

NOTES ON THE HYDROLOGY OF LAKE NAIVASHA.

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The hydrological features of Lake Naivasha are not only of scientific interest but are also of some economic importance. A record of the fluctuations of lake level has been maintained with four short breaks since the end of 1908, readings being taken weekly. A bathymetrical survey was carried out in 1927 with sufficient precision to enable the volume of water and the area of the lake to be calculated approximately as the level varies. Evaporation meter readings were started in 1917, but, in the case of those prior to 1920, the method adopted is not regarded as sufficiently reliable to be of value; the records are incomplete for the years 1927 and 1928, but complete records exist for 14 years. The number of rain gauges in the drainage area of the lake, 1,203 square miles, is still regrettably small. Only six have been established and of these the longest record is from 1904. However, a number of gauges outside the drainage area, under climatic conditions which appear to correspond fairly well with one or other part of the drainage area, provide useful data for co-ordination and check. With the help of these a reasonably accurate knowledge of the rainfall on the drainage or catchment area and on Lake Naivasha itself is thought to have been achieved, though, in the case of a region where much of the rainfall is of the instability type, precision is impossible of attainment. Two of the gauges, situated within half a mile of one another, under apparently identical topographical and climatic conditions occasionally show pronounced divergence owing to local thunderstorms, which cause high precipitation on one, but not on the other.

The circumstance which is thought sufficient to justify deductions from records, provisional though they must necessarily be in some cases, is that from April 1st, 1935, to March 31st, 1936, the Public Works Department, in the course of hydrographic survey, maintained a continuous record of the flow to the lake of the Melawa (Morendat), Gilgil and Karati Rivers which drain most of the catchment area of Lake Naivasha. By applying the percentage of the rainfall which was ascertained to have been discharged from areas presenting similar geological and topographical features to the remaining portion of the drainage area, where only short flood channels exist, a sufficiently accurate assessment of the whole surface discharge to the lake during that year is believed to have been obtained.

Lake Naivasha lies in long. $36^{\circ} 20'$ E., lat. $0^{\circ} 45'$ S. Since records were commenced, the elevation of its surface has varied from

6,217.70 feet above mean sea level on November 17th, 1917, to 6,194.66 on February 21st, 1936, a range of 23 feet. The volume of water in the lake has fluctuated from 68,400 million cubic feet (.464 cubic mile) to 22,700 million cubic feet (.154 cubic mile), and the superficial area from 2,390 million square feet (80.3 square miles) to 1,640 million square feet (58.8 square miles). Its fluctuations from 1909 to 1935 are shown in Plate I, fig. 1, and an outline of probabilities in respect of the major changes during preceding years is indicated by a dotted line. The greatest depth of the lake is found on the floor of an extinct crater, about half a square mile in area. Crescent Island and the adjacent island are parts of the wall of the crater. The depth of water within the crater has varied from about 80 feet in 1915 to 57 feet in February, 1936. Outside the Crescent Island crater, the maximum depth of the lake has fluctuated from about 45 feet in 1917 to 22 feet in February, 1936.

It is not intended to deal in this paper with the history of Lake Naivasha in Quaternary times. The results of the investigations of Dr. Erik Nilsson of the Swedish Geological Expedition are recorded in his "Quaternary Glaciations and Pluvial Lakes in British East Africa" (Stockholm, 1932) and no new light has been thrown on the geological history of the lake since his surveys. The evidence that the highest level of the lake was about 400 feet above present level during the Second Pluvial, extending over the Gilgil pass in continuity with the enlarged Nakuru—Elmenteita Lake, is not likely to be assailed as it accords with the conclusions of other observers. Dr. Nilsson found five other beaches, demarcating rest levels of the lake, between the maximum and present-day levels and considers also that the lake dried up completely during two arid periods subsequent to the Second Pluvial. Nor is it intended to deal with the geological features of the drainage area of the lake, except in so far as considerations of percolation from the lake bottom and run off from the drainage area are influenced by them. It may be mentioned, however, that excepting the ancient lake sediments consisting of silts, sands, and diatomites, which occupy only a very small percentage of the drainage area, the solid rocks are all volcanic in origin and are highly faulted by the meridional Rift Valley fractures. The lavas constitute a varied assemblage of soda-rhyolites and soda-trachytes, except in the Aberdare Range, a part of the western flank of which lies within the drainage area, where a different series, ranging from intermediate to basic, is found east of the early main fault of the Rift Valley. Lake Naivasha occupies a shallow pan in the lowest part of the cross section of the Rift Valley at the latitude of the lake, the drainage area rising above it to some 6,000 feet eastward and 4,000 feet westward. The volcanic rocks in its vicinity are the most recent of all. They exhibit sharply defined craters, tuff cones, fresh lavas and numerous steam vents. Meteorologically the drainage area is partly in the sub-arid and partly in the

