Bulletin No. 5.

TANGANYIKA TERRITORY

GEOLOGICAL SURVEY DEPARTMENT

The Hydrology of Lake Tanganyika

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PREFACE.

The subject of the hydrology of the lakes of Equatorial Africa is one of outstanding geographical importance in many ways. This contribution regarding Lake Tanganyika is a welcome and valuable one to both the scientific and economic aspects of African geography.

The subject is on the borderline of geological research, one aspect of which in this country is concerned with various phases in the history of the ancient lake systems and their deposits.

A consideration of existing conditions is therefore a necessary step towards the satisfactory interpretation of earlier cycles. The geographical aspects of this subject have a definite geological relationship and it is hoped that in due course a review of the fascinating subject of the old lake systems and their deposits will follow as a sequel to the present paper.

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CONTENTS.

THE HYDROLOGY OF LAKE TANGANYIKA.

I.—Introduction.

Whereas the hydrology of the other great Central African Lakes has received considerable attention resulting in a good deal of literature, Lake Tanganyika has been neglected since Theeuws, the former General Manager of the Belgian Grands Lacs Railway Company, wrote his fundamental paper in 1920 [27]. But even this very important contribution to our knowledge cannot boast of such long continued observational material as we possess for the great source lakes of the Nile nor of a less detailed yet continuous record like the one which Dr. Dixey's efforts have produced for Lake Nyasa. The vital importance of the regimes of Lakes Victoria and Albert for the prosperity of the Anglo-Egyptian Sudan and Egypt and the serious troubles from which the once flourishing river traffic on the Shire has been suffering during the last decades amply account for the great interest that theoretical and practical science has taken in the Nile Lakes and in Nyasa; while the facts that the fluctuations of Lake Tanganyika had not, until recently, created problems of immediate practical significance, and that the war and the consequent repeated changes of Administrations had interfered, to a certain extent, with observational activities, may be taken as sufficient excuse for the comparative backwardness of our knowledge. It is, however, high time that such material as we do possess for Lake Tanganyika were sifted and used in an attempt to fill the existing gap in Central African hydrology and to co-ordinate, as far as possible, the results with those already elaborated for the other lakes. Moreover, with the ever-increasing prominence of trans-Tanganyikan shipping and the slowly but steadily increasing capital invested in port and marine works, it is obvious that a more definite knowledge of the likely or possible highest and lowest lake levels must very seriously concern those responsible for the development of Central African transportation.

As several excellent accounts of the general physiography and geography of the Tanganyika Basin exist* one may assume that the primary geographical facts are at the command of the reader of the present notes which will, therefore, be restricted to the purely hydrological aspect.

II.—Subdivisions of the Basin.

The area occupied by the lake itself is 32,000 sq. kms. and the territory discharging into Lake Tanganyika falls into four well-defined subdivisions, the characteristics of which are contained in Table I (areas from [10]).

Vide, e.g. [19, pp. 325-346].

Table I.—Characteristics of Tanganyika Basin Subdivisions.

Subdivision	Area	Percentage of total	Climatic characteristics
	Sq. Kms.		
Lake Tanganyika	32,000	13·4	On sub-humid sub-arid border belt
Kivu-Rusisi Drainage ...	14,300	6	Sub-humid
Western Shore Drainage ...	36,000	15	"
Eastern Shore Drainage ...	30,400	12·6	(Sub-humid in north) (Sub-arid in south)
Malagarasi-Ugala System ...	126,000	53	Sub-arid
Total ...	238,700	100	

Of these subdivisions the northern represents the geologically only recently acquired contribution of the over-spill from Lake Kivu; the west coast is a narrow strip of ground varying between 10 and 40 kms. in width in the north but gradually widening southward and reaching over 100 kms. near the south end of the lake; the east coast drainage averages 50 kms. in width and attains 100 kms. only in the Rugufu system; the Malagarasi-Ugala drainage, on the other hand, stretches far east to the Oceanic Divide nearly 500 kms. distant.* It is undoubtedly the most important contributor to the lake, providing 40% of the total inflow even if one makes ample allowance for the considerable loss of water which is bound to occur in the large swamp areas filling the depression in which the upper Malagarasi, the Utinde and Ngombe meet (comp. Table IV.).

The maximum length of the lake, measured along its axis, is 670 kms., its greatest width, just north of the mouth of the Malagarasi, 82 kms., and the shortest distance from the eastern to the western shore (from the southern promontory of Kirando Bay to Cape Kavembe) only 26 kms. The coast line measured on the latest 1 in 1,000,000 map (G. S. G.S.No.2465), is 1970 kms. if one includes Ubwari Peninsula and 1,830 kms., without this somewhat abnormal feature.† For details *vide* Table II.

Table II.—Length of Coast Line.

Subdivision of Coast	Point to point distance	Actual length	Degree of sinuosity
	Kms.	Kms.	%
East and West Coasts from North end to 5°S.Lat.	400	440	10
East Coast from 5°S.Lat. to Kirando Point ...	290	430	48
West Coast from 5°S.Lat. to Cape Kavembe ...	310	440	42
East and West Coasts from Kirando via south end to Kavembe	350	520	48
Total ...	1350	1830	35·5

*Prof. Halbfass [12, p. 522] is, thus, mistaken when he states "that the farthest source streams are only 100 kms. distant from their mouths."

†A circle enclosing an area equal to that of the lake would have a diameter of 203 kms. so that the shortest possible coast line for a sheet of water of 32,000 sq. kms. would only be 637 kms. long or roughly one-third of the actual coast.

III.—Climatic Considerations.

Professor Jaeger's very lucid hydrographic map of Africa [17] well illustrates the fact that Lake Tanganyika lies in that narrow strip of ground (his "Trockengrenze") which separates sub-arid from sub-humid Africa, the 1000mm isohyet which determines this border zone practically coinciding with the west coast of the lake. On the other hand and largely owing to the accidents of topography, the drainage basin of Tanganyika includes areas of higher precipitation and lower temperature with the result that a fairly wide range exists of the climatic factors influencing the hydrographic regime. By far the largest part of the basin has typical trade-wind climate with a single rainy season, normally from December to May, and a long dry season which stands under the strong evaporating influence of the S.E. Trade. Only the northern tributary areas, Kivu and Rusisi, enjoy the equatorial climate type with a more favourable distribution of rainfall over the year.

Although we are, as yet, far from an accurate knowledge of rainfall distribution in space and time and of the very important and characteristically very considerable deviations from the mean, which find their expression in the much complained of "abnormality" of East African weather, one can, by combining a careful scrutiny of the prevailing natural vegetation types with the study of the meagre statistical material, arrive at fairly accurate values for the mean Annual *Rainfall*. Basing one's computations on the following six representative stations on or near the coast, from north to south, Usumburu (800mm), Ujiji (830mm), Albertville (1000mm), Karema (650mm), Kasanga (900mm) and Kambole (1270mm), 900mm will probably be a sufficiently reliable figure for the mean annual precipitation on the lake itself. Figures for the different tributary basins, likewise determined from vegetational as well as statistical data, are given in Table IV.

It is less easy to obtain a correct idea of the mean annual *Evaporation* as no observational material exists. Theeuws [27,p.195] gives 1350mm, a figure which tallies well with that worked out for Lake Victoria by Dr. Hurst, 1310mm [13,pp.38-40] from the mean rainfall on the lake, the estimated run-off from the basin and the mean annual discharge over Ripon Falls. Owing to the smallness of run-off plus outflow compared with the rain actually falling on the lake, Dr. Hurst considers his figure "a fair estimate" and in his later work [14,p.61] thinks it "somewhat greater than perhaps might be expected by comparison with the southern Sudan." Accepting this view and taking account of the slightly higher mean annual temperature on Lake Tanganyika as well as of the S.E. Trade's influence on the latter, one may, thus and for the time being, safely adhere to Theeuws' value of 1350mm.

IV.—Characteristics of the Water.

