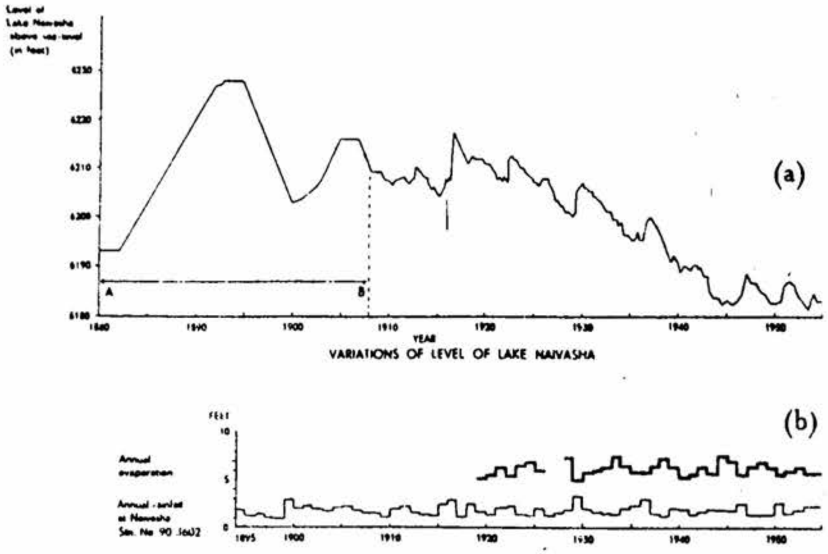


Fig. 3.4 Annual water level records of Lake Naivasha (1911-1980) and some data for previous years.
F = According to Fisher, v.H = According to von Höhnel, H = According to Hobley,
RR = Railway records, TD = According to Thompson and Dodson, R = Record starts.

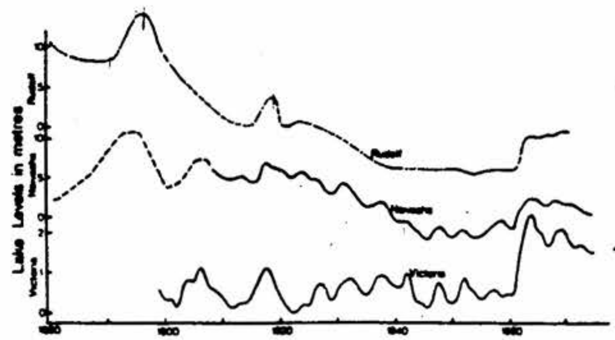


<u>Fig. 3.5</u> (a) Variations of level of Lake Naivasha. Probable major fluctuations of level in the region A-B of the graph are taken from Sikes, 1936. From about 1860 to 1882 Crescent Island was joined to the mainland and acacia trees grew along the lake shore, but were then killed by the rise of the water level, their stumps remaining submerged until 1935. During the period of low level at the end of the nineteenth century, it is probable that the lake did not rise above the 6,195-foot level.
(b) Annual evaporation from Lake Naivasha and annual rainfall at Naivasha.
(From Thompson and Dodson 1963)

The values given in the table have also been inserted in Fig. 3.4, which is otherwise copied from Åse (1982). A few comments about the diagram might be added. The very low water level before 1883 is also indicated by Tetley (1948) who writes: "There were reports that in recent years there were still some trees appearing from below the surface of the lake as it continued to fall recently". The water level before 1883 might thus have been even lower than that of the mid 1940's. In Fig. 3.4 I have tentatively let the lake level rise before 1883 at about the same rate as between 1883 and 1888. The extremely high level in 1894 indicated by Sikes (from Hobley's description) seems a bit doubtful*, since the rainfall that year in Naivasha (cf. Thompson and Dodson 1963, p. 10) seems to have been about 2 feet i.e.

* Levelling of the cliffs east of Naivasha railwaystation in Oct. 1985 revealed a cliff base of c. 1896 m a.s.l.

about average. However, Gregory's description (1896) shows that 1893 must have been a very wet year. The dropping of lake level just before the turn of the century seems reasonable from the precipitation figures. The high precipitation during the first years of the 20th century might have made the lake level rise, a rise that is not possible to trace from Sike's material, but that appears in Thompson's and Dodson's attempt indicating a rising lake level up to c. 6217' (cf. Fig. 3.5), which should correspond to c. 1895.5 m a.s.l. in Fig. 3.4 around 1905. Incidentally, this is just one solar spot cycle after the assumed high water level of 1894-95. In the middle of 1917 the highest modern lake level was recorded i.e. 6220.0 feet or 1895.9 m above sea level. Once again, we find that this corresponds well with a sun spot cycle (c. 11 years) after 1905. The next high water occurs, however, in 1923. Other peaks in the water level occur in 1930, 1937-38, 1948, 1964 and 1979. Of these, the sun spot cycle fits reasonably well to the peaks of 1937-38 and 1948, but later on the cyclical trend is not as easily recognized. Vincent, Davies and Beresford made (1979) a statistical study of the water level variations of Lake Naivasha (cf. Fig. 3.6).They found an indication of an 11 year cycle, but more statistically significant was a variation with a period of about 7 years.



<u>Fig. 3.6</u> Annual average levels for the Lakes Naivasha and Rudolf (1880-1974) and Victoria (1899-1974). Victoria level post-1961 are less 1 m. Dashed values are from indirect indicators. Dots are linearly interpolated values. (From Vincent, Davies and Beresford, 1979)

More interesting, perhaps, than the statistical variation of the water level is a comparison with data from Lake Victoria and L. Turkana (Rudolf). Vincent, Davies and Beresford (1979, p. 178) found that even in L. Turkana there were high water levels around 1895, 1918 and in the early 1960's. The two latter maxima are also found in the material from Lake Victoria (no observations are available here for the time around 1895). The material from Lake Victoria also shows a maximum from the time around or just before 1905.

The monthly variations of the water level of Naivasha appear from Fig. 3.7. One would expect that the lake level would normally show two peaks, one during the long rains in April-May and another during the short rains in November. This is obviously not the case. The lake level normally drops during the beginning of the year, until the long rains start in April. However, water level normally continues to rise even during June, July and August and the maximum occurs in September. During the short rains water level normally drops. To some extent this can be explained by the fact that evaporation is very low in June, July and August but shows a definite increase in September-October. Even the so-called Zaire-monsoon from the Atlantic ocean and Lake Victoria sometimes gives some precipitation during the middle of the year. The hydrology of the drainage area is discussed further in chapter 4, where the intricate question of the existence of an outlet of Lake Naivasha is also discussed.

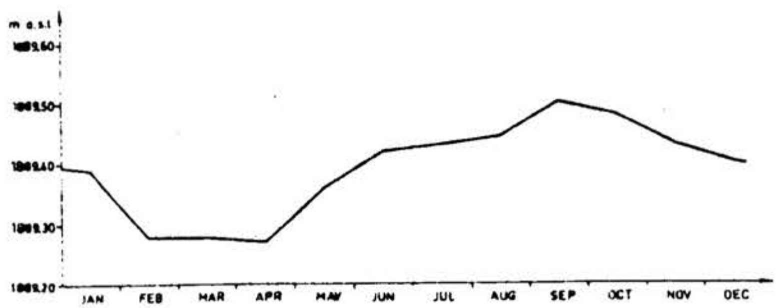


Fig. 3.7 Monthly variations of water level in Lake Naivasha. (From Åse 1982)

CHAPTER 4

THE WATER BUDGET OF LAKE NAIVASHA AND ITS DRAINAGE AREA

By Per Syrén

Introduction

The main purpose of this project was to study the water balance of Lake Naivasha and the hydrological and the climatological conditions within its drainage area . The question that I wanted to answer through such an investigation was whether the water level fluctuations of Lake Naivasha are influenced by a subterranean inlet and outlet. The more practical applications of this study can be outlined in several points, of which a few are mentioned below.

When we understand the water balance, and know the proportions of each factor in the water balance equation, it is possible to improve the agriculture of an area. This is one of the most important aspirations for all developing countries. The water balance for an area can be defined with the following equation:

$$P = E + R + \Delta S$$

P = Precipitation
E = Evapotranspiration
R = Runoff
ΔS = Changes in water storage

Agriculture can be improved by introducing new, more profitable crops. But very often these crops are more sensitive to drought and therefore require some irrigation system. Thus, this requires knowledge about the availability of water.

Hydrological knowledge about runoff, water discharge, duration etc is also necessary for the ongoing calculations of sediment transport in the River Malewa.