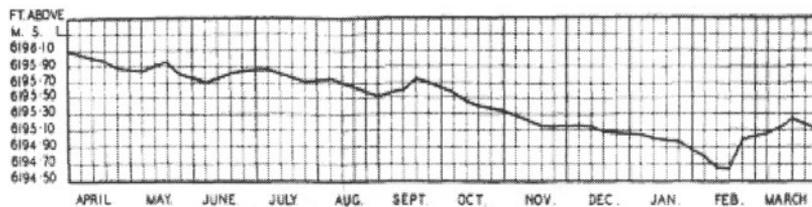


FIG. 1. VARIATIONS OF LAKE LEVEL, BETWEEN APRIL 1st 1935 AND MARCH 31st 1936

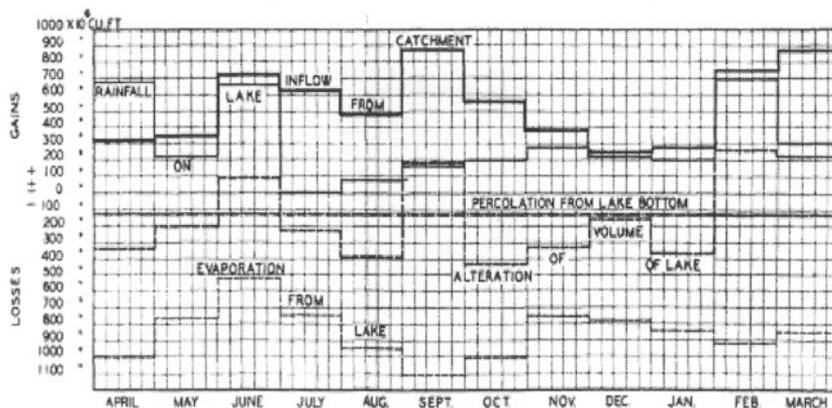


FIG. 2. DIAGRAM SHOWING MONTHLY GAINS IN VOLUME OF LAKE FROM (1) INFLOW FROM CATCHMENT (2) RAINFALL ON LAKE (3) RISE IN LAKE LEVEL, AND LOSSES FROM (1) EVAPORATION FROM LAKE (2) PERCOLATION FROM LAKE BOTTOM (3) FALL IN LAKE LEVEL DURING THE PERIOD APRIL 1st 1935 AND MARCH 31st 1936. TOTALS FOR THE YEAR: MEAN RAINFALL ON THE CATCHMENT AREA OF 33650 MILLION SQ. FEET OR 1203 SQUARE MILES - 3.18 FEET OR 106675 MILLION CU. FEET. INFLOW INTO THE LAKE FROM THE CATCHMENT AREA - 6496 MILLION CU. FEET A RUN-OFF OF 6.11% OF THE RAINFALL OR 194 FEET IN DEPTH ON THE CATCHMENT AREA. RAINFALL ON THE LAKE - 2.23 FEET OR 3724 MILLION CU. FEET. EVAPORATION FROM LAKE - 6.16 FEET OR 10287 MILLION CU. FEET. PERCOLATION FROM THE LAKE BOTTOM - .92 FEET OR 1536 MILLION CU. FT. A MEAN FLOW OF 49 CU. SECS OR .8 CU. SEC PER SQ. MILE. MEAN AREA OF LAKE SURFACE - 59.9 SQ. MILES. REDUCTION OF VOLUME OF WATER IN LAKE - .96 FEET OR 1603 MILLION CU. FEET.