Temperature.—W. A. Cunnington, during the 1904-5 Tanganyika Expedition observed a minimum surface temperature of 23° Centigrade and a maximum of 27°. At a depth of 140m the temperature becomes almost constant, varying only between 23·5 and 24° [quoted in 19,p.332]. The German survey of 1913 [15; summarized in 12,p.525] confirms and extends these earlier observations. Surface temperatures fluctuated from 26·3° in the north to 23·3° in the south; a slight temperature gradient of about 1° exists between 75 and 100m depth. From 180m to the greatest depths sounded the water is practically homotherm at 23·15° Centigrade. We thus have a volume of water well over 1 km., and in places more than 1·5 km.

deep, which has adjusted itself to the mean temperature of the air resting on it and keeps itself thus adjusted in spite of the fact that the temperature of the rain falling on it and of most if not of all of the run-off discharging into it, must be considerably less. This is not only a further proof, for the correctness of Professor Halbfass' view (quoted and endorsed by Prof. L. W. Collet [2a,p.135]) that the deep lakes, from a thermic point of view, are very effective indicators of climate, but an important extension of its range as the heretofore greatest depth at which lake temperatures have been recorded (Caspian, 947m) has been carried down to beyond 1200m. This constancy of temperature would also seem to preclude the possibility of undercurrents, which Capt. Jacobs [15,p.7] likewise doubts as he was unable, during his survey to establish any corresponding surface currents.

Chemical Composition.—A number of analyses [12,p.527;29,pp.46/7] show that the water is distinctly "fresh" with a total mineral content varying between 470 and 570mg/l. The low chlorine content (·40mg/l) is somewhat unexpected as the Malagarasi which drains the salt deposits of Uvinza must bring in a constant flow of this element. No analysis has revealed even traces of iodine whereby the theory of a "Relict Lake" receives a further, though minor, setback.

Hydraulics.—The absence of currents has already been remarked upon. Observations on the short-period fluctuations of the Lake Level are as yet far too scant and unreliable to permit any statements regarding tides and seiches although it seems fairly safe to assume that the latter at least exist. The frequent and terrific storms of the wet season and the steady drag of the S.E. Trade-wind in the dry season must, of course, result in considerable disturbance of the surface, waves of 2m and more in height being not uncommon.

V.—Depth of the Lake.

For a long time everyone seems to have been under the impression that the greatest depth of Lake Tanganyika was about 300m, the figure adopted as late as 1909 by H. Meyer [19,p.326]. The first systematic soundings appear to have been taken by the Belgian explorer Dr. L. Stappers in 1912/3 who is reported by Capt. Jacobs [15,p.2] to have reached a greatest depth of 1430m in the southernmost basin. No other records of this work have come to the knowledge of the present writer. The figure has, however, been accepted by the latest authors [12,p.517;16,p.302]. Capt. Jacobs himself, in 1913, took a series of transverse soundings which are shown on a map accompanying his report to the German Government [15]. His traverses cover the northernmost part, north of Ubwari Peninsula, very fully, whereas they cross the bulk of the lake only four times: From Ras Remba, a little north of Kigoma, to Musama; from Ras Kungwe to the Mtoa Archipelago, north of the Lukuga mouth; from Edith Bay, north of Karema, to Ras Tembwe; and from Kala to Vua Bay. They show a greatest depth of 1277m in the northern and of 800m in the southern basin and bring out well the sill, with a maximum depth of only 136m, which separates the two Basins as a submerged continuation of the Kungwe promontory. It must, however, be pointed out that later publications mention even greater depths. Thus Theeuws [27,p.628] gives a maximum of 1800m and Dr. Scholz [24,p.82] quotes soundings "in places 1000m below the level of the Indian Ocean," i.e. likewise depths of approximately 1800m. It would seem that these figures emanate from Dr. Stapper's observations although the present writer has no means of verifying this suggestion. Jaeger [16,p.302] speaks of *three* separate submerged basins, which likewise leads one to the belief that more detailed records of the Belgian Expedition of 1912-3 must exist than those available in this country. Whatever the results of fuller investigations, we definitely know that Lake Tanganyika is of very great depth and that, with a mean surface level of 771m above sea level, the lake bottom lies between 660m and probably over 1000m below sea level. This is much lower than Lake Nyasa (270m) and shows the same order as the other two great lake-filled depressions: Lake Baikal (1060m) and the Caspian Sea (970m).

VI.—Fluctuations of Lake Level.

It is not intended in the present paper to deal with the geological history of Lake Tanganyika nor to attempt the fascinating task of co-ordinating large scale fluctuations of its level with the tectonic and climatic changes of the Pleistocene period. Although a good deal of research has recently been done by Fourmarier, Salée, Teale and others and although undoubted instances of former very much higher levels have been found or can be deduced from a study, still in its infancy, of the pre-Pleistocene and Pleistocene development of the tributary river-systems, it is felt that our knowledge is as yet too scanty to produce more than, at the best, a still rather vague working hypothesis.* For the immediate purpose, therefore, i.e. for a study of the geographical rather than of the geological complex and of its practical consequences, it will suffice if we restrict our investigations to the "historic" period, that is to the seventy-three years which have elapsed since Burton and Speke discovered the lake in 1858.

Before, however, going into detail it is desirable to try and settle the controversy about the *Lukuga Outlet:* Is it a periodic phenomenon or is it a solitary "debacle", an important incident in the lake's history which has profoundly changed its regime once and for ever? The latter view has been expounded by Theeuws in his classical study and, considering his intimate acquaintance with the Lukuga valley, his technical interests in and responsibilities for a river along which he has built one of the railways under his administration, and last but not least his long continued opportunities for studying all aspects of the problem on the spot, it is not easy to discard off-hand as unreal or fanciful his very closely reasoned deductions which can be summed up as follows:—

(1) The theory, already suggested by Stanley, is upheld according to which there were originally two lakes separated by the now submerged sill, the southern of which, with a much higher level than the northern, discharged through the old Lukuga [27,pp.633/5].

(2) The Lukuga Depression is doubtlessly originally a rift valley through the Mugila Massif which has later become an erosive valley [*ibid* p.636].

(3) The present Lukuga discharge exists doubtlessly without interruption since 1875 and *there is nothing to show that prior to that date an intermittent outflow level had existed* [*ibid* pp.631/2].

(4) In future the lake has a limit beyond which it cannot rise . . . the balance of its gains and losses, formerly exclusively used to raise the level of an independent lake, is now tributary to the Congo [*ibid* p.133].

*In this connection it is interesting to note the native legends quoted by Stanley [26, Vol. II, pp. 11/14] which point towards a witnessing by Man of at least certain phases of Tanganyikan rifting and flooding, just as the most recent investigations by Drs. Leakey and Reck seem to prove that Man was present when certain phases of Great Rift Valley tectonics and volcanicity were in progress.

(5) The commencement of the breach of the alluvial bar shutting off the ancient Lukuga valley dates from 1872 and is due to a gradual soaking of the surface during annual high water. The first real breach took place in May 1878 after an exceptionally heavy rainy season and the final breach in January or February 1879 [*ibid* pp.52/3]. (Here it should be noted that not all of these dates tally with those of Cameron [2,Vol.I,pp.304-308] who definitely stated in 1874 that natives had asserted that they had travelled great distances along the banks of the river whose entrance he was then exploring for the first time, and that it joined the Lualaba. Stanley, however, not only quotes contradictory native evidence [26,Vol.II,pp.9-14], among others a statement that there are two Lukugas, one running into the lake and one into the "Rua" (=Lualaba), but [26,pp.44-47] shows clearly on his detailed sketch map that the final sweeping away of the last swamp-covered bar was imminent in July 1876.)