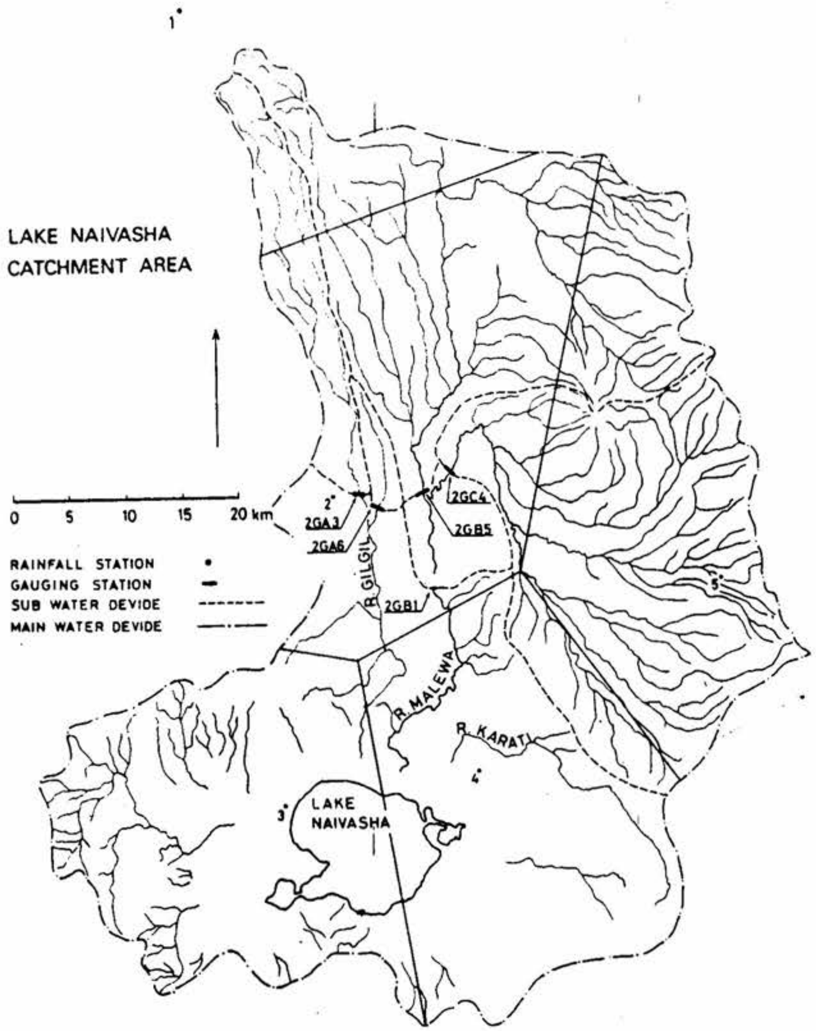


Fig. 4.1a Lake Naivasha catchment area. Drainage and location of rainfall and river gauge stations. The full drawn straight lines refer to the Theissen method of computing the average rainfall.

Available data and topography

The study is based on data collected during a visit in Kenya in 1983.

- Hydrological data on water discharge and sediment load were obtained from the Ministry of Water Development, Nairobi.

- Meteorological data on precipitation and evaporation from the Kenya Meteorological Department, Nairobi, and from the publication: Monthly and annual rainfall in Kenya 1931-1960.

- Lake level data for Lake Naivasha were registered by R. Mennel at Korongo farm, and were collected by Lars-Erik Åse in July 1981.

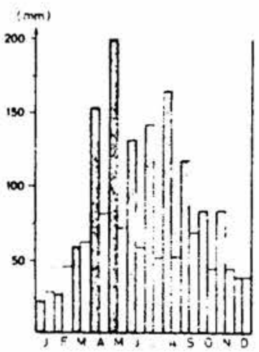
Available data

Data on water discharge are available from four river gauge stations as follows (cf. also Fig. 4.1a).

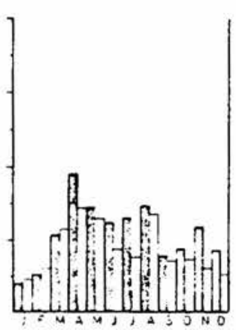
Station, 2GB1.	River Malewa during the periods	Jan. 1931 - Dec. 1949.
		Jan. 1951 - Dec. 1959.
		Jan. 1963 - Dec. 1980.
Station, 2GB5.	River Malewa during the period	Jan. 1959 - Dec. 1980.
Station, 2GC4.	River Turasha during the period	Jan. 1962 - Dec. 1980.
Station, 2GA3.	River Gilgil during the period	Jan. 1962 - Dec. 1980.

In this study data on precipitation are used from five rainfall stations (Fig. 4.1b). Of these, four are situated within Lake Naivasha's drainage area. The station Bahti forest is situated about 5 km outside of the main watershed, but is assumed to be representative of the northern parts of the catchment area (cf. Fig. 4.1a). Data were obtained from the East African Metrological Department except for the station at Korongo farm, where the records were obtained from R. Mennel.

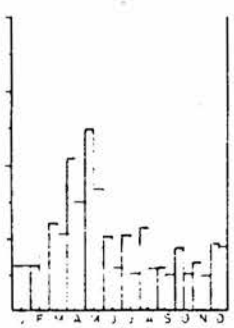
Station 1. 2409 m a.s.l
Bahti forest (1931-1983)
annual rainfall 1226 mm.



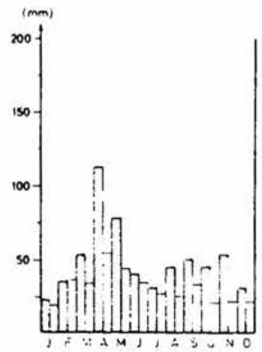
Station 2. 2006 m a.s.l. Gilgil
railway stn. (1931-1960, 1962-1982)
annual rainfall 650 mm.



Station 3. 2006 m a.s.l
Korongo farm (1949-1945, 1959-1983)
annual rainfall 664 mm.



Station 4. 1900 m a.s.l
Naivasha D.C. (1910-1983)
annual rainfall 608 mm.



Station 5. 2631 m a.s.l
N. Kinangop (1931-1960)
annual rainfall 1093 mm.

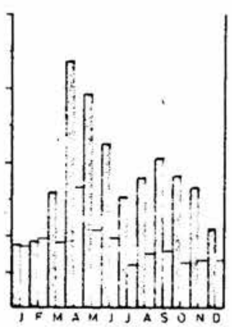


Fig. 4.1b

Filled bars show actual average rainfall, unfilled bars standard deviation at 1σ over the period 1931-1960.

The evaporation data were obtained from the Kenya Meteorological Department in Nairobi, and are in the form of monthly totals of the Naivasha water supply during the period 1965-1983. There are also records of annual evaporation from a study by Brind and Robertson (1958). These data were taken during the period 1919-1957.

Variations of the water level in Lake Naivasha were registered at Korongo farm during the period 1964-1980 and are given as monthly averages in m a.s.l.

The topographical map SA - 37 - 1 Nyeri is used for the drawing of all figures of drainage areas, drainage pattern, hypsographic curves and for the location of the different gauging stations. The geological maps No. 43 SW and NW are used for the production of the schematic map of the distribution of soils and bedrock within the catchment area.

Topography

The Lake Naivasha catchment area covers an area of approximately 3300 km^2 and is drained by three major rivers. These are, the River Malewa, the River Gilgil and the River Karati. Within the catchment area there are great contrasts in relief, slope, climatic conditions, vegetation, lithology and land use. In Figure 4.2a the hypsographic curve for the whole catchment area is outlined. 30% of the total area of the Lake Naivasha catchment basin is situated between 1890-2100 m a.s.l. The lake, at a level of 1890 m, covers about 12% of the catchment area. 55% are situated at levels between 2100-2700 m a.s.l. Only about 15% of the area has an altitude between 2700-3900 m a.s.l. This area is situated on the slopes of the eastern escarpment of the Rift Valley. This study is concentrated to the two major subcatchments i.e. the River Malewa and the River Gilgil.

The River Malewa drainage basin covers an area of 1553 km^2 and the hypsographic curve is outlined in Figure 4.2b. Here about 73% of the area is situated at levels between 2100-2700 m a.s.l. This corresponds to the Kinangop plateau. About 22% of the area consists of the hills

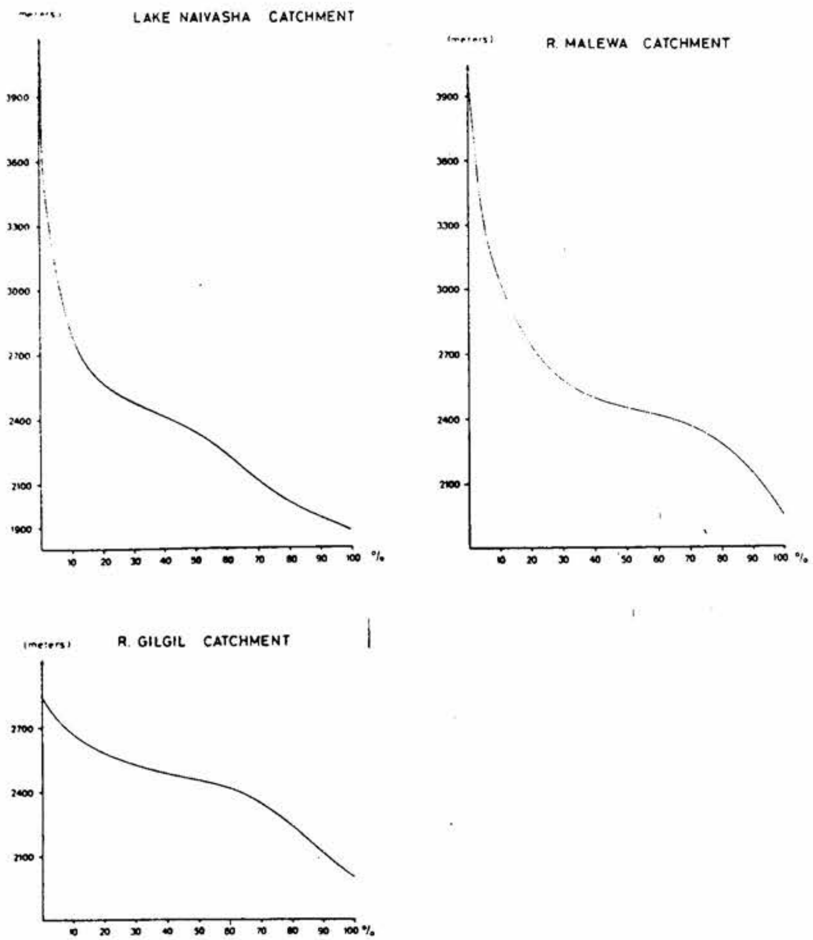


Fig. 4.2a-c Lake Naivasha catchment area, River Malewa and River Gilgil catchment areas. Hypsographic curves based on 1:50 000 topographical map SA-37-1 Nyeri.

and slopes of the Nyandarua Range, having an altitude of 2700-3900 m a.s.l.

The River Gilgil drainage basin (Fig. 4.2c) covers an area of 151 km^2 and represents the flattest subcatchment area. About 83 % of the area is located between 2100-2700 m a.s.l and there are not any areas situated above 2900 m.