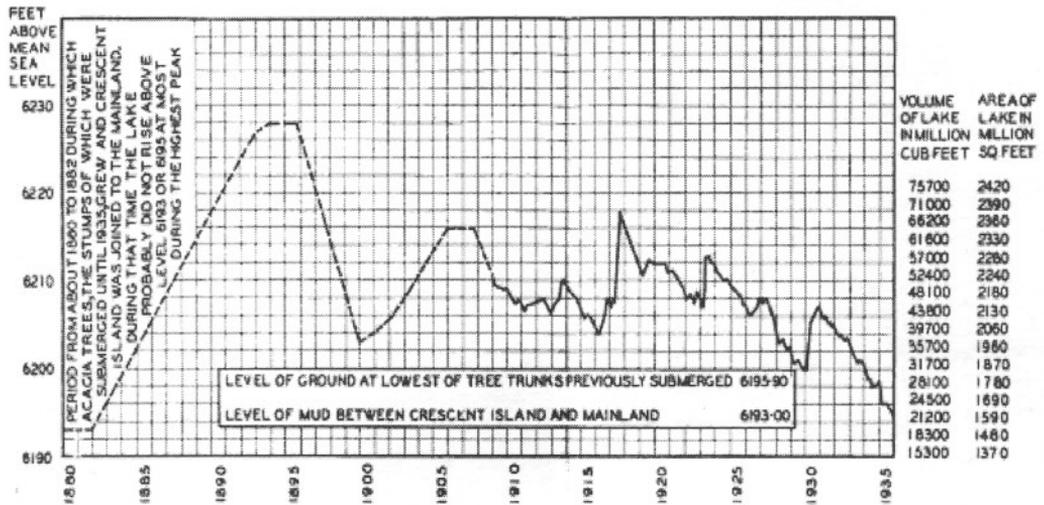
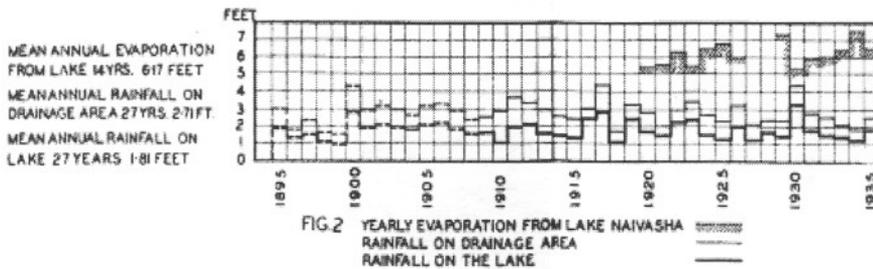


FIG.1 VARIATIONS OF LEVEL OF LAKE NAIVASHA



sub-humid zone, the former predominating; the 40 inch isohyet crosses it. The rainfall decreases rapidly from the Aberdare Range and Kinangop Plateau westward across the lake. The average annual rainfall is assessed at 32.52 inches or 2.71 feet.

Plate II and the following schedule set forth the results obtained from the observations during the period April 1st, 1935, to March 31st, 1936.

DISCHARGE INTO LAKE NAIVASHA FROM ITS DRAINAGE AREA.

Catchment.	Area of catchment in square miles.	Rainfall in feet depth.	Rainfall in million cubic feet.	Discharge to lake in million cubic feet.	Discharge expressed as average depth over catchment in feet.	Discharge expressed as percentage of rainfall.	Maximum rate of discharge cusecs.	Minimum rate of discharge cusecs.	Mean rate of discharge cusecs.
Melawa ...	618	3.80	65,470	5,004	.291	7.65	745	28	153
Gilgil ...	108	3.43	10,327	438	.146	4.25	236	1	14
Karati ...	52	3.05	4,453	121	.086	2.81	189	0	4
Remainder ...	425	2.23	26,425	933	.081	3.63*	—	—	—
Totals for drainage area	1,203		106,675	6,496					
Means ...		3.18			.194	6.10			

* Assessed as average of percentages of Gilgil and Karati catchments.

The higher percentage of the rainfall on the catchment of the Melawa River which is discharged, in comparison with the others, is explainable by the occurrence, over greater portions of the area, of argillaceous soil. The presence of forests at the headwaters of the river and its tributaries must also have an important influence on the preservation of a perennial flow by reducing soil evaporation. The mean discharge percentage of 6.10% from the drainage area of the lake is low. The year under review has followed four years of sub-normal rainfall, of which the year immediately preceding it had the lowest record. In consequence the soil and rocks would have been severely dried out. The ground water level would be below the bottoms of the valleys. At the surface, in the exposed parts, there was probably little moisture left, except the water of imbibition, after months of drought. If one is justified in assuming that the leakage of water from the lake is constant at 1,536 million cubic feet per annum (the figure arrived at for the year April 1st, 1935, to March 31st, 1936,