(6) The top of the bar which blocked the Lukuga outlet prior to the "debacle" lay at 781·8m* [*ibid* pp.52/3] and the rocky sill of the present outlet lies at 769·7m [p.131], so that the establishment of the outlet, with an average depth over the sill of 2m must have lowered the lake's surface by approximately 10m, the former higher level being marked in many localities (Kigoma Bay, Ujiji, Albertville cliff, etc.) by terraces or old high-water marks. (Capt. Jacobs [15,p.3] gives figures for such marks: Ujiji, foot of "Livingstone Tree", 782·8; Usumburu 779·7).† The maximum discharge after the final breach is computed at 2300cbm/sec. and the end of the "debacle", i.e. the time when equilibrium was attained, is put towards the end of the decade 1880-1890 [*ibid* pp.56 and131].

Thus far Theeuws' very definitely stated views are based on undoubtedly correct and irrefutable local observations. The problem has, however, a much wider and more regional aspect which one cannot afford to overlook and which, after it had been for the first time clearly grasped by Reichard [22a,pp.389-391], and also touched upon by Sieger [24b,pp.579-582] has since been repeatedly emphasized by such outstanding authorities on African Geography as Jaeger [16,p.274;17,p.178] and Meyer [19,pp.330/31]:

Whereas in a humid climate, where mean precipitation exceeds mean evaporation, streams and rivers are permanent, hollows in the ground fill up and spill over and all drainage reaches the sea; the characteristic hydrographic conditions prevailing in an arid climate, with evaporation exceeding precipitation, are intermittent streams, shallow lakes or pans in the depressions in which excessive evaporation prevents spilling over, and an interior basin drainage without outlet to the sea. It is obvious that gradual transitions must exist between these two extremes and that lakes which, like the great Central African Lakes, lie within the border zone between the sub-humid and sub-arid hydrographic regimes may, conceivably, be subject to marked alterations, periods of discharge to the sea alternating with periods of dischargelessness.

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*All altitudes regarding Tanganyika levels in the present paper refer to the Indian Ocean, Admiralty Chart datum at Dar es Salaam.

†According to the statement of the present native headman of Kigoma who was "a child just big enough to be entrusted to look after the goats" in about 1879 "when the first European graves were dug on the ridge above his village," Luanza Promontory was then an island (communication by Mr. Longland, Acting Provincial Commissioner).

The main cause of such changes in the regime will, of course, be climatic as in the delicately balanced climate of the belt of transition from humid to arid general periodic fluctuations of climate must necessarily be felt more acutely: whilst in a fully humid or fully arid region a slight change, say, towards aridity will still maintain the original character of the climate, a similar change in the marginal zone of transition may easily convert the sub-humid parts into sub-arid ones for the time being. To these climatic causes, however, other secondary causes must be added which are due to the morphological accident of the outlet, leading to the formation of barriers during periods of low water and to the gradual or sudden reopening of these barriers during periods of high water, causes which, therefore, may be said to emphasize and to widen the amplitude of the primary climatic causes. As Dr. Dixey [4,p.3] has pointed out human activities, leading to soil erosion and to accentuated aggradation, may well play an important part in these morphological changes and thus in the fluctuations of lake levels.

A third group of causes of fluctuations in the levels of lake which, like Tanganyika and the other great African Lakes, fill recent tectonic depressions, must not be overlooked. The crust movements which have created the lake basins can not be considered to have ceased entirely; in fact, serious and frequent earthquakes definitely prove their continuance [8,p.76-78] thereby establishing the possibility of further differential uplift or subsidence of dimensions large enough to influence the surface level of the lakes. Contrary to the climatic and morphological causes, these tectonic causes will, of course, as a general rule, not show any periodicity.

In the light of the foregoing considerations it would, thus, appear safer to look upon the Lukuga as an intermittent outlet of Lake Tanganyika and upon the "debacle", so well described by Theeuws, as a recurrent rather than a unique phenomenon.* Recent and more detailed geological investigations by Fourmarier and others have, furthermore, shown that some of Theeuws' morphological statements [27, 631/2] can no longer be upheld and the analogous conditions prevailing at the Shire outlet of Lake Nyasa likewise speak in favour of the view which *includes Tanganyika among the lakes of the arid-humid transition zone, possessing an intermittent (periodic?) outlet.*

Neither on Lake Tanganyika nor on Lake Nyasa, however, have we as yet witnessed a full cycle of outlet activity. The latter's outlet was flowing freely at the time of its discovery (September 1859, when Livingstone [17a, p.121] described the Shire above the cataracts as "a broad deep river with but little current") and is at present passing through a period of increased choking up; Tanganyika's outlet, on the other hand, was at the height of obstruction when it was first mapped by Stanley in 1876 and is to-day once more in full function: a fortunate coincidence which enables us to visualize, by combination and comparison, the general trend of a full cycle on either lake.

Of the *actual amount of the discharge* we know practically nothing and it is much to be regretted that the Belgian authorities, even to-day, keep no accurate records of the depth and velocity of water over the Lukuga sill. In 1874 Cameron had found the channel, though severely swamped and soaked, yet practically entirely blocked [2,Vol.I,pp.306/7]; in 1876 Stanley

*In this connection Cameron's text (*vide* p. 6) becomes of considerable importance as the atives quoted by him might, conceivably, have referred to a former period of Lukuga discharge.

[26] was the first to witness an actual though scarcely noticeable flow; after an exceptionally heavy rainy season the first real breach took place in May 1878 [27,pp.52/3], after which E. C. Hore [12a,p.147] reported a rapid flowing stream in 1879 and J. Thomson [28,Vol.I,pp.105-198], later in the same year a tearing river. In 1883 V. Wissmann [30,pp.292-298] who measured the same, found a width of 145m, a depth of 4m and a velocity of 1m/sec. (which would give a discharge of between 500 and 600cbm/sec.). In the following years equilibrium must have been gradually established. 1894 witnessed the lowest lake level known since the outflow commenced with a depth over the sill of only a few centimetres (16 according to Theeuws, *loc. cit.*p.131) and J. E. S. Moore in 1898 noted a depth of not more than one foot [19a,pp.185-226]. Since then the outflow has been continuous, the depth of water, at low level fluctuating between 1 and 2m.

Having thus dealt with the problem of the Lukuga outlet, the known facts regarding the fluctuations of the lake level will now be considered.

(a) *Periodic(?) fluctuations of long amplitude.*—Although it is probable that these exist nothing definite can be said about them as the available observations do not cover a sufficiently long period. Furthermore, it is quite likely that the amplitude of such fluctuations may be long enough to be affected and even obliterated by tectonic happenings in a shatter-belt of still marked instability.

(b) *Periodic fluctuations of short amplitude.*—In 1858, when the lake was discovered, its level was rising and in the late 'sixties Livingstone likewise reported a tendency to rise. Whether or not this took place continuously or in periodic jerks, it is impossible to tell; it seems obvious, however, that up to the date of the latest overflow and of the breach of the Lukuga barrier, Lake Tanganyika must have risen to the historic maximum of approximately 782m, i.e. about 10m above its present mean level. From 1879 the newly established (or re-established) outlet led naturally to a first rapid and later more gradual lowering of the surface which continued to 1894, when the lowest known level (769·86m) was attained. Then followed, probably, a period of rise until, early in the twentieth century, the disturbing effects of the "debacle" had been overcome and the regime of the lake once more became normal. Unfortunately we possess only very few reliable data for this period, collected by Theeuws [27,p.131] and converted to Dar es Salaam Zero as follows :—

1888	...	770·96m	
1894	...	769·86m	Lowest low water
1900	...	771·31m	High water
1906	...	770·76m	Low water
1908	...	770·96m	,, ,,

When, in 1909, the extension of the Central Railway to Kigoma had been definitely decided on and Lake Tanganyika thereby been drawn into the problems of African communications, the German authorities commenced regular observations and the arrival, at the lake, of the first Railway survey parties in 1910, enabled the records of lake levels to be referred to a definite sea level datum. These readings were continued until May 1916 and resumed by the Belgian military authorities early in 1917. From 1918 to 1920 there is a gap which, however, can be filled by using figures published by Theeuws. For 1921 no records exist. Since then regular weekly readings, and since 1929 regular daily readings were taken without interruption, first by the

Administrative Officer of Kigoma and later by the Engineering Department of the Tanganyika Railways. From 1923 onwards regular observations also exist from Albertville which the Director of the Grands Lacs Railway Company has very kindly communicated.