Climatological conditions

Rainfall

Because of its marginal nature and unreliability, rainfall is the most important climatic element in semiarid areas such as central Kenya. However, this general classification does not reflect the true conditions over large areas within the Lake Naivasha basin, for example in the eastern parts of the catchment where the escarpment of the Nyandarua Range rises. Here the orographic effects and local climatological conditions seem to have a pronounced effect upon climate, which is otherwise influenced by the large circulation systems like trades and fluctuations of the ITCZ (the intertropical convergence zone) (Jackson 1977, p. 9)

Analysis of rainfall in the Naivasha catchment area is very important, because rainfall is the major factor to be taken into account in order to find the causes of the variations in lake level and to forecast its future behavior. In this study data from five rainfall stations, covering a fairly long period, are available. It can be noted from Figure 4.1a-b that the rainfall decreases from the upper parts of the River Malewa and the River Gilgil headwaters to the lake surroundings. At rainfall station no. 5, North Kinangop forest (Fig. 4.1a), situated on the Kinangop plateau, the average annual rainfall is 1093 mm (1931 - 1960). In the upper parts of the River Gilgil at rainfall station no. 1, Bahti forest, it amounts to 1226 mm (1931 - 1980), at station no. 3, Korongo farm, the average annual rainfall during the period 1951 to 1960 is 664 mm.

Rainfall seasonability and variability

The variability of rainfall receives particular attention in most semi-arid areas, due to the fact that droughts are common and that rainfall is characterized by the occurence of a few extremely hard showers. The annual distribution and the variation in rainfall can be showed in many ways. One possibility is outlined in Figure 4.1b where the monthly averages and the corresponding standard deviations during the period 1931-1960 are represented. In this diagram the long rains during April-May are obvious, but the short rains that normally occur in Kenya during October-December are not as evident.

Another way of describing the variation of rainfall from year to year is to define the beginning and end of the periods of rainfall. In Jackson (1977, p. 60) the use of 5 day periods (pentades) is explained as the totals of precipitation for three consecutive pentades, and the middle pentade is designated as "rainy" if:

- the total rainfall for the three pentades together amounts to at least 76 mm.
- the rainfall amounts to 7.6 mm or more in each of at least two of the three pentades.

In Figure 4.3 the analysis of rainy pentades is shown for station no. 3, Korongo farm, situated on the western side of Lake Naivasha. The unreliability of rainfall, especially during the short rains, appears very clearly here.

A way to study rainfall variability within a catchment area is to analyze the correlation between rainfall stations, (cf. Jackson 1977, p. 84). In Figure 4.4a, the monthly average rainfall from 1931 - 1960 at station no. 5, North Kinangop forest at 2631 m a.s.l. (which has an average annual rainfall amounting to 1096 mm), is correlated with the similar values for station no. 2, Gilgil Railway stn. The latter station is situated 630 m below the former, and receives about 400 mm less precipitation annually. From this diagram it can be seen that the correlation coefficient of +0.83 is strongly dependent on the values for the months of April and May.

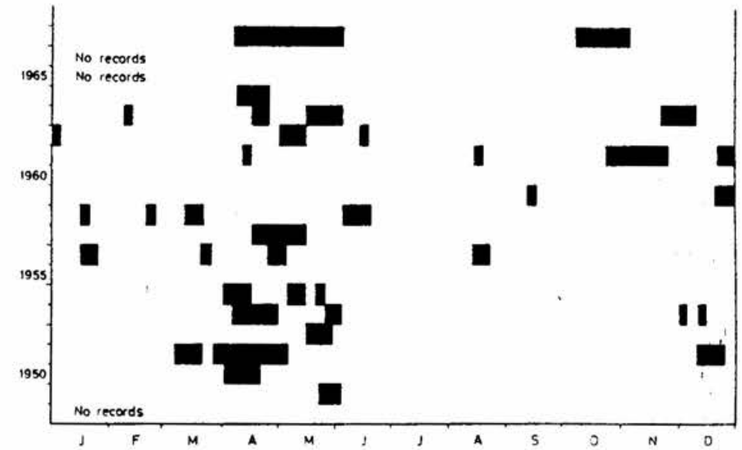


Fig. 4.3 Korongo Farm. Rainy pentades.

Thus, the conclusion is that rainfall at stations close to each other, but at different altitudes, shows a greater correlation during the more rainy periods when showers cover a greater area. During the other months, when precipitation is more local due to orographic effects, the difference in altitude between the stations leads to a decrease in the correlation coefficient.

Two stations that are not so closely situated to each other, but that are at nearly the same altitude, were also studied. In figure 4.4b, station no. 1, Bahti forest, at 2400 m a.s.l and with an average annual rainfall of 1226 mm, is correlated with station no. 5, North Kinangop forest. Here we have the almost reversed situation. The correlation coefficient is +0.82 between the two stations, but here the correlation is more dependent on the values from the dry periods, indicating the similar orographic effect at both stations. During months of rainy periods the distance between the two stations leads to a decrease in the correlation coefficient.

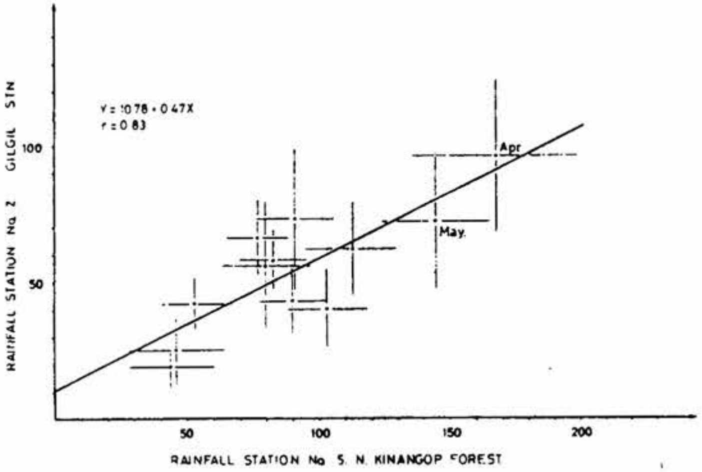


Fig. 4.4a Correlation between the average monthly values on precipitation at station No. 5 and No. 2 (1931-1960).

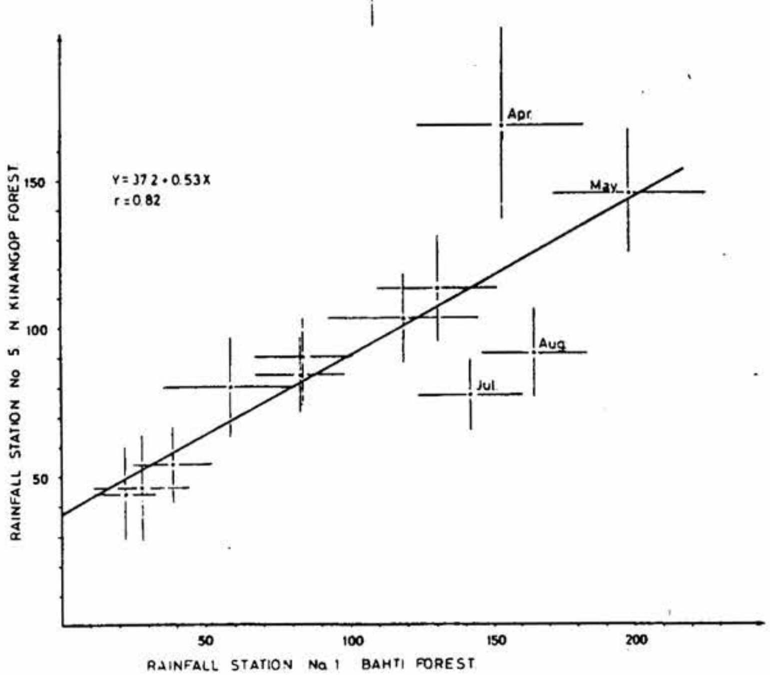


Fig. 4.4b Correlation between the average monthly values on precipitation at station No. 1 and No. 5 (1931-1960).

Rainfall probability - recurrence intervals

In an investigation by Brind and Robertson (1958) analyses on rainfall probability are made for the two stations, no. 5, North Kinangop forest and no. 4, Naivasha D.C. Their calculations are based on data from the period 1911 - 1956, and they assumed that rainfall distribution approximates the normal probability function. In the present study the analysis on rainfall probability or recurrence intervals for station no. 4, Naivasha D.C are based on data from the period 1931 - 1980. The method used is described by Jackson (1977, p. 77) as one of the most common.

Data are arranged in descending order and a rank m is assigned to each value, m = 1 for the largest value and m = n for the smallest, n being the number of values. The return period T, is given by: T = n+1/m

These computed T-values, or return periods are then plotted graphically against the corresponding amount of annual rainfall.

In this analysis of return periods of annual precipitation (Fig. 4.5) at Naivasha D.C, an annual rainfall of 1083 mm is estimated to occur once in 100 years. The actual maximum rainfall recorded is 942 mm, which was received in 1961. The values computed by Brind and Robertson (1958) of return periods at Naivasha D.C estimate an annual rainfall once in 100 years to 1156 mm. Recorded maximum rainfall at this study is 1036 mm.

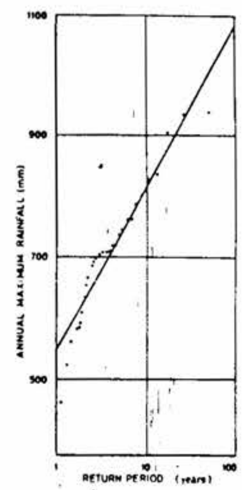


Fig. 4.5 Naivasha D.C. Recurrence intervals of annual maximum rainfall based on data from 1962 to 1980.