according to the method reviewed later in this paper) it can be deduced as probable that the average annual discharge from the drainage area of the lake to the lake is of the order of 9% of the rainfall and that in 1930, a year of high rainfall, it was about 13%. The effect which diversions of water by riparian holders of land may have on the regimen of the lake is indeterminate, but it is thought to be so small that it may be neglected. Authorised diversions from streams in the drainage area amount, in the aggregate, to 1.788 cusecs. It is impossible to ascertain to what extent this is exceeded. The excess may well be several times that flow during dry weather conditions. On the other hand, not only are many of the diversions intermittent, but much of the water must get back to the streams. From these considerations, it is regarded as reasonable to assess the net annual loss to the lake from this cause as the aggregate of the authorised diversions, assumed to be flowing continuously throughout the year. This is equivalent to a loss of 48 million cubic feet, or less than 1% of the discharge from the catchment area.

Sub-surface inflow to the lake is indeterminable, but requires consideration in respect of probability. The formations in the vicinity of the lake are the Quaternary lacustrine sediments and volcanic rocks. The former predominate on the north and east sides of the lake and the latter on the south and west sides. Usually the sediments have gentle surface gradients towards the lake, while the volcanic rocks are steep and extend as promontories into the lake. The mechanical constitution of the sediments is such that they are capable of transmitting water between the grains as well as being moderately absorptive. The transmission rate has not been examined, but the absorptive capacity of a fair average specimen was found to be 32% by weight from complete dryness. Of this, the water of imbibition amounted to 14.5%. Subterranean caves and channels, eroded by water and perhaps originating in ant bear holes, also exist. The volcanic rocks are very varied in mechanical constitution, but the bulk of them would transmit water readily through anastomosing joint cracks and crevices which abound in the recent lavas. While boring for water in similar rocks in other parts of the Rift Valley, the water supplied to the drilling bit was found to soak away very rapidly. Sometimes the rocks are cavernous. That this may extend to a considerable depth is shown by the occurrence of a cavern 2 feet deep in a borehole in the Kedong Valley in rhyolitic lava at a depth of over 700 feet. From observations on two wells in Naivasha township it appears that the level of the ground water in the sediments adjacent to the lake is ordinarily approximately coincident with lake level and fluctuates with it, though there is some lag. When the lake level is rising rapidly there is a slight gradient from the lake to the water level in the wells. The writer is not aware of any wells or boreholes having been sunk near the lake through the lava to the ground water, but the level of the water in Sonachi crater about $1\frac{1}{2}$

miles from the west shore also appears to be at lake level and to vary with it, though this has not been ascertained by precise levelling. It would seem therefore that the ground water level is preserved at lake level, both in the sediments and volcanic rocks, to an unknown distance from the lake shore. The levels of ground water in the lower parts of the Rift Valley (at those places where a water table, either perched or otherwise, occurs), as determined where boring for water has been carried out to some depth, indicate that, if Lake Naivasha did not exist as a body of water (or, in other words, if the area occupied by it had no perennial streams discharging into it) the level of the ground water would be likely to lie between 200 and 700 feet in depth. It seems to the writer to be most probable that the hydrostatic equilibrium of the ground water with the lake extends to no great distance inland from the shore of the lake and then dips. The lake surface and ground water surface would, in fact, take the shape of an inverted dish. It is thought that, under these circumstances, such seepage as there may be to the lake would only occur during, or shortly after, rain in the immediate vicinity of the lake. Such seepage water would be immediately subjected to transpiration of the rank vegetation growing both above and below the lake margin along most of its perimeter as well as to intense evaporation from the heated shallow water near the lake shore. From these considerations it is thought that sub-surface percolation to the lake may be disregarded as a contribution to inflow.