These continuous records from 1909 to 1931 have been plotted on the attached chart (Appendix I), great care having been taken in co-ordinating correctly the figures obtained from various sources.* This required an investigation into the history of the various gauges used from time to time and as the results of this investigation are not only of historical interest but are of importance with regard to the accuracy of the levels now published for the first time, a résumé of the same is given in Appendix II. The graph of fluctuations contains two short periods (1919 and 1921) for which interpolation became necessary but the line as shown may be taken as reasonably correct for all practical purposes. The maximum of 1909 plotted from the German records based for this particular year "on the verbal statement of the mechanic on board the small German vessel", would appear somewhat high. No great reliability can be attached to it and the graph, at this point, has accordingly been drawn in broken lines. For a few years only either the maximum or the minimum levels are available; in these cases the missing figure has been obtained by adding or subtracting the value for the mean annual fluctuation (*vide* below). An analysis of the graph reveals maxima in 1909, 1917 and 1927, and minima in 1911, 1923 and 1929, that is a relation to the sunspot cycle sufficiently marked to deserve closer investigation and, furthermore, very interesting and close relations to the fluctuations of the other Central African Lakes which will be discussed in a later chapter.

(c) *Annual fluctuations.*—Theeuws [27,p.194] has computed the mean annual fluctuation, representing the balance between precipitation and run-off on the one, and evaporation and discharge on the other hand at 0·75m, Jacobs [15,p.2] gives 0·75m to 1·00m, Halbfass [12,p.523] 0·75m and Meyer [19, p.330] 0·50 to 1·00m. The values for the fourteen years with complete records available between 1913 and 1931 are given in Table III.

Table III.—Annual Fluctuations of Level.

Year	Difference between High and Low Water m.	High Water
1913	0·67	—
1914	0·69	Low
1915	0·77	—
1917	0·57	High
1922	0·79	—
1923	0·65	Low
1924	0·75	—
1925	0·78	—
1926	0·60	—
1927	0·80	High
1928	0·80	—
1929	0·90	Low
1930	0·53	—
1931	0·83	High

*Annual charts, covering the period from 1923 to 1931, have likewise been prepared and show, on the whole, a very satisfactory agreement between the Kigoma and Albertville readings.

The mean of these values work out at 0·72m and the variations from the maximum (0·90) at 25% and from the minimum (0·53) at 26%. The absolute value is thus considerably in excess of that on Lake Victoria, where it reaches only approximately 0·25m. No connection is apparent between the amount of the annual fluctuation and the stage of the lake level in its major cycle. But it is remarkable how much the fluctuations in successive years can vary, the two consecutive years 1929 and 1930, e.g., showing the largest and smallest values observed during the fourteen years under discussion.

(d) *Daily fluctuations.*—No records exist at present which would permit of any definite statement regarding daily variations of the Lake level due to air-pressure, currents or tides. It would, however, be of the greatest interest if such records could be obtained by an early establishment of suitable instruments at Kigoma, Albertville, Mpulungu and Usumburu.

VII.—The Regime of Lake Tanganyika.

Both Meyer [19,p.330] and Halbfass [12,pp.516,522] lay great emphasis on the fact that, with a comparatively small inflow from the tributary rivers, or, in the latter's terms, with a negligibly small inflow, the regime is almost entirely determined by precipitation directly on, and evaporation from, the lake surface. A more detailed computation of the regime elements, however, shows that these views are somewhat exaggerated and that the mean inflow (or run-off from the tributary basins) is, with 60% of direct precipitation and 40% of evaporation, by no means negligible and can, in exceptionally wet years or at periods of an eastward shifting of rainfall-intensity, become even more important.

Taking 900mm for the mean rainfall on the lake and 1350mm for the evaporation (comp. Chapter III) the annual quantities for a surface of 32,000 sq. kms. work out at:

Mean Precipitation 29×10^9 or *29 Milliard Cbm.*
Mean Evaporation 43×10^9 or *43 Milliard Cbm.*

To arrive at a rough estimate of the inflow (or run-off) the individual contributary basins have been carefully analysed with the result set forth in Table IV. To allow for excessive evaporation from the great swamp areas at the Utinde-Ngombe-Malagarasi Confluence (Theeuws' "Lake Zimba") the estimated run-off for the basin concerned has been taken as only 5%.

Table IV.—Basins Contributing Run-off.

Tributary Basin	Mean annual rainfall		Area	Estimated Run-off	Total reaching Lake: Million Cbm.	Total reaching Lake: % of Total	
	mm.		sq. km.	%	p.a.		
Kivu-Rusisi	1100	29% sub-humid	14,000	15	2,300	13·5	60%
West Coast	1000		36,000	15	5,400	31	
East Coast (North)	900		10,000	15	1,300	7·5	
East Coast (South)	700	71% sub-arid	20,000	10	1,400	8	
Malagarasi	900		23,000	8	1,700	10	40%
Ngombe-Utinde	800		49,000	5	2,000	11·5	
Ugala Sinde	750		54,000	8	3,200	18·5	
Total ...			206,000		17,300	100	

The *total computed inflow* is, thus, approx. 17×10^9 or *17 Milliard Cbm.* corresponding to 530mm depth, a figure which tallies well with Theeuws' 16 Milliard Cbm. arrived at through a consideration of precipitation on and evaporation from the lake and of the mean rise of lake level through a number of years.

The *mean annual outflow* can now be computed as Outflow=Precipitation +inflow — Evaporation at 3×10^9 or *3 Milliard Cbm.*, representing a depth of 94mm.

This leaves out of consideration the entirely unknown and probably negligible quantity of *seepage* as well as any possible gains from *groundwater* or *sub-surface springs*, and, for roughly 32 million seconds p.a., gives an average outflow of approximately 90cbm/sec. Taking mean lake level at 771·7m and the level of the sill at 769·7 this would give an average depth of water over the sill of 2m and, with an average width at the mouth of 60m, an average velocity 0·75m/sec. which, in the absence of more accurate measurements, all fits in very well with actualities.

VIII.—Future Changes and Technical Considerations.

The foregoing numerical statements and, chiefly, the wider geographical aspect of the factors determining the hydrology of Lake Tanganyika leave, it is thought, but little doubt that the following is a correct appreciation of the state of affairs :

> Lying within the marginal belt between the sub-arid and sub-humid climatic zones of East Africa, the lake basin and with it the actual regime of the lake itself are liable to experience periodic changes of climate of an amplitude large enough to create long period fluctuations of level of such dimensions as to interfere seriously with the works of man on the lake shores. Although exact observations have not as yet been extended long enough to permit of even a rough guess at the length of these longer climatic periods—which must not be confounded with certain apparent shorter periods probably connected with the shorter 11-year sunspot cycle—one is not only justified but forced, by a consideration of Lake Tanganyika's known past history and by comparison with the actual happenings on Lake Nyasa, to postulate such alterations between a relatively drier and a relatively wetter climatic regime. If one of these dry periods continues for a number of years, lake level will drop below the Lukuga sill and silting up of the Lukuga gap by hill-wash, consolidated by swampy growth, will soon rebuild a barrier strong enough to bank up the lake during the initial years of the succeeding wet period, until the top of the barrier has been reached and soaking and overspill once more lead to a breach. These fluctuations of level are of an order of from 13 to 15m, i.e. very much greater than the shorter period fluctuations which, during the short time which has elapsed since equilibrium was established after the last breach, have never attained to more than 2·5 to 3m. In addition to these foreseeable long period changes of level, due to a combination of climatic and morphological causes, sight must not be lost of the possibility of unforeseeable changes due to probably still continuing tectonic movements, which might affect the shape and depth of the basin and thus the surface level of the lake.