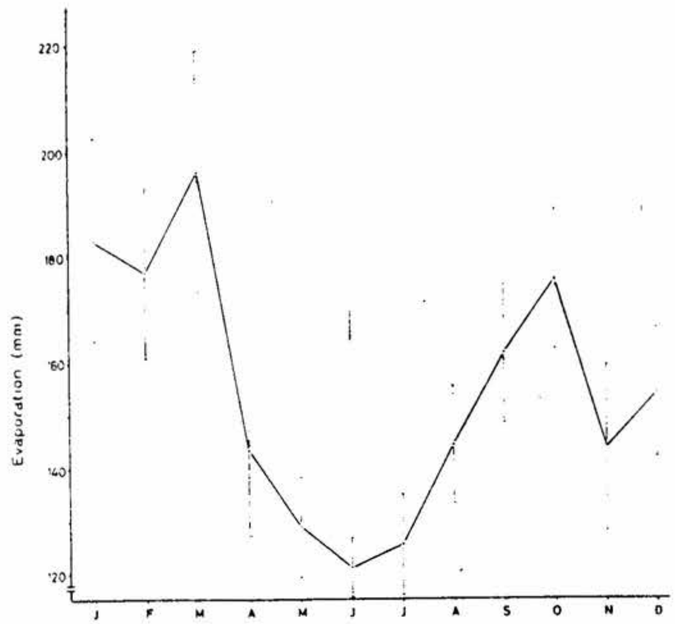


Fig. 4.6 Average measured pan evaporation at Naivasha water supply 1965-1982. The thin lines indicate the variation within 95% confidence interval.

Evaporation

It is always difficult to estimate evaporation. In the case of Lake Naivasha, limited available records together with the general problem of estimating evaporation from pan observation makes any estimate unreliable. As can be seen from Figure 4.6 the average annual measured pan evaporation amounts to 1865±106 mm.

There are problems in defining the amount by which the monthly figures of measured evaporation should be corrected by the use of a panfactor. In other words, free water evaporation from an evaporation pan usually results in figures that are too high, due to the fact that the walls of the pan tend to heat the water to a higher temperature than normal. From a study by Brind and Robertson (1958) it is suggested that the pan-factor for the station Naivasha D.C varies between 0.84 - 1.04. Therefore a multiplication factor of 0.80 which is normally used for the class-A pan in Kenya, (Brind and Robertson 1958) may be too low.

The average precipitation and potential evaporation are shown in Figure 4.7 (1965 - 1982). The evaporation amounts to 1492 mm (multiplication factor 0.80 is used), i.e. more than twice the annual precipitation in Naivasha D.C. These figures point out the very decisive influence of evaporation upon the water budget of Lake Naivasha.

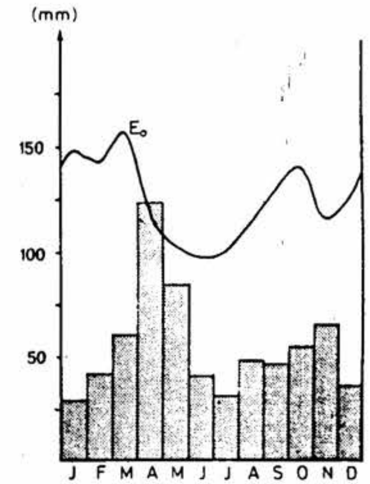


Fig. 4.7 : Average precipitation and potential evaporation (E_0) at Naivasha D.C 1965-1982. The panfactor used is 0.80.

In an attempt to test these measured evaporation figures the following test is made:*

Under certain conditions a lake could be considered as a huge evaporation pan. If the water level drops during a period without precipitation, discharge of water to the lake, or runoff from the lake, the sinking of the water level in e.g. mm should represent the evaporation figure. In this particular case potential evaporation equals actual evaporation. If, however, the water level of the lake also is influenced by ground water flow, the whole idea of the lake as an evaporation pan must be abandoned.

In the case of Lake Naivasha, it can not a priori be assumed that the lake level is not influenced by inflow and outflow of ground water. Nevertheless, it was considered to be worth testing whether changes in water level during dry periods corresponded only to evaporation and

* This paragraph is written by Lars-Erik Åse.

thus, if the test came out well, whether the "pan factor" of 0.80 was correct or not. The following periods were selected for the test: January 1968, March 1973 and January 1975.

During these three months, there was less then 5 mm of precipitation recorded at Korongo farm or at Naivasha D.C. Some runoff occurred, however, in the catchment. The effect of this runoff on the lake could be calculated according to the method described on pp. 63–65, in this paper. The potential evaporation, multiplied with the pan factor of 0.80, was registered at Naivasha D.C. (Naivasha water supply). The changes in water level during the test were registered at Korongo farm. The results of the test are given in Table 4.1.

Obviously, as the ratio of column (7) in Table 4.1 varies so much, the test was useless as an indication of whether the pan factor was correct or not. However, as the values show such great variation they indicate strongly that there is important groundwater flow to and also from the lake.

Table 4.1

(1) Period	(2) Inflow	(3) Calculated Lake level change due to inflow	(4) Actual Lake level change	(5) Computed potential evaporation	(6) Actual potential evaporation	(7) Ratio $\frac{(6)}{(5)}$
Jan 1968	$3.4 \cdot 10^6 m^3$	+ 0.021 m	- 0.250 m	271 mm	209 mm	0.77
Mar 1973	$2.8 \cdot 10^6 m^3$	+ 0.018 m	- 0.110 m	128 mm	235 mm	1.83
Jan 1975	$2.9 \cdot 10^6 m^3$	+ 0.020 m	- 0.150 m	170 mm	203 mm	1.20

Runoff

Main rivers and drainage pattern

As can be seen from Figure 4.1a the main rivers and also the main tributaries to Lake Naivasha, are in descending order, the Malewa, Gilgil and Karati Rivers, which all enter the lake from the northern and eastern parts of the catchment area. A different drainage pattern is formed by these rivers as compared to those of the southern part of the drainage basin, where the rivers are of ephemeral character, and

tend to disappear before entering the lake. The difference can be explained by different precipitation pattern and differnt soil conditions (cf. e.g. Marie Morisawa 1968, p. 162). Obviously, the most important river for the water budget of Lake Naivasha is the River Malewa.

Construction of discharge rating curve

The available hydrological data for gauging station 2GB1, River Malewa, during the periods 1931 - 1949 and 1951 - 1959 are in the form of daily average waterlevel readings, and are therefore converted into corresponding water discharge values. The construction of the discharge waterstage diagram (rating curve) for the station 2GB1 is based on data that are collected at the Ministry of Water Development in Nairobi.

When plotting the values to a diagram (Fig. 4.8) a normal rating curve is shown, but there is not a good correlation when the curve is adapted to a continuous equation. Therefore the GHT-values i.e. the gauge height values, are divided into six intervals. A linear equation Y = a + bX is fitted to each of these intervals, where X is the discharge in cubic feet per second and Y is the GHT-value in feet (Fig. 4.8 and Table 4.2).

Table. 4.2

Equation number	Gauge height interval	Equation Y = a + bX	Correlation coefficient (r)
1.	0.00-0.99	$Y = 0.08 + 7.59x10^{-3} X$	0.988
2.	1.00-2.29	$Y = 0.53 + 3.79x10^{-3} X$	0.998
3.	2.30-2.99	$Y = 1.23 + 2.26x10^{-3} X$	0.997
4.	3.00-4.00	$Y = 1.76 + 1.58x10^{-3} X$	0.999
5.	4.01-7.49	$Y = 2.21 + 1.26x10^{-3} X$	0.999
6.	7.50-9.10	$Y = 3.06 + 1.06x10^{-3} X$	0.999

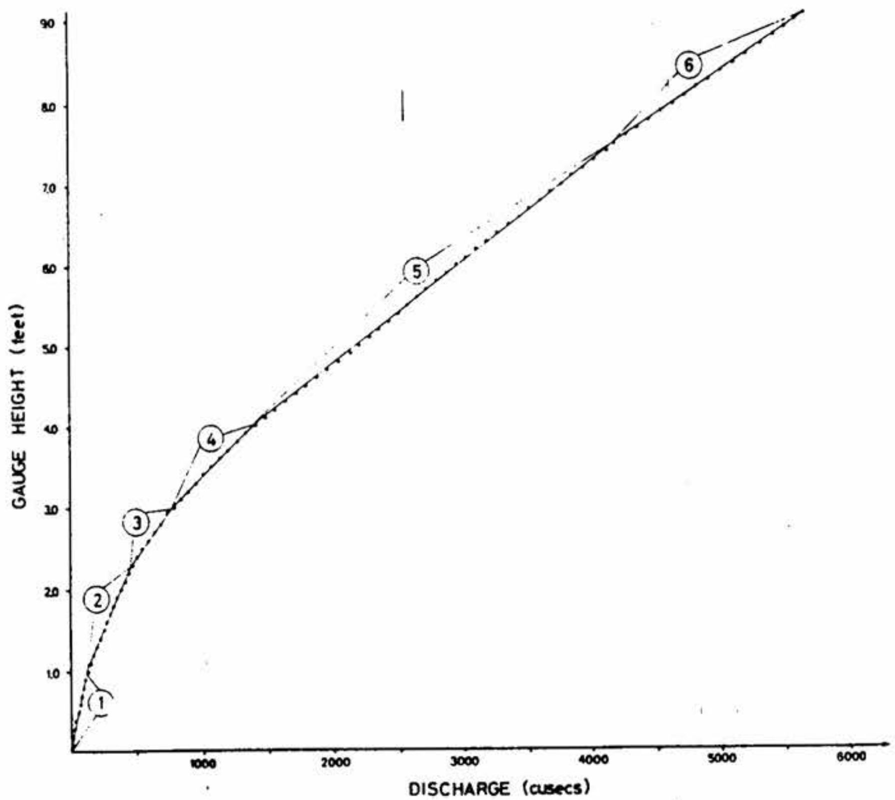


Fig. 4.8 Discharge rating curve for river gauge station 2GB1, in River Malewa.