In the evaluation of the hydrological factors affecting a lake, reservoir, or river, the determination of the evaporation from its surface is often the most uncertain. There is no generally accepted standardisation of evaporation meter and the factors which influence correlation between the readings of any particular kind of meter and the evaporation from an adjacent large sheet of water are complex and not readily reducible to a formula. Evaporation is mainly dependent on the difference between the tensional force of the vapour due to the temperature of the evaporating surface and that of the vapour already in the atmosphere, being greatest when there is the greatest difference between the temperature of the evaporating surface and the dewpoint; but it is influenced by the breaking up of the surface by wind, transpiration of vegetation in the water and other circumstances. The type of meter adopted at Naivasha consists of a concrete tank three feet square and two feet six inches in depth with a closed overflow chamber and a rain gauge alongside. The evaporation is calculated from measurement of the water required to fill the tank to overflow level, the rainfall and the overflow (if any). In Egypt, the evaporation from an extended water surface is calculated as .88 of the measured evaporation from a tank one metre cube in capacity (The Nile Basin, Hurst & Phillips, Vol. 1, p. 60, Physical Department of Min. of Pub. Works, Cairo, 1931). In the case of Lake Naivasha, however, strong drying winds frequently occur, replacing the air in proximity with the water

and breaking up the water surface; much of the lake is very shallow and becomes highly heated during sunshine; while considerable areas adjacent to the shore are occupied by reeds, papyrus, and other water vegetation. These circumstances cause higher losses from the lake, in relation to those from an evaporation meter, than is usual. Moreover the surface temperature of the water, even in the deep portions of the lake, is sometimes slightly higher than that in the evaporation tank. On March 22nd, 1936, a hot still day following similar ones, it was found by the writer that the midday temperature of the water in the evaporation tank was 24°C., while the surface temperature of the deep water between the horns of Crescent Island was 25°C. At the same time the temperature of the shallow water close to the shore amongst water weeds was 31°C. In the early morning the temperature of the shallow water had sunk to 17°C. On June 6th, 1936, a cool day with frequent sunshine and a moderate wind, the early afternoon temperature of the air was 20°C., the tank water 22°C., deep water 21°C., and shallow water 23°C. During the following early morning when the air temperature was 13°C., that of deep water had sunk to 20°C. and shallow water to 18°C. For these reasons it is considered by the writer that, under the circumstances prevailing at Lake Naivasha, it is more correct to assess the average evaporation from the lake surface as equivalent to the readings of the meter. It has, in fact, been held by Prof. Carpenter, State Agricultural College, Colorado, that the evaporation from four of the lakes in that State is slightly greater than that recorded from evaporation tanks of three feet cube.

The total evaporation from the evaporation tank during the year April 1st, 1935, to March 31st, 1936, was 6.16 feet depth and, taking that from the lake as equivalent, the volume lost by the lake amounted to 10,287 million cubic feet. The mean annual evaporation for 14 years is 6.17 feet, with maximum and minimum of 7.48 feet and 5.13 feet. Dr. Hurst of the Physical Department of the Egyptian Public Works Ministry has regarded the mean annual evaporation from Lake Victoria as 1,310 mm. (4.30 feet) (The Lake Plateau Basin of the Nile, Cairo, 1925). Gillman has adopted Theeuw's figure of 1,350 mm. (4.43 feet) for Lake Tanganyika (The Hydrology of Lake Tanganyika, Dar es Salaam, 1933). At those two lakes, however, the mean atmospheric humidity is likely to be much higher than at Lake Naivasha and the average water temperature during sunshine may even be lower, on account of the ratio of shallow water to deep water being so much less than in the case of Lake Naivasha. Moreover, it would appear that the estimates of evaporation for Lakes Victoria and Tanganyika are not based on actual measurements. With regard to the evaporation from Lake Victoria Drs. Hurst and Philips observe (The Nile Basin, Vol. 1, p. 61): "The annual total is computed from rainfall + runoff —outflow over Ripon Falls. There are uncertainties about the runoff

which is estimated from scanty data." In some hot arid countries, where the atmospheric humidity is low and the water temperature high, annual evaporation up to 12 feet has been recorded. On the other hand, in cold humid countries, the annual evaporation is less than the annual rainfall, as in England.