If this conception of the present life history of Lake Tanganyika is accepted, certain statements by former technical investigators are, obviously, no longer tenable. Thus Theeuws [27,p.135] is wrong if he states that, apart from negligible erosion of the rocky Lukuga sill, the level of this sill represents the limit to any future lowering; and Capt. Jacobs [15,p.4] is likewise on very insecure ground when he maintains without giving any reason for so sweeping an assertion, that "with regard to the harbour works at Kigoma one need not reckon with a future change of level of more than 1m (*sic.*) in either direction." If, therefore, one has to oppose strongly such misleading technical advice, one does so with the reassuring knowledge that the results of the present much wider and fuller studies have the full backing of competent and authoritative geographical opinion.

The question, thus, becomes acute how to counteract, if possible, the larger foreseeable fluctuations which, if they were allowed to overtake us unawares, would prove detrimental not only to a good deal of native activity all along the shore of the lake, but also to many costly structures, notably quay-walls, slipways and dry docks, already built or to be built in future, as well as to far from negligible sections of railways.

Counter measures obviously fall under two categories, those destined to prevent an unwelcome rising and those to avoid an even more disastrous falling of the lake.

As regards the first eventuality, matters are comparatively simple once one has understood the function of the Lukuga outlet and the dangers to its permanence by a possible re-establishment of a bar or barrier. For should signs of such a re-forming bar become evident it would be easy for modern technical science to devise methods and plant to keep a sufficiently deep channel open; or better still, and probably cheaper in the long run, to install "prophylactic" works designed to prevent hill-wash or to lead it into harmless channels. The only drawback from the point of view of Tanganyika Territory would be the fact that works destined to protect its ports would necessarily lie on foreign ground, a drawback which, however, can and will undoubtedly be overcome by international agreement.

To safeguard against a level sinking below the Lukuga sill, is more complicated, especially as a number of costly installations already exist which, with such sinking, would lie high and dry and thus be unapproachable for the shipping they are there to serve. Dredging in front of these structures is possible only to a very limited extent owing to the danger of impairing the safety of their foundations. Quay-walls might be replaced by jetties which, running out into the lake at an angle, could be convieniently lengthened to follow the receding water; slipways and dry docks could, similarly, be replaced by floating docks. In any case it would be wise to build only jetties and floating docks in future, unless the second alternative is resorted to. This would consist in constructing a barrage on the Lukuga sill in order to store up, by restricting or entirely stopping the outflow, the annual surplus during the early stages of an incipient dry period against the latter's peak years. This method, theoretically correct and feasible, would of course require much fuller and much more accurate computations of the lake's regime than the data now available permit; and it would also require a much fuller knowledge of the larger climatic cycles' amplitude than we can dare to hope for in the immediate future. Progress in meteorological and geophysical science, in co-operation with cosmic physics, alone will in due course enable us to predict the periods during which, and the extent to which, such a barrage should do its work.

To counteract the unforeseeable fluctuations due to tectonic disturbances is, of course, beyond the scope of man. He has done his duty if he has drawn attention to the possibility of their occurrence !

A minor technical difficulty already unpleasantly felt in connection with the short period fluctuations of 2 to 3m amplitude is the influence of these changes of lake level on the regime of the Luiche River in its delta, which the Central Railway crosses at a level of only about 10m above present mean lake level. During high water of the lake the river floods are banked up, which leads to extensive silting in the many delta channels, whilst during periods of low water, with the base-level of erosion lowered by as much as 2m, increased erosional force of the river-floods as a rule seeks new outlets, whereby existing channels are shifted and bridges either put out of action or dangerously overstrained, with consequent constant anxiety for the engineer responsible for the safety of the line.

IX.—Comparison with other Central African Lakes.

To facilitate such a comparison, essential for a correct synthetical understanding of Central Africa, Table V has been compiled which contains the necessary areas of land and water, the five main elements determining lake regime, and certain important data and ratios whose significance for a comparative study will presently become evident. It is obvious that, with the exception of the fairly accurate figures for the areas, the information given in this Table is, as yet, very tentative; but it is claimed that the unavoidable errors and generalizations are of the same order for all four lakes and that, therefore, conclusions drawn therefrom must be relatively, if not absolutely, correct. It is further realized that the elements given for Lake Albert carry an additional factor of doubt as they do not—and, from the material thus far published, cannot—take into account any part that the Victoria Nile may play in the lake's regime; for it is clearly a mere assumption, made to bridge the gap in our knowledge, that Lake Albert is, so to speak, a tributary to the Victoria Nile when, evidently, the topographical arrangement of the Nile's inlet and outlet make it more than probable that the lake must, at least to a certain extent, be considered as a "backwater" of the river.

Table V.—Comparison of Central African Lake Regimes.

Regime element	Unit	Nyasa	Tanga-nyika	Victoria	Albert
I. *Areas* (to nearest 1000 sq. kms.):					
Total Area of Basin	sq.km	140,000	238,000	260,000	54,000
Area of Lake	,,	26,000	32,000	66,000	5,000
Lake Area in % of Total	%	19	13·5	25·5	10
Area of tributary	sq.km	114,000	206,000	194,000	49,000
Drainage of which—					
in humid Climate	%	11	—	13	100
in sub-humid Climate	,,	27	29	55	—
in sub-arid Climate	,,	62	71	32	—
II. *Main Elements*:					
(a) Precipitation on Lake ...	mm	1000	900	1260	†1000
(b) Evaporation from Lake ...	,,	1300	1350	1310	1500
(c) Inflow	,,	490	530	330	2000
(d) Outflow	,,	negligible	94	280	‡600
(e) Seepage	,,	?	?	?	?
III. *Ratio*: $\frac{\text{Evaporation}}{\text{Precip. + Inflow}}$	—	0·87	0·94	0·82	0·50
IV. Difference between highest and lowest H.W.* for period 1903-1931 (1903-1920 only for Nyasa)	m	1·70	1·5	1·8	2·8
V. Mean Annual Rainfall in contributary Basins	mm	1000	850	1100	1400
Climate Type		Sub-arid Sub-humid	Sub-arid	Sub-humid	Sub-humid humid
VI. Mean Inflow in Cbm. p.a. per sq. km. of tributary Basin ...		114,000	82,000	119,000	225,000
VII. *Depth*	m	786	1430 (?1800)	80	48

Areas computed by C.G.
Elements for Nyasa and Tanganyika computed by C.G.
Elements for Victoria and Albert from Hurst [13].

A scrutiny of the data contained in sections III to VI of the table immediately suggests that the four lakes under discussion can be arranged into a climatically dominated series thus :

Tanganyika; Nyasa; Victoria; Albert,

*The figure for Lake Albert refers to Mean Water.

†Comp. 13, pp. 34, 36 and 62; it does not seem correct to base the rainfall on the lake on one single station lying, like Butiaba, in the rain shadow of the Eastern Scarp, 1000mm having therefore been substituted for Hurst's 800mm.

‡Not taking into account the Victoria Nile.

and that the first two form a sub-group expressive of more arid, the last two one expressive of more humid conditions.

The mean annual rainfall over the contributary basins indicates a gradual change of climate type from a distinctly sub-arid one in the Tanganyika Basin to an almost full humid one in the Albert Basin. The mean inflow (or run-off) per year and square kilometre of drainage area likewise emphasizes this change from sub-arid to humid and, taking as it does into account topographical peculiarities by including the estimated percentage of run-off, signifies that climate both shapes and overrules the accidents of topography. The differences between the highest and lowest H.W. levels observed over a lengthy spell of years also show a distinct dependence of the lake levels on the climate type of the tributary basins, the ratio between mean annual rainfall (in mm) and this difference in H.W. (also in mm) being almost constant for the three larger lakes (Tang. 0·57; Nyasa 0·59; Vict. 0·61) while the somewhat lesser figure (0·5) for Lake Albert is probably due to the fact that the difference in this case is given for mean and not for high water and may, as explained above, share in the uncertainty introduced into all Lake Albert figures by the Victoria Nile.