Runoff analysis of River Malewa

Using the discharge rating curve described above, the monthly discharge is calculated from daily discharge for each catchment area. The average annual flow during the period 1932 - 1980 is 153×10^6 m^3, which equals a water column of 100 mm over the drainage area (the latter values are henceforth given in parenthesis). During the same period the recorded annual maximum flow is 328×10^6 m^3 (211 mm) in 1964, and the recorded annual minimum flow is 53×10^6 m^3 (34 mm) in 1939.

Records of the flow of the River Malewa are analysed to determine the frequencies of annual and monthly volumes of flow. Return periods or recurrence intervals for the years 1932 - 1982 are calculated according to the method described on p. 49. In figure 4.9a the line of best fitting is estimated, and the annual flow to be expected once in 100 years is about 480×10^6 m^3. This result corresponds very well with a former investigation made by Brind and Robertson (1958). Their computation is based on data on annual flow during the period 1932 - 1956 and estimates an annual flow once in 100 years of c. 475×10^6 m^3.

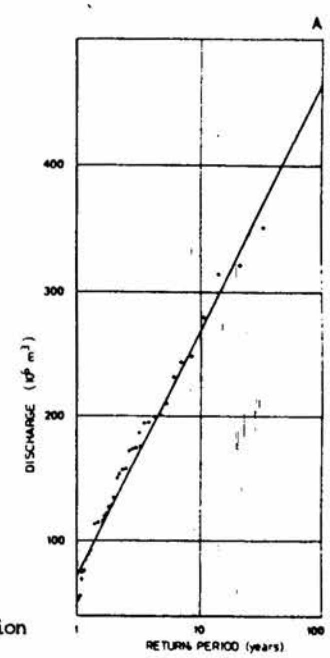


Fig. 4.9a

River Malewa. Recurrence intervals of annual maximum discharge at gauging station 2GB1. Based on data from 1931 to 1982.

The return periods of monthly flow to be expected are based on data from the months of May and August over the period 1932 - 1980. The monthly flow to be expected for the month of May once in 100 years is c. 97×10^6 m^3 and for the month of August c. 84×10^6 m^3 (Fig. 4.9b-c). The recorded maximum flow for these two months is 86×10^6 m^3 in 1963, and 81×10^6 m^3 in 1971, respectively.

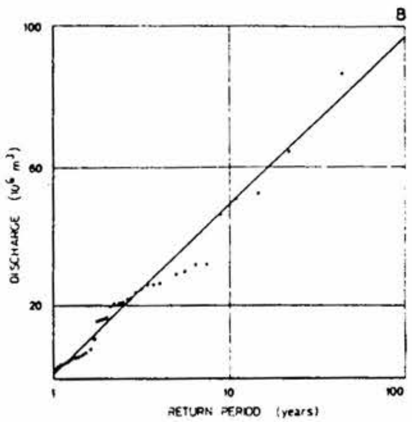


Fig. 4.9b

River Malewa. Recurrence intervals of monthly maximum discharge for the month of May at gauge station 2GB1. Based on data from 1931 to 1982.

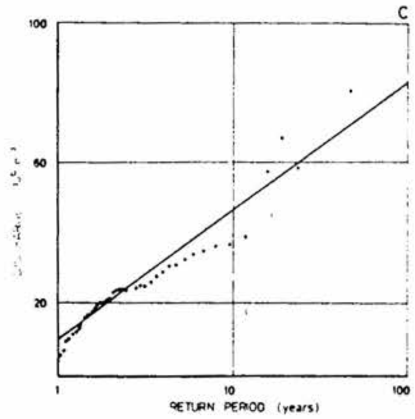


Fig. 4.9c

River Malewa. Recurrence intervals of monthly maximum discharge for the month of August at gauge station 2GB1. Based on data from 1931 to 1982.

Runoff analysis of River Gilgil

The available data used for discharge are listed on p. 41. The same analysis is carried out for data on River Gilgil, as was for the River Malewa, to determine the frequency of annual and monthly flow to be expected.

The average annual flow from the River Gilgil during the period 1962 - 1980 is about $24x10^6$ m^3 (159 mm). The flow is equal to about one seventh of that of the River Malewa. It can be seen in the analysis of recurrence intervals in figure 4.10a that the highest annual flow to be expected in 100 years is $121x10^6$ m^3 (798 mm). The highest actual flow during the investigated period is $49x10^6$ m^3 (322 mm). These values correspond very well with the results from the investigation made by Brind and Robertson (1958). Their computation indicates a maximum recurrent 100 year flow of $111x10^6$ m^3, and an actual annual high flow of $71x10^6$ m^3 from the investigated period 1941-1946.

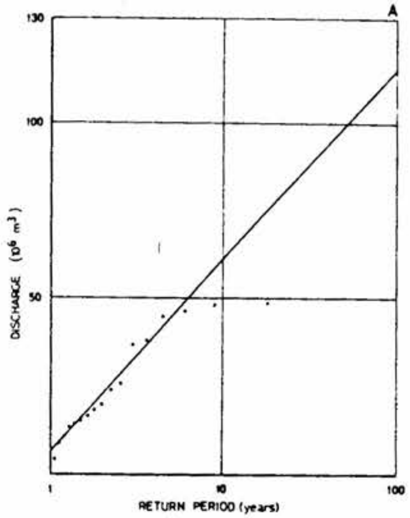


Fig. 4.10a

River Gilgil. Recurrence intervals of annual maximum discharge at gauge station 2GA3. Based on data from 1962 to 1980.

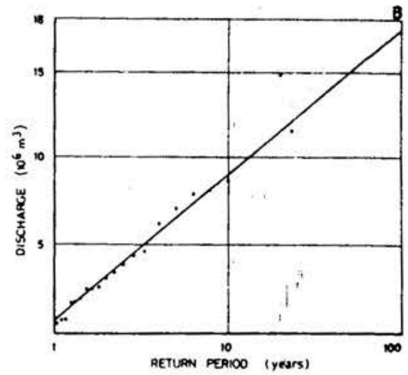


Fig. 4.10b

River Gilgil. Recurrence intervals of monthly maximum discharge for the month of August at gauge station 2GA3. Based on data from 1962 to 1980.

The return periods of monthly flow to be expected are based on data from the months of May and August over the period 1932 - 1980. The monthly flow to be expected for the month of May once in 100 years is c. $97x10^6$ m^3 and for the month of August c. $84x10^6$ m^3 (Fig. 4.9b-c). The recorded maximum flow for these two months is $86x10^6$ m^3 in 1963, and $81x10^6$ m^3 in 1971, respectively.

Rainfall-runoff relationship

The relation between rainfall and the amount of water transported out of the catchment area is described by the runoff coefficient. That is, if the average rainfall on the catchment area is 100 mm and the measured discharge, caused by that rainfall, out of the catchment area is 50 mm, the actual runoff coefficient is 0.50. This coefficient depends on a number of different factors within the catchment area, e.g. slope, soils, vegetation, evaporation, catchment size, and the characteristics of the rainfall (cf. e.g. Marie Morisawa 1968, p. 11).

In a study by Brind and Robertson (1958) the rainfall runoff relationship is based on annual data. The correlation between rainfall and runoff is found to be +0.89 for the Malewa catchment area and +0.64 for the Gilgil catchment area. The equation of the line of regression for Malewa is $Y = 0.285\ X - 6.71$, and for Gilgil $Y = 0.271\ X - 4.69$, where Y is runoff in inches and X rainfall in inches.

In the present study similar computations are made but on the basis of monthly values. For the River Malewa catchment area the average precipitation is computed for each month from 1936 to 1937, and from 1952 to 1954, from precipitation stations no. 1, 2, 4, and 5 using the Theissen method (Otnes and Reastad 1971, p. 136) . In figure 4.11 these average rainfall values are plotted against the corresponding discharge (in column of water) at gauging station 2GB1, and as can be seen there a is very poor correlation i.e. +0.55. The same analysis on rainfall runoff for the River Gilgil catchment area over the periods 1963 - 1966 and 1968 - 1970 is plotted in figure 4.12. Here the correlation is only +0.53. The reasons for this low correlation between rainfall and runoff can be explained mainly by e.g. the two factors:

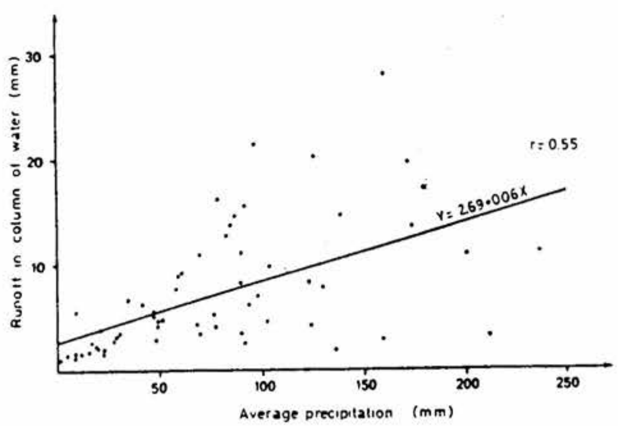


Fig. 4.11 River Malewa catchment area. Correlation between average rainfall on the catchment, computed by the Theissen method, and runoff at station 2GB1.