The mean rainfall on the lake during the year under review is computed at 2.23 feet in depth or 3,724 million cubic feet. The level of the lake surface went down from 6,196.10 feet above mean sea level on April 1st, 1935, to 6,195.14 feet on March 31st, 1936, a drop of .96 feet, or reduction of volume of 1,603 million cubic feet. Applying the formula: evaporation + percolation from the lake = inflow + rainfall on the lake + reduction of volume of the lake, it is found that percolation from the lake (expressed in millions of cubic feet) = $6,496 + 3,724 + 1,603 - 10,287$ or 1,536 million cubic feet, or a uniform depth of .92 feet over the lake bottom of 1,670 million square feet mean area during the year. This loss amounts to a sub-surface flow from the lake at an average rate of 49 cusecs, or .81 cusecs per square mile. The loss by percolation might, however, be more suitably spread over the area adjacent to the lake, at which the ground water is in hydrostatic equilibrium with that of the lake (if this were determinable), as well as the area of the lake itself. The authorised diversions by pumping from the lake for short distances from the shore by riparian landowners are 2.011 cusecs in the aggregate. It is thought that these diversions of water would have no great influence because, not only is the pumping intermittent, but much of the water would percolate back to the ground water at lake level. The conditions at Lake Naivasha, in respect of loss by percolation, appear to be not dissimilar from those prevailing at large reservoirs in strata of fair permeability and where the natural water table is at a lower level. Losses by percolation (or absorption) from reservoirs in Rajputana have been stated by Culcheth to be 3.62 feet depth per annum; and in the case of the Sagar Reservoir, the loss from percolation and absorption is stated as having ranged from 1.56 feet to 1.83 feet per annum. As already mentioned, considerations of the depth at which ground water has been found by boring in the most recently formed parts of the Rift Valley lead to the view that if it were not for the perennial streams, the ground water at Lake Naivasha would be at a considerable depth. In other words, the lake surface and adjacent ground water form a water table analogous to that of an artificial reservoir in permeable strata. It is a matter of conjecture what happens to continuous percolation at the rate of 49 cusecs, a flow which, if concentrated, would be much the same as the normal flow of the Thika River above its confluence with the Chania River at the Blue Posts Hotel. It is clear that, in common with much of the portion of the rainfall on the Rift Valley which percolates beyond the influence of soil evaporation and transpiration, it does not re-emerge as springs. The rainfall and other conditions in the

Rift Valley are such that, on hydrological grounds, one would expect some re-emergence if there were no cause inhibiting it. Nor does escape laterally through the boundary walls of the Rift Valley appear possible on geological grounds and there is no hydrographical support for such a theory. The springs at Lakes Magadi and ENEGARAMI, amounting in the aggregate to 28 cusecs (Coates, 1908), may possibly account for some of the percolation in the southern part of the Rift Valley, though the origin of these springs has been regarded as more likely to be magmatic than meteoric, on chemical grounds. In a brochure entitled "The Underground Water Resources of Kenya Colony" (Sikes, London, 1934, page 24), the writer has advanced the view that much of the portion of the rainfall on the Rift Valley which percolates deeply is carried to the surface again by meeting upward discharges of vapour of magmatic origin. Boring for water has shown the temperature-depth gradient to be very steep sometimes, and at two boreholes steam was encountered. The region in the neighbourhood of Lake Naivasha has many steam vents and any water percolating laterally would be likely to meet high temperatures where the water would be vaporised and ascend, either through visible vents, or to within reach of soil evaporation.

Plate I, fig. 1, shows, plotted to a small scale, the recorded levels of the lake from 1909. An outline of probabilities regarding the major lake fluctuations during the preceding few decades is shown by dotted lines. Plate II, fig. 2, shows the evaporation records from 1920, except for a break in 1927 and 1928, the records for those years being incomplete. It also shows the mean rainfall on the drainage area and the lake from 1909, to the extent that the co-ordination of records permits of precision of determination. Probabilities regarding the mean yearly rainfall from 1895 to 1908 are indicated as dotted lines. These latter are, however, only obtained by deduction from the records of Fort Hall and Machakos.

An examination of the diagram will show the close correlation between rainfall and evaporation. During years of low rainfall, the number of hours sunshine in the year would ordinarily be higher and the mean humidity lower than normal, resulting in greater loss by evaporation. In years of high rainfall the converse would prevail. The level of the lake usually responds fairly rapidly to rainfall on the drainage area, but there sometimes seems to be a considerable lag if the ground is very dry and the rainfall spasmodic. A subsidiary peak in the lake level record sometimes occurs in dry months succeeding rain after a portion of the rainfall which sinks has had time to feed the permanent streams by seepage at stream level. The extent to which lake level responds to a year of high rainfall and low evaporation depends very greatly on the rainfall of the preceding year or years. If the rainfall of the preceding year has been above the mean, the soil