There can be no doubt that evaporation from the surface of tropical lakes plays an important role in their regime and it is, therefore, essential that the degree of influence of this element should be carefully studied. The first obvious ratio which offers itself for this purpose is, of course, that of evaporation to precipitation. If, however, one scrutinizes carefully the figures for the main elements, one soon finds that inflow is by no means a negligible factor, when as close an approach as possible to a correct "Profit and Loss Account" is aimed at, not even for Lake Victoria, leave alone Lake Albert where without consideration of inflow such an account would be entirely misleading. It was, therefore, deemed expedient to base comparisons on the ratio

$$\frac{\text{Evaporation}}{\text{Precipitation} + \text{Inflow}}$$

whereas outflow has been, and can be, safely omitted as it does not throw any direct light on the climatic conditions which rule the regime and as, furthermore, it is of an intermittent nature in some of the lakes.

This ratio between climatically determined loss and gain not only brings out once more, as was to be expected, the dependence of regime on climate type, the influence of evaporation over precipitation plus inflow decreasing rapidly from the sub-arid to the humid end of the series; but it also shows that evaporation is by no means that outstanding factor determining the regime which recent attempts to account for the doubtlessly existing correlation between lake levels and sun-spot numbers have led Brooks [1,p.342] and Jaeger [26,p.275;27,p.179] to assume.* To the present writer the figures of Table V seem to call rather for caution regarding a too rapid interpretation of these correlations, a standpoint also taken up by Dixey [6,p.335]. But this question will be further discussed in the last chapter.

Although it can thus be shown that marked variations exist in the *intensity* of the regime of the four lakes, variations which, to repeat it, are closely

*Dr. Brooks' rainfall figures are based on ten stations in Uganda which are representative neither of the lake nor of the whole basin, as has already been pointed out by Phillips [21] and Dixey [4,p.1]; and it has, furthermore, been overlooked that only a small part of Uganda drains into Lake Victoria.

connected with gradual changes from one basin to the other of the general prevailing type of climate, the graphs depicting the fluctuations of high water (mean water in the case of Lake Albert) during the last twenty-eight years (Appendix III) make it equally clear that the *trend* of these fluctuations, certainly in its general aspect but frequently also as regards its minuter detail, is the same for all four lakes.

In other words: although each lake basin has its own individual dominating climate sub-type, dependent on the general geographical position and on tectonically determined present day surface forms, the larger area covered by the combined basins of the great Central African Lakes must be considered as a unit which reacts uniformly to regional variations in the climatic conditions.

There is, however, a masking of this uniformity in the case of Lake Nyasa whose graph, from 1924 onwards, no longer repeats the ups and downs so strikingly parallel for the other three lakes, but shows an uninterrupted rise of level. There can be no doubt, as Dixey has pointed out [7,p.2], that this apparently irregular rise is due to the blocking of the Shire River and had we the data to extend the Tanganyika graph backwards to 1876 we would find a similar irregularity in the shape of a line descending continually from 782m in 1876 to 770m in 1894, expressive of the lowering of the lake due to the re-establishment of its temporarily blocked outlet.

Thus far, everything seems to be clear and the present investigation and comparison fully endorse with regard to all four lakes Dixey's views who says about Nyasa [7,p.2]: "The essential factor in determining the level is not the outflow but the balance of rainfall and evaporation over the lake and the lake basin, and this balance is determined by climatic factors of regional character . . . . although their effect is masked to a greater or lesser degree by the state of activity of the Shire River." What still remains unclear, however, is the problem why the intermittent outlet activities on Nyasa and Tanganyika should not coincide in time: in 1859 the Shire was flowing and is now blocked, seventeen years later the Lukuga was still blocked and is now flowing.

As has already been pointed out (p.7) this intermittent regime of the outlets is due to morphological as well as to climatic causes and, furthermore, the morphological causes can be accelerated by human activity. Thus, either there is no periodicity in the climatic changes, no long amplitude cycle which might determine this intermittency; or, should there be such a cycle, the assisting morphological causes must be assumed to be of sufficient magnitude and importance to delay or expedite, as the case may be, the building up or the destruction of the temporary barrier to such a degree as to veil very successfully the purely climatic causes. The problem requires, therefore, for its solution not only a long continued study of the levels on those lakes which, by possessing a permanent outlet, will give better insight into the existing cyclic variations of climate, but also a very careful analysis in the field, of the epigene geological forces, their influence on surface morphology and their interaction with human activity in as far as they contribute, together with the vegetation, to the formation and destruction of the barriers. That we are, thus, still far from a satisfactory solution need not be emphasized.

Under the circumstances the present writer must be permitted to differ from Dr. Dixey when he says [7,pp.2/3]: "Since these (climatic) factors have clearly caused the levels of Lakes Victoria and Albert to fall since the predicted (sunspot) maximum of approximately 1928, it is reasonable to suppose that their influence will similarly affect Lake Nyasa within a few years at most." For, first of all, Tanganyika, Victoria and Albert have all risen since their descent from the 1927 maximum to a secondary minimum in 1929, and Tanganyika as well as Victoria are still rising (no data are available for Lake Albert after 1930); and secondly, as precipitation on the lake plus inflow exceeds evaporation in the average year (*vide* Table V), the rise of Lake Nyasa should continue, with a fair degree of probability, until it overtakes the barrier-building geological forces through over-spilling and back-scouring.

In summing up the results of the foregoing comparison one arrives at the following conclusions: the three great and one smaller lake which fill tectonic depressions in the high "back-bone" of Eastern Central Africa are all situated on, or in the neighbourhood of, the marginal belt separating a sub-arid from a sub-humid climate, but all, largely owing to their tectonic origin, also border on areas of higher rainfall. Tanganyika, occupying the westernmost position in the great westward sweep of the 1000mma isohyet, is truest to type; Nyasa to a lesser and Victoria in more pronounced degree reach with their tributary basins into the sub-humid belt situated, as they are, within the great southern and northern eastward bulgings of the same isohyet; while the basin of Lake Albert is already sufficiently far removed from the marginal belt to penetrate at least in parts into a humid climate.

While all four lakes, thus, share climatic peculiarities, including periodic climatic changes, of a regional character, there exists a well marked grading within this larger region which results, on the one hand, in a varying intensity of the general factors which determine the regime of each lake and, on the other hand, in a distinct difference regarding their present geographical history: Tanganyika and Nyasa, the first somewhat more pronouncedly, lie so close to the margin of a definitely sub-arid climate that certain small changes of climate, periodic or otherwise, in the direction of aridity will, with the assistance of corresponding morphological changes, temporarily interrupt their discharge to the sea; while Victoria and Albert, at the other end of the marginal series, lie so near the sub-humid belt that it would require a very marked change of climate to deprive them even temporarily of their outlets. Any comparative discussion of observations connected with the regime or the history of these lakes must, therefore, be conducted with an eye on both the regional similarity of their general setting and the individual peculiarities of their basins. Only thus can one hope to arrive at a correct synthesis and at correct predictions regarding the future course of events.

X.—Correlation with Solar Activity.

In 1923 Dr. Brooks of the Meteorological office published his well-known graph [1] showing that for a period of nineteen years (1902 to 1921) there existed a correlation co-efficient between sunspot numbers and the level of Lake Victoria of + 0·82 for monthly figures and rising to + 0·90 when annual means were used; a correlation so striking that Sir Napier Shaw [24a, Vol.II,p.6] calls it the most effective relation thus far established.

These interesting investigations were extended to Lake Nyasa by Dr. Dixey [4-7] with the remarkable result that a curve-parallel exhibited fluctuations almost exactly resembling those of Lakes Victoria and Albert, and thus a similar correlation with sunspot variations, until 1924 when, owing to terrestrial reasons fully explained (*vide* p.17), the similarity ceased. As Dixey put it in 1924 [4,p.3]: "The level of Lake Nyasa varies in close sympathy with the number of sunspots."

The present paper has, at long last, afforded an opportunity for including Lake Tanganyika in these investigations, Appendix III now showing for the first time the curve parallels for sunspot numbers and levels of all four Central African Lakes. From this it will be seen that Tanganyika, too, follows closely the variations of Victoria and Albert during the period (1911-1931) for which accurate data are available. Through the courtesy of the Director, Meteorological Office, Air Ministry, who very kindly supplied the necessary data, it has been possible to extend Dr. Brooks' original sunspot graph thus bringing it up to date.