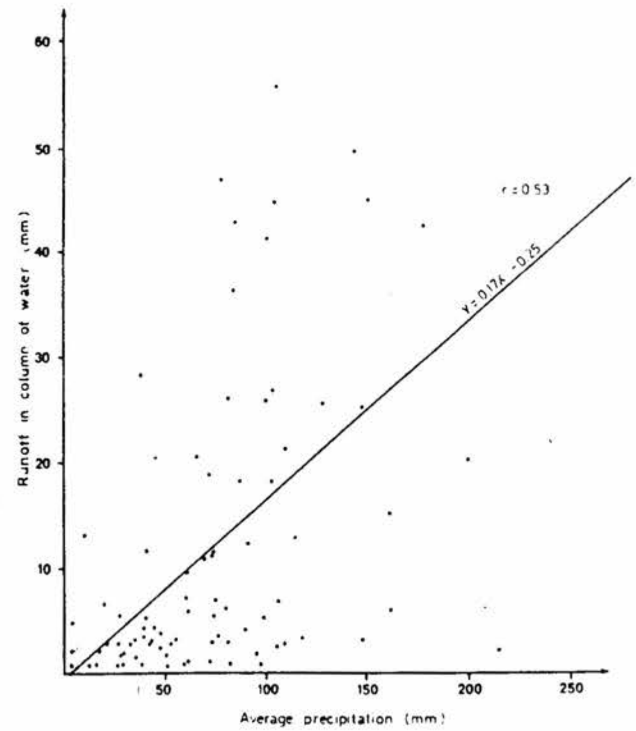


Fig. 4.12 River Gilgil catchment area. Correlation between average rainfall on the catchment, computed by the Theissen method, and runoff at station 2GA3.

- The network of rainfall stations is not dense enough. Computation of the average precipitation over the actual catchment area using the Theissen method leads to large errors in the figures for the amounts of rainfall, since the rainfall stations are not representative.

- Also, the calculations of correlation become very much dependent on short "gathering time" when using monthly values on precipitation and runoff. Suppose that a heavy shower occurs at the end of a month and is registered at a rainfall station. The runoff caused by this rainfall may not be recorded until the following month due to the delay (gathering time). During this latter month the runoff figures are compared with the wrong rainfall figures: I.e. the correlation would probably be better if the year was divided into rainy and non-rainy periods.

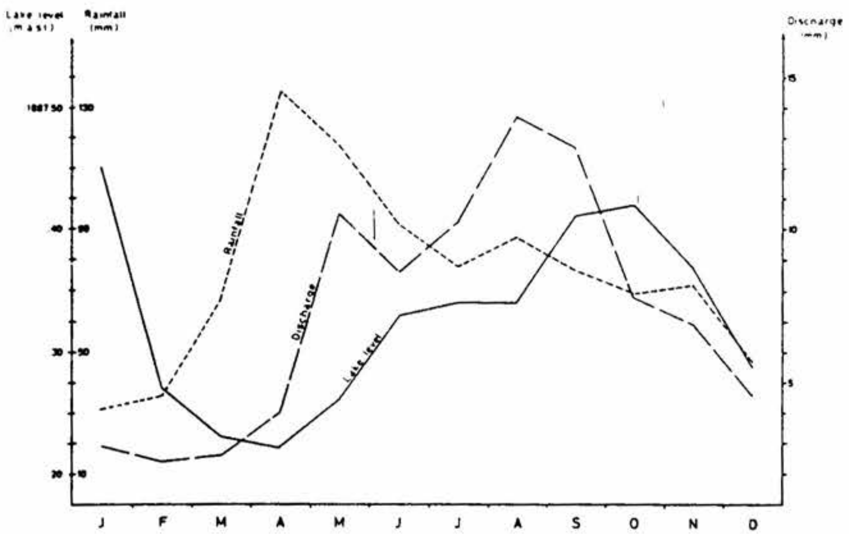


Fig. 4.13 Monthly average rainfall on the River Malewa catchment area, runoff at gauge station 2GB1 and lake level (1932-1959).

Apart from these two factors mentioned above, there are other effects on the runoff ratio, caused by variations in soil moisture, infiltration capacity and evaporation, that lead to a low correlation. As all these factors vary over time and with the amount and duration of rainfall, it is difficult to compare the runoff caused by one rain with that from another. And as will be shown later groundwater flow probably has great influence on river discharge. Also, this latter factor might make it difficult to compare rainfall with actual overland runoff.

The average monthly values for runoff and average precipitation for the River Malewa catchment area during the period 1932 to 1959 are shown in Figure 4.13. The average annual runoff is 87±23 mm, and the annual average rainfall 906±201 mm, i.e. the average runoff coefficient is about 0.1. As can be seen in this diagram there is also a delay between rainfall and runoff. One reasonable explanation for this delay is that the river discharge is to a great extent influenced by groundwater sources.

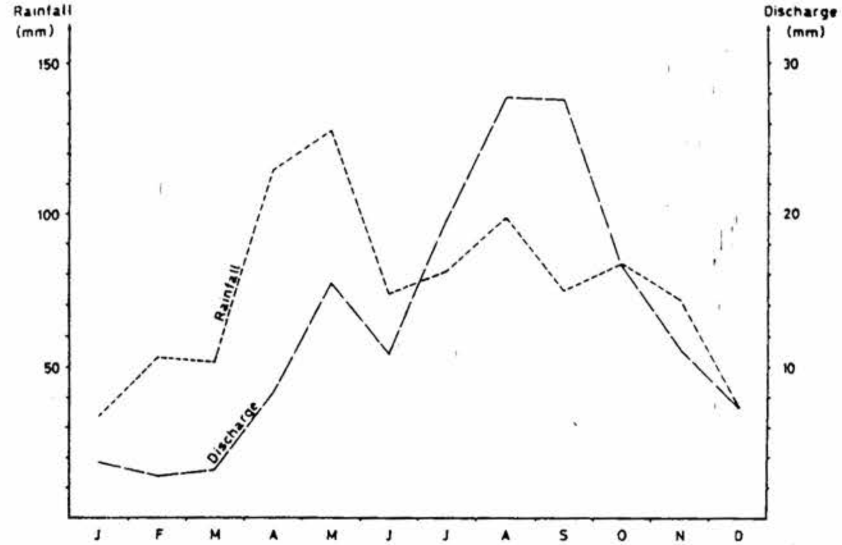


Fig. 4.14 Monthly average rainfall on the River Gilgil catchment area, runoff at gauge station 2GA3 (1962-1980).

Figures for the annual average runoff and precipitation of the River Gilgil catchment basin during the period from 1962 to 1980 are shown in Figure 4.14. The average annual precipitation amounts to 899±262 mm and runoff is 159±72 mm; the average runoff coefficient is about 0.18. In this diagram too there is a clear delay between precipitation and runoff, probably due to the same reason mentioned above.

As the influence of groundwater on river discharge seems to be rather significant, there might be a similar direct inflow of subsurface water to Lake Naivasha. In Figure 4.13 the average monthly water level in the lake from 1932 to 1959 is compared with inflow from the River Malewa at gauging station 2GB1, and with rainfall on the River Malewa catchment during the same period. As can be seen, there is a definite delay between these curves. The fact that the average annual highwater level in the lake occurs half a year after the period of the long rains, and about two months after the average highwater discharge, implies a subsurface inflow of water to the lake. Sikes (1936, p. 78) mentions the possibility of a subsurface inflow to the lake, but he states that such seepage water would be immediately subjected to evapotranspiration, and that it may be disregarded as a contribution to inflow.

Lake level variations and the water budget

Lake level in relation to inflow

The variations in lake levels during the last 100 years are discussed in Chapter 3 of this paper. In a previous investigation, made by Brind and Robertson (1958) the water balance for Lake Naivasha is based on annual values for the factors affecting lake levels, and from these figures no clear relationship between the factors of the water balance equation could be established.

In the present study the water balance for the lake is based on monthly averages of the relevant factors, which probably describes the conditions in a more accurate way. It is also more "sensitive" to the great variations in inflow (R), the factor which affects the short time variations in lake level the most.

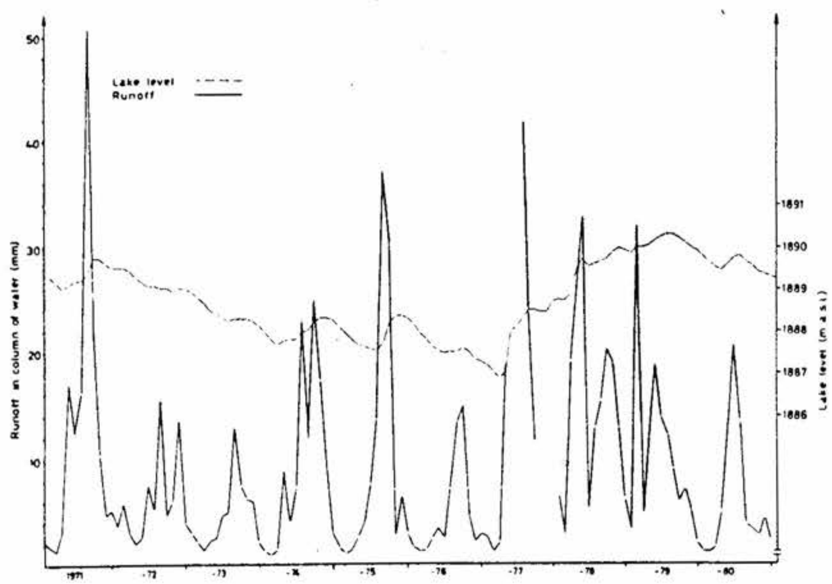


Fig. 4.15 Monthly average water level in Lake Naivasha and runoff at gauge station 2GB1 (1971-1980).

As can be seen from Figure 4.15, the lake level over the period 1971 to 1980 fluctuated between 1886.9 and 1890.3 m a.s.l. The relationship to inflow from the River Malewa is quite obvious. It should be noted that the inflow from the River Gilgil, the River Karati and the lake surroundings are neglected in this diagram.

During the period 1972 - 1976 there is on the whole a trend towards a falling of the lake level, that amounts to about 0.5 m/yr. or 0.04 m/month. This falling lake level is not caused by any general trend of diminishing inflow, but is due to a period of five consecutive years when the inflow was at or below the average annual inflow for the whole period 1931-1980.