and rock within the zone of evaporation will have been well soaked and a higher runoff is experienced during the ensuing year of abnormally high rainfall. The mean rainfall of 1917 was practically the same as that of 1930, namely 61% above the mean, but the former was preceded by a year when the rainfall was 12% above the mean and the latter by one having a rainfall 15% below the mean. The rise during 1917 was much higher in consequence than that in 1930. A series of dry years has a cumulative influence in the same way. As the lake drops in level, the area exposed to evaporation becomes smaller, but this is probably compensated for by the greater intensity of evaporation on account of the proportion of shallow water to deep water being increased. Since the peak of 1930, the rainfall of 1931 was average and the four subsequent years were below the mean. The fall of lake level, since the peak of 1930, has been 12.20 feet, equivalent to a reduction of lake volume from 46,500 million cubic feet to 22,700 million cubic feet, or 51%, while the area of the lake has been reduced in the same period from 2,160 million square feet to 1,640 million square feet, or 24%.

The data regarding variation of the pH and alkalinity values of the water with lake volume are not as extensive as one would wish. These values would vary according to the part of the lake from which specimens of water are taken. The only determinations available to the writer, from which deductions are possible, are from a sample taken by Miss Jenkin of the Fresh Water Biological Laboratory, Ambleside, on July 2nd, 1929, at the surface of the deep water off Crescent Island (Reports of the Percy Sladen Expedition to some Rift Valley Lakes in 1929, *Annals and Magazine of Nat. Hist.*, Ser. 10, Vol. IX, p. 543, June, 1932) and one taken at the same locality by the writer on March 21st, 1936. The determinations from the latter were made by courtesy of Mr. V. A. Beckley, M.A., Scott Agricultural Laboratory, Nairobi. On July 2nd, 1929, when the first sample was taken, the lake volume was 33,000 million cubic feet and pH was determined as 8.3 and alkali (as one-tenth normality) .039. On March 21st, 1936, the lake volume was 23,500 million cubic feet and pH was determined as 9.16 and alkali .0494. The reduction of lake volume between the two determinations was 30% and the increase of alkalinity 26.7%. The increase in pH value is higher than one would expect and may be due to difference in method of determination. Scanty as the information is, it lends support to the view that the alkalinity of the lake varies approximately with its volume and that leakage has no great effect on it. The view that the comparative freshness of the lake is due to its having dried up in recent geological times has been expressed by Nilsson (*Quaternary Glaciations and Pluvial Lakes in British East Africa*, p. 73) and, in the view of the writer, the evidence in favour of it is much more cogent than the theory that it is due to leakage.

The evidence that lake level did not rise above 6,193 feet above mean sea level (or 6,195 at most), as indicated on Plate I, fig. 1, for a long period, which cannot have been less than 20 years and was probably greater, is strong. Moreover it is probable that water level did occasionally reach to, or near to, that level at peaks during this low lake period, which seems to have terminated in 1882, when the lake started to rise. The lowest level of the lake since records started is 6,194.76, on February 25th, 1936. The evidence regarding the length of the period of low lake level rests on the occurrence of a number of erect stumps of large acacia trees (*Acacia xanthophloea*) on the south shore of the lake. The base of the lowest tree is at level 6,195.90 and lake level had receded to it in April, 1935. A section of this stump was cut by the writer a couple of feet above ground level. Only the heartwood now remains. The circumference is 7.67 feet, the average diameter being 2.44 feet. The writer is advised by Mr. Gardner, Conservator of Forests, that the minimum period of life of the tree could not have been less than 20 years and is likely to have been greater. It is considered that the tree would have been killed if the lake level (and consequently the ground water under the tree) had risen substantially above its roots—or at most to just below ground level at the base of the tree. It is thought, however, that peak rises must sometimes have reached that level, or near it; for otherwise other large trees would have grown below it at this or other parts of the then-existing lake shore. There are in fact a few small tree stumps below that level and these had time to grow between peaks.