An inspection of these latest graphs shows that parallelism between sunspots and lake levels (always excepting Lake Nyasa with its recent explained abnormality) continues very satisfactorily from 1922 to 1928. In 1929, however, when all three lakes stood at a distinct minimum, sunspot numbers again soared up and their rapid decline during 1930 and 1931 is countered by an unexpected steady rise of lake levels which, at least in the case of Tanganyika for which alone the latest maximum is known at the time of writing (772·60), is continuing into 1932. A glance at Dr. Brooks' earlier graph will show that something similar, though in the opposite direction, had happened just prior to the period for which his remarkably high correlation co-efficients were computed, in as much as in 1900/1901 high water in Lake Victoria coincided with a pronounced sunspot minimum. Lake Nyasa, *vide* Dr. Dixey's graph [4,p.1] on the other hand, reacted "correctly", its level standing at a minimum from 1900 to 1902. The abnormal high level of Lake Victoria in 1878 [1,p.343;20,p.81] at a time of sunspot minima would likewise seem to illustrate a break in smooth correlation.*

It will thus be seen that, as one extends observations both in time and space, certain irregularities appear and although these may not in the aggregate reduce the high correlation co-efficient to such an extent as to render its value problematical, their existence must either be accounted for by direct reasoning or must be taken as a warning against premature generalizations. And if one who, like the present writer, is hardly competent to venture into a field somewhat removed from his ordinary preoccupations may be forgiven for doing so, he would suggest that the sunspot numbers which we observe and use are, after all, only an indication or, at best, part of the totality, of solar activity and that a much fuller understanding of this totality and of its interaction with the terrestrial atmosphere might, conceivably, wipe out or explain much that at present looks "irregular."

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*It is interesting to note that Lake Gombo, a shallow intermittent lakelet in the great transverse valley of the Mukondokwa through the East African Rand Mountains [11] which only fills in years of exceptionally heavy rainfall over some typically arid contributary basins, shows the following very close correlation :

Sunspot Maximum.	Lake Gombo.
1873	1873 full
1884	No record.
1895	1894-1897 full
1906	1907 full
1917	1919 full
1925-1928...	1927 full

In 1930 it filled again unexpectedly, thus imitating the "irregular" rise of the Great Lakes.

Such fuller understanding would also, in all probability, help towards a correct grasp of the actual sequence of events which connect lake levels to sunspot variations or solar activity, a sequence which is by no means as yet clear. That evaporation plays an important role is obvious; that rainfall is "certainly an essential factor" [Dixey,6,p.335] has again been proved, it is believed, in the present paper, both as regards precipitation on the lakes proper and over their tributary basins; and that increased evaporation from a solarised water surface must increase the amount of vapour in the atmosphere above the solarised water which fact, in its turn, must affect conditions of the atmosphere over the adjoining land surfaces, has not only been authoritatively stated by Sir Napier Shaw [24a,Vol.II,p.339] but is self-evident to anyone who has watched this impressive process over Lake Nyasa and the Livingstone Mountains [10a,p.103], where sunshine and steamy haze over the lake, high cloud and rain on the mountains make it so visibly clear.

Enough has been said to show that we are still far from a solution of the problems set by the fluctuating levels of the Great African Lakes. On the other hand, it is hoped that the additional material gathered in this study of Lake Tanganyika may, in more competent hands, assist towards a fuller recognition of the interdependence of cosmic radiations and terrestrial happenings.

Dar es Salaam,
6th June, 1932.

C. GILLMAN.

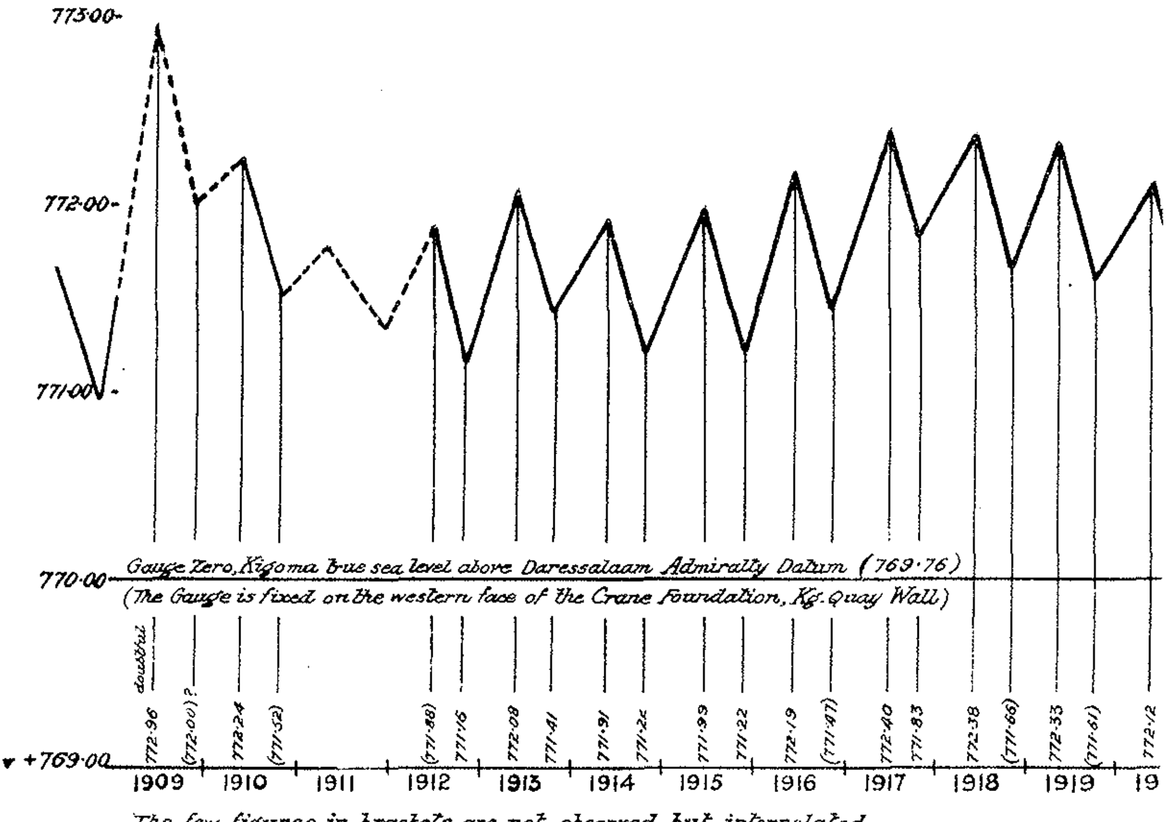
APPI

LAKE TANGANYIKA, FLUCTUA

(No records being available for 1911 and 1921 the graph .