During the period 1972-1976 lake level dropped 2.26 m and the total inflow from the River Malewa and the River Gilgil was 798×10^6 m^3. This can be compared with the total of six average years, 1962-1980, which amounts to 1080×10^6 m^3. From this it can be concluded that the water balance of Lake Naivasha has a rather unstable equilibrium, and that inflow just below the average makes the lake level drop considerably. On the other hand, lake level is also very sensitive to high inflow. As can be seen from Figure 4.15, water level rose from 1887.00 to 1888.00 m a.s.l during May 1977. Runoff during this flow was so heavy that no records are available due to damage to the gauging station 2GB1, but if the discharge is estimated from the two gauging stations 2GB5 and 2GC4 (cf. Fig. 4.1a) the inflow should be at least 106×10^6 m^3 during the month of May 1977. This can be compared with an annual average discharge at station 2GB1 of 155×10^6 m^3.

According to p. 55 and computations of runoff probabilities such high flow for the month of May can not be expected more often than perhaps once in 100 years (Fig. 4.9b).

Water balance computations of Lake Naivasha

As mentioned above, an earlier attempt to establish the proportions between the factors influencing the water balance failed, most likely because annual values were used. In the present study an attempt is made to explain the lake level variations from the monthly values of the factors in the water balance equation. That is, the equation for the lake can be defined as:

$$P + R - E \pm I = \pm \Delta S$$

P = Average precipitation on the lake.
R = Inflow from River Malewa and River Gilgil transformed to column of water on the lake.
I = The possible seepage to and/or subterranean outlet from the lake.
E = Potential evaporation.
ΔS = Changes of water level i.e. changes of storage.

An analysis of the monthly values for the factors mentioned above was made for two periods, January 1972 - December 1974, and January 1978 - December 1980. The two periods were chosen for two reasons. Firstly, there is only two data missing for the factors of the equation used, i.e. runoff data for the River Gilgil in January 1973 and June 1980. Secondly, the aim is to check the method under different circumstances, i.e. falling and rising water level. In Table 4.3 and 4.4 all factors are converted into columns of water (mm) on the lake, taking

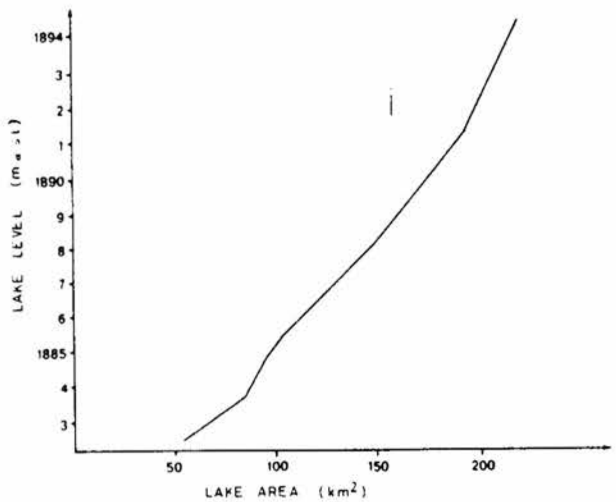


Fig. 4.16 Relationship between lake level and lake area in Lake Naivasha. Based on the lake survey in 1927.

the actual lake area in consideration. Figure 4.16 shows the area - water level diagram based on data from the lake survey in 1927. The factor ΔS corresponds to the expected monthly water level change, obtained by using the water balance equation: $\Delta S = P + R - E$.

Example 1. January 1972 to December 1974

The results obtained by using the equation, $\Delta S = P + R - E$, are listed in Table 4.3. The calculated water level change, ΔS, for each month is plotted in Figure 4.17. These calculated water levels can be compared with those actually measured at Korongo farm. From this it can be seen that the lines follow each other very well, but that they gradually separate. The vertical distance between the two lines is called ΔH. Results from regression analysis of this successive "line-separation" with time can be seen in Figure 4.18, where the monthly difference, ΔH, is plotted against the corresponding month. The line of equation obtained from this regression analysis is Y = 140.3 + 22.8 X, and the correlation coefficient is +0.89. In other words, the calculated amount of water that successively would accumulate in the lake according to this computation should be about 23 mm/month.

Table 4.3. Computations of expected water level change ΔS, using the water balance equation $P + R - E = \Delta S$ (1972-1974).

YEAR 1972	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
R(Malewa)	33.6	56.1	28.6	18.6	25.0	72.7	49.6	149.2	44.2	57.7	131.9	38.3
R(Gilgil)	5.2	5.9	3.8	3.4	3.7	10.5	15.6	21.4	12.8	7.7	7.2	5.0
P	11.3	122.3	45.6	12.2	69.1	112.1	16.2	47.1	15.1	66.4	39.0	5.4
E_o	140.4	105.4	146.3	135.4	111.5	92.6	112.8	134.3	134.5	143.7	135.2	104.0
ΔS	-90.3	+78.9	-68.3	-101.2	-13.7	+102.7	-31.4	+83.4	-62.4	-11.9	+42.9	-55.3
YEAR 1973												
R(Malewa)	27.3	21:2	13.9	23.2	26.5	48.4	51.4	133.5	78.2	65.2	61.9	22.1
R(Gilgil)	---	3.8	3.7	4.1	4.6	5.3	6.2	13.2	29.6	22.7	5.1	4.6
P	43.8	44.9	2.0	55.9	69.8	39.2	5.1	7.4	65.9	23.9	54.2	6.2
E_o	129.4	129.7	188.1	166.8	118.6	123.8	123.4	136.9	125.9	158.6	108.6	150.7
ΔS	(-58.3)	-59.8	-168.5	-83.6	-17.7	-30.9	-14.8	+17.2	+47.8	-46.8	+12.6	-117.8
YEAR 1974												
R(Malewa)	12.4	10.0	15.1	96.9	42.5	78.3	247.0	128.2	258.2	178.2	93.4	31.0
R(Gilgil)	3.6	3.8	4.6	5.4	4.7	3.8	14.2	31.8	39.0	10.4	1.1	0.6
P	3.3	4.2	60.3	162.3	116.9	117.1	99.7	47.1	42.5	20.1	48.7	23.2
E_o	180.8	163.7	167.7	82.5	120.2	105.5	82.0	104.8	104.8	147.8	96.9	112.4
ΔS	-161.5	-145.7	-87.7	-182.1	+43.9	+93.7	+278.9	+102.3	+234.9	+60.9	+46.3	-57.6

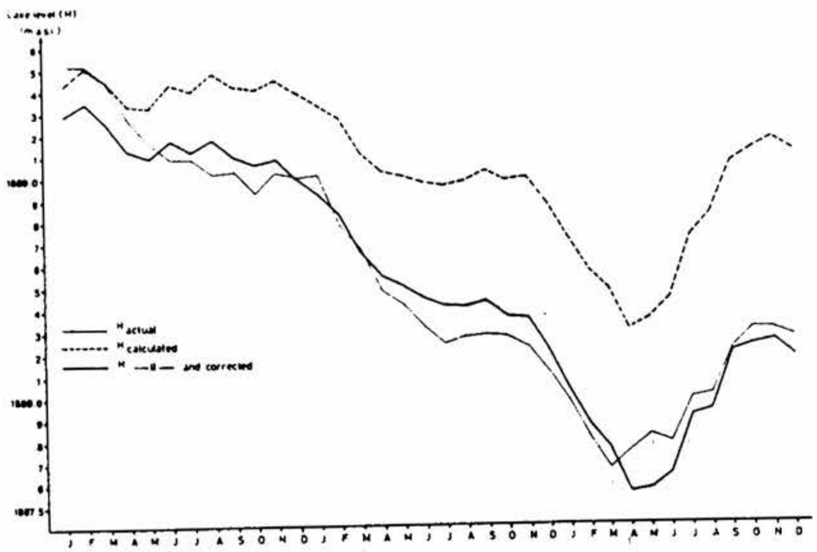


Fig. 4.17 The water level (H) during the period from 1972 to 1974. (H) actual: measured in Lake Naivasha at Korongo Farm. (H) calculated: Obtained by using the water balance equation. (H) corrected: The calculated (H) values corrected for each respective trend value.

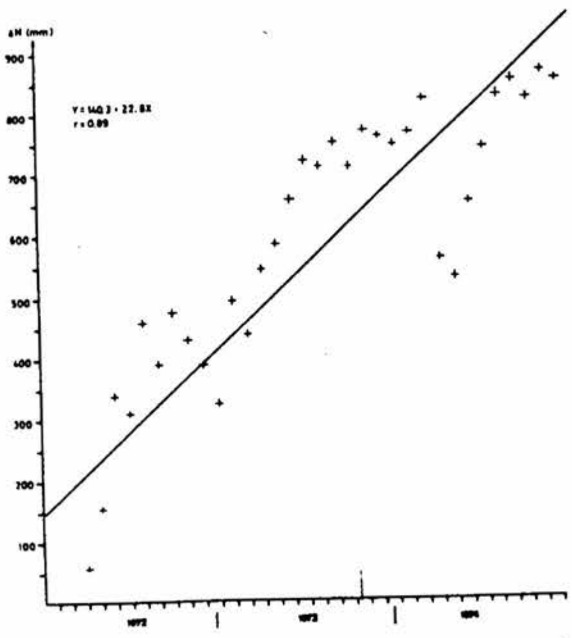


Fig. 4.18 Analysis on regression of the successive "line-separation" (ΔH) with time (1972-1974).

Example 2. January 1978 to December 1980

Results from the calculation described are listed in Table 4.4. The calculated factor ΔS is plotted in Figure 4.19. As in the former example the calculated water level curve gradually separates from the actual one. The analysis of regression between the factor ΔH and the respective month is shown in Figure 4.20. The line of the equation is $Y = -79.9 + 27.9X$ and the correlation coefficient is +0.98. In this latter example the calculated volume of water that would gradually accumulate in the lake amounts to 28 mm /month.

Table 4.4. Computations of expected water level change ΔS, using the water balance equation $P + R - E = \Delta S$ (1978-1980).