Very old Masaj of the Purko clan, now residing near Narok, recall that it was customary to drive cattle to Crescent Island for grazing when they were boys and that the island was then connected with the mainland. The level of the mud is 6,193 feet and, in view of its consistency, it would scarcely be possible to drive cattle across as a regular practice, unless the lake were at least six inches lower, or 6,192.50. The writer understands, however, that during low lake level at the end of 1935 and the beginning of 1936 some cattle were, in fact, driven across, though they had to swim for part of the way. By courtesy of Major Buxton, District Commissioner, Narok, the writer had an opportunity of hearing information from Masikonde, until recently Chief of the Purko Clan. Masikonde appears to be about 80 years of age. He is confined to his hut but is very clear-headed. His father's village was on the mainland opposite Crescent Island and he himself had accompanied cattle to the island while a boy. He was a moran when the first European arrived at Naivasha. He remembered that year as it was the one during which he had gone to live at Elmenteita. This European would be G. A. Fischer in June, 1883. Masikonde stated that the lake had then started to rise, but it was still possible to get across to Crescent Island. It would appear that, when James Thomson visited the lake at the end of September, 1883,

Crescent Island must have been still connected with the mainland (though papyrus or reeds may have been growing in a foot, or so, of water), for in describing the lake (Through Masai Land, p. 199) he makes no mention of Crescent Island and states: "There are three small islands grouped in its centre, though possibly they may simply be beds of papyrus rising from a very shallow part." It seems more likely that these were floating islands of papyrus which are not infrequent when the lake is rising.

When Teleki and von Höhnel visited the lake in August, 1888, it is clear that the level was already high. Crescent Island and the two adjacent islands were separated from themselves and from the mainland (Discovery of Lakes Rudolph and Stephanie, Vol. 2, p. 295). The lake was very high during Gregory's visit in 1893. Hobley, describing his journey from the coast to Uganda in 1894 (Kenya from Chartered Company to Crown Colony, p. 79), records: ". . . the lake was so high that we were unable to pass between the reed-beds and the cliff, where the railway now runs, so we clambered over the bluff. . . ." From this description and other information as well as examination of the levels, the writer is of the opinion that lake level cannot have been less than 6,228 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. It probably remained high in 1895 as the rainfall at Machakos in that year was well above normal. There then followed four years of severe drought, culminating in the "famine years" of 1898 and 1899. During this period the lake must 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. The writer knows of no determination of level in 1900 but the lake is known to have been very low in 1899 and 1900. The heavy rainfall of 1900, followed by several years of rainfall above the mean, caused the lake to rise to a peak in 1906 and 1907. Continuous records were commenced at the end of 1908, when the level stood at 6,210.90.

Evidence in favour of the fluctuations of level of the larger lakes of the Rift Valley with the 11 year sunspot cycle has been referred to by Brooks in the case of Lakes Victoria and Albert (*Journ. E.A. & U. Nat. Hist. Soc.*, Vol. 22, p. 47, 1925), by Dixey in the case of Lake Nyasa (*Nature*, 1st November, 1924), and by Gillman for Lake Tanganyika (*Hydrology of Lake Tanganyika*, Bull. No. 5, Geol. Surv. Tanganyika Terr., 1933). For Lake Naivasha, the peaks of 1894-95, 1906-7, and 1917 correspond almost exactly with maximum sunspot activity; that of 1930 is a year out, the maximum having been in 1929. The years 1927 and 1928, when the lake was falling, were, however, also years of high sunspot numbers. Although the year 1900 was a year of low sunspot activity and corresponds with low lake level, the

years 1913 and 1923 show peaks in lake level when sunspot numbers were low. Correspondence between lake levels and sunspots does not appear to be very strong in the case of Lake Naivasha, but there may well be correlation, which is influenced by other factors as well. The time during which the levels of Lake Naivasha are known is too short for deductions regarding the applicability of long-period cycles. The Brückner 35 year cycle may possibly have some significance as far as Lake Naivasha is concerned on account of the co-ordination of the 1894-95 and 1930 peaks and the 1900 and 1935 depressions. In this connection it is to be observed that the 1930 peak would probably have been much higher, if the year had been preceded by one, or two, years of rainfall in excess of the mean, instead of being preceded by three dry years. The application of this cycle would, however, appear to connote a peak about 1859 or 1860. If the Keele 76-year cycle, which is based on the Nile flood records from A.D. 640 (Proc. Inst.C.E., Vol. CCII, p. 389), and corresponding with the average period of Halley's comet, has any applicability, it might mean that the lake is only just entering a low level period corresponding with that from 1860 to 1882. It is worthy of note in this connection that Lake Baringo also shows dead tree stumps at about the same relative level as in the case of Lake Naivasha and it is reasonable to assume that the major periods of low and high level fluctuations of these lakes are due to a common climatic cause rather than some purely local one.

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