YEAR 1978

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
R(Malewa)	65.3	26.3	187.5	255.3	298.2	48.0	117.3	138.8	183.6	165.5	113.8	54.2
R(Gilgil)	4.6	3.7	17.7	20.8	29.7	11.6	42.7	25.7	38.2	38.5	22.7	6.2
P	61.1	61.8	238.3	115.5	46.6	36.7	16.2	67.5	60.4	26.6	23.7	82.4
E_o	130.1	136.7	107.3	104.8	109.2	84.9	91.4	120.5	131.3	125.8	108.6	110.2
ΔS	+0.9	-44.9	+336.2	+286.8	+265.3	+11.4	+84.8	+111.5	+150.9	+104.8	+51.6	+32.6

YEAR 1979

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
R(Malewa)	27.9	279.8	42.3	104.2	160.6	118.6	105.5	76.8	52.4	62.9	44.9	18.1
R(Gilgil)	5.8	10.2	2.5	2.5	9.2	7.4	13.9	10.0	5.7	2.8	2.7	1.9
P	48.9	71.9	41.8	111.5	69.9	105.8	44.0	58.7	30.9	16.5	41.1	17.6
E_o	117.6	116.2	145.4	105.1	103.5	83.0	108.1	114.0	134.3	179.7	116.2	135.2
ΔS	-35.0	+245.7	-58.8	+113.1	+136.2	+148.8	+55.3	+31.5	-45.3	-97.5	-27.5	-97.6

YEAR 1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
R(Malewa)	12.2	11.1	15.3	46.1	123.3	187.2	122.6	34.0	31.0	24.5	43.1	21.0
R(Gilgil)	1.6	1.4	1.7	1.6	2.0	---	6.6	4.7	6.6	2.6	2.7	2.6
P	38.3	16.9	46.9	92.5	249.6	56.3	0.5	3.3	41.4	23.3	58.2	5.3
E_o	169.0	174.4	184.4	133.5	83.9	107.8	131.8	158.6	182.2	106.6	143.4	117.6
ΔS	-116.9	-145.0	-120.5	+6.7	+291.0	(+135.7)	-2.1	-116.6	-103.5	-56.2	-39.4	-88.7

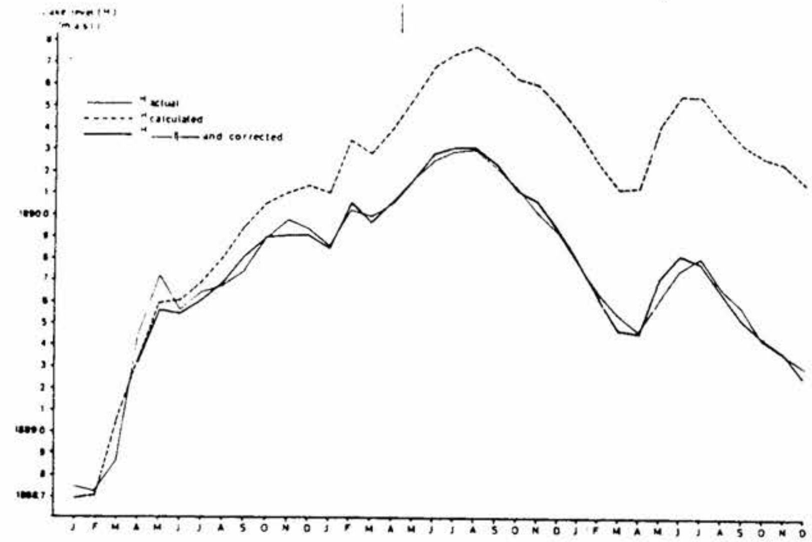


Fig. 4.19 The water level (H) during the period from 1978 to 1980. (H) actual: measured in Lake Naivasha at Korongo Farm. (H) calculated: Obtained by using the water balance equation. (H) corrected: The calculated (H) values corrected for each respective trend value.

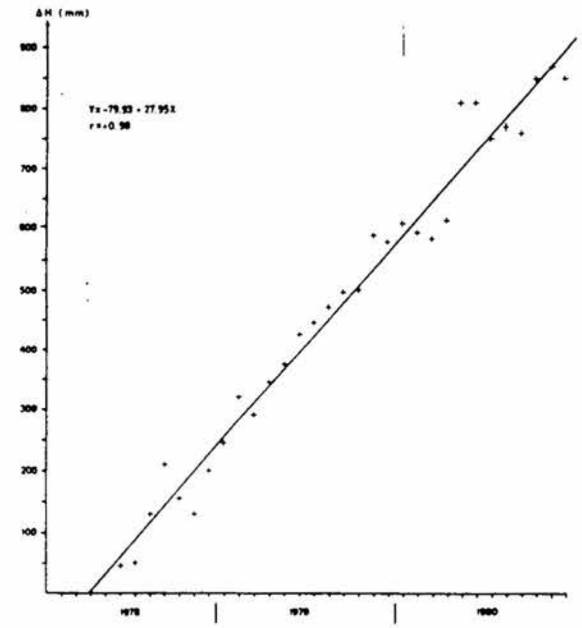


Fig. 4.20 Analysis on regression of the successive "line-separation", (ΔH) with time (1978-1980).

Conclusions

The two examples describing the water balance of Lake Naivasha show that it is possible to find a very good correlation between the monthly values for river inflow (R), the average precipitation on Lake Naivasha (P) , and the potential evaporation (E). There is also a good correlation between the two lines of calculated and actual water level. The successive vertical separation between the two lines (the linear factor ΔH) indicates that there should be an accumulation of water in the lake amounting to c. 25 mm/month (average value for the two periods 1972-1974 and 1978-1980), according to the computations described. The reason for this linear factor in predicting the water level can be explained by one or several of the following factors:

- A systematical error in the runoff (R). That is, the measured discharge figures exceed the actual ones, by a certain amount, due to use of an inaccurate rating curve. This would mean a difference between measured and actual inflow to the lake amounting to c. 30 % of the total annual inflow. Such a difference seems to be far too much.

- A systematical error in calculation of the average rainfall of the lake, using unrepresentative rainfall stations. However, as the rainfall is largely due to local showers, the fact that there is a pronounced linear trend in the factor ΔH speaks against this possibility.

- A systematical error in the evaporation figures, i.e. the pan factor used (0.80) results in figures for evaporation that are too low.

- A subterranean outlet of Lake Naivasha, i.e. the calculated accumulation of water corresponds to the volume of water lost through seepage. The main fact opposing this is that the lake is filled with thick layers of sediments. These sediments might be so impermeable that the seepage from the lake could be eliminated.

Of these four possible explanations the most probable is a combination of the two latter ones. Thus, the actual evapotranspiration from the lake might exceed the potential evaporation figures used. And, as there seems to be a considerable inflow of ground water, there might very well be a similar seepage of water out of the lake.

This latter possibility is very interesting, because it indicates the feasibility of regarding Lake Naivasha partly as the exposed ground water table (cf. Sikes 1936, p. 77). This will explain the delay between the curve of the average inflow to the lake and the curve of average lake level in Figure 4.13. That is, the lake level variations can be considered as the result of both the annual variations of the groundwater table, and of short time variations due to increasing or decreasing river inflow.

Addendum

Since the previous chapters were written another visit has been made by two of the authors (Syrén and Åse) to Lake Naivasha and its surroundings. The field work during this stay was conducted in October 1985. As some of the findings are of importance for the interpretation of the changes in water level and water budget of the lake they will be briefly described below. Also, a few facts that make the description of Lake Naivasha and its surroundings more "up to date" have been included.

The surroundings of Lake Naivasha have changed mainly due to the increased development of geothermal energy at the Olkaria site in the Hell's Gate area and to the fact that both Hell's Gate and Longonot are now (since 1984) national parks. The actual electricity generated at Olkaria now equals ca 15% of Kenya's total. The establishment of Hell's Gate National Park has lead to a definite increase in the number of herbivores such as eland, of which a large herd is found in the area, kongoni and other antelopes, and gazelles. Even carnivores such as lions (a lion "kill" was found in October 1985) seem to be on the increase in the area. Rock hyrax are now abundant around Fisher's tower.

The lake level of Lake Naivasha has, except for an increase during the heavy rains in 1981, on the whole decreased during the 1980's. The decrease was very rapid in 1984, so that the water level in October 1985 was 1.2 m (4 feet) lower than at the time of the depth survey in October 1983. This has meant that Oloidien Bay is now, once again, separated from the main lake, and according to a reading made in Oct. 1985, had a pH of 8.8, whereas the pH of the main lake was around 7.8. Salvinia molesta now seems to have disappeared from Oloidien Bay and most of the southern part of the main lake, but is still very abundant in the northern part and in the lagoons of the western part of the lake. In spite of the decreasing lake level, some water lilies were observed in various parts of the lake in October 1985. This might possibly be due to a decrease in the coipus population; not a single one was seen during our stay at the lake. Even the population of crayfish seems to have decreased, especially when compared to the conditions in the mid 70's.

During our stay at Elsamere on the southwestern shore of the main lake (opposite to Hippo point) comparative studies were carried out on the combined effect of the absorbtion of water and evapotranspiration from Salvinia and Papyrus, compared to the evaporation from a free water surface under comparable conditions. The results from two sets of experiments indicated that the combined effect of the absorbtion and evapotranspiration from living Salvinia equalled c. 80-90% of the evaporation from a free water surface. One set of experiments gave the value 82%, the other 92%. The corresponding figure from a single pan with Papyrus gave 93%. The figures strongly support Syrén's conclusion that the water balance of Lake Naivasha greatly depends on groundwater flow, since neither the belts of Salvinia nor the Papyrus seem to deprive the lake of water, as compared to the evaporation from the free surface of the lake. The calculated accumulation of water in Lake Naivasha (cf. p. 69) is probably not due to the use of too low evaporation figures.

Stockholm, November 11, 1985

Lars-Erik Åse

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