This Chart has been comp

1909 - 1916 Ger.
1917 Belg
1918 - 1920 Thee
1922 Belg
1923 - 1928 Dist
1929 - 1931 T.R



The few figures in brackets are not observed but interpolated by using the mean value (0·70 m) of annual fluctuation

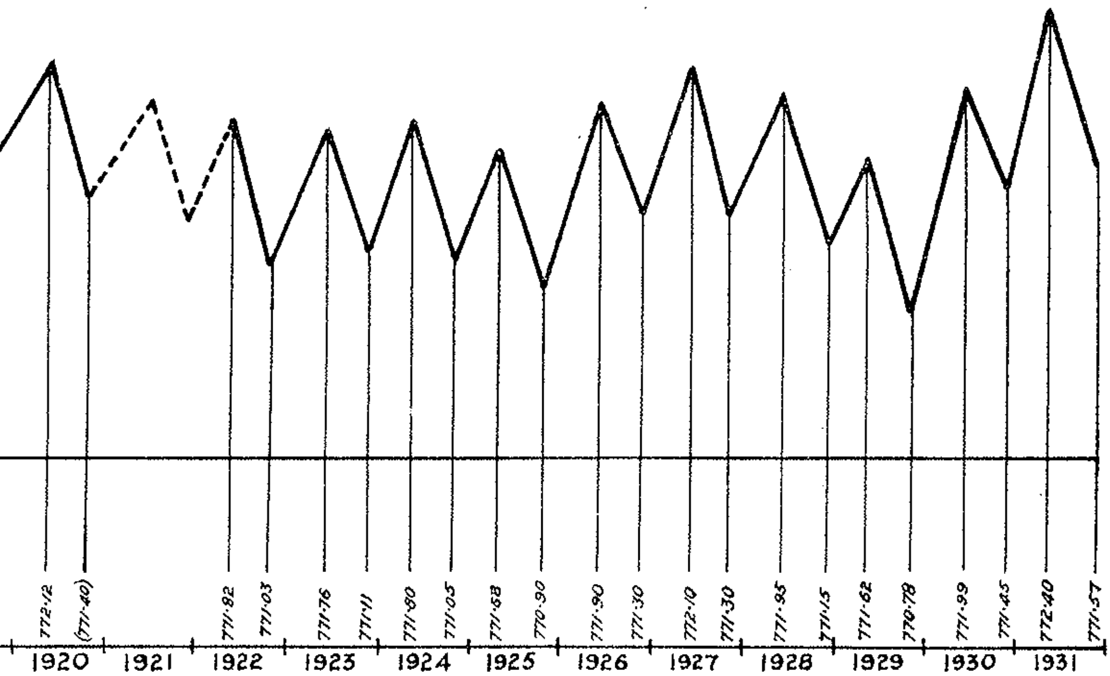
H.H.W.

ıPPENDIX I.

ATIONS OF LEVELS, 1909 TO 1931

ph has been completed by interpolation shewn by broken line)

ompiled from the following records
German Rly. File XXVIII T.B
Belgian military Graph
Theeuws "Le Lac Tanganyika"
Belgian Records of Albertville
District Officer's Records Kigoma
T.Rlys. -do- -do-



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Appendix II.

HISTORY OF GERMAN GAUGES AT KIGOMA.

(*Vide* German Railway Commissioner's File XXVIII T.B.).

The First Gauge was erected in February 1913 just off the East coast of Nyansa Peninsula, north of the slipway. It was fixed by 3 B.M.s. Its Zero was checked in February 1914 and was found to have risen 8mm.

On 23rd September, 1914, the gauge was upset and re-erected on the old site.

In October 1914 it was run over by a steamer and re-erected near the corner of the slipway. On 1st November, 1915, it was shifted to the West side of the 20-ton Crane Foundation on the quay-wall.

The Gauge Zeros for these periods are as follows (true sea level Dsm. German datum, differing from Railway levels by 2·356 or, say 2·36m).

PERIOD		GAUGE ZERO	
From	To	Expressed in true height above Dar es Salaam Sea Level	Expressed in terms of Railway Long. Sect. Levels
III 1913	XII 1913	769·33	771·69
I 1914	IX 1914	769·34	771·70
X 1914	X 1914	769·59	771·95
XI 1914	X 1915	768·72	771·08
XI 1915	V 1916	769·88	772·24

During the Belgian occupation, December 1916 to April 1918, records were taken on the same gauge (Zero 769·88 above true sea level).

From January 1923 to December 1929 readings on the same gauge were taken by the District Officer, and from January 1929 to date by the Railways (P.W.I.). The District records use Zero=772·40, the Railways 770·00. The 772·40 Zero was determined by the District Officer (Longland) in 1922 from the B.M. (value engraved) on northerly slipway winch foundation. The District Officer did definitely *not* alter the German Gauge and there is no record that the District Engineer did.

There are, at present, *three* datums at Dar es Salaam (*vide* Marine Superintendent's KWL/23 of 30th October, 1930):

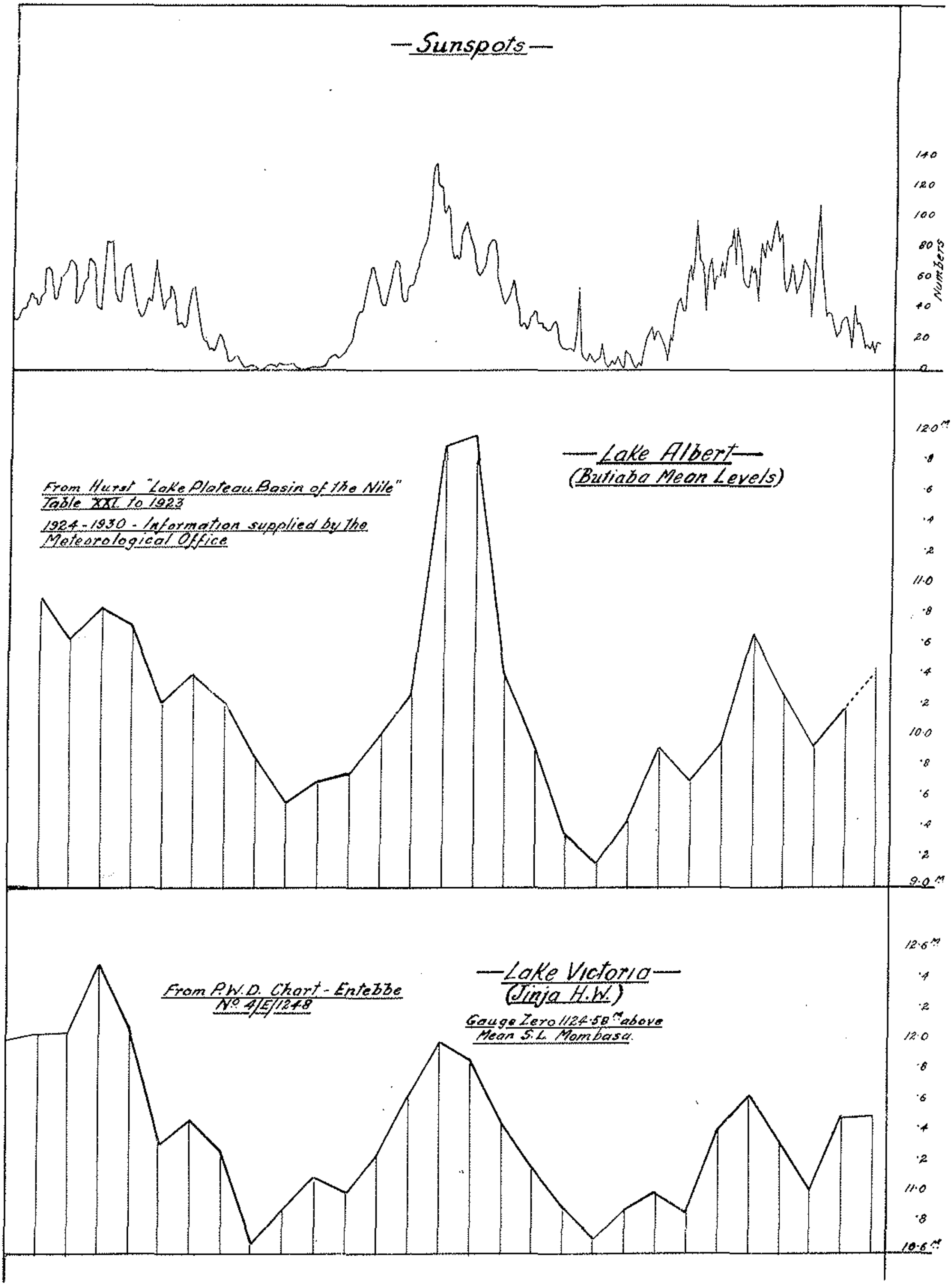
(1) The P.W.D. or Harbour datum
L.W.O.S.=30·39 feet below Post Office B.M.
(2) The Admiralty Chart datum
1 ft. below (1).
(3) The German datum
1·45 ft. below (1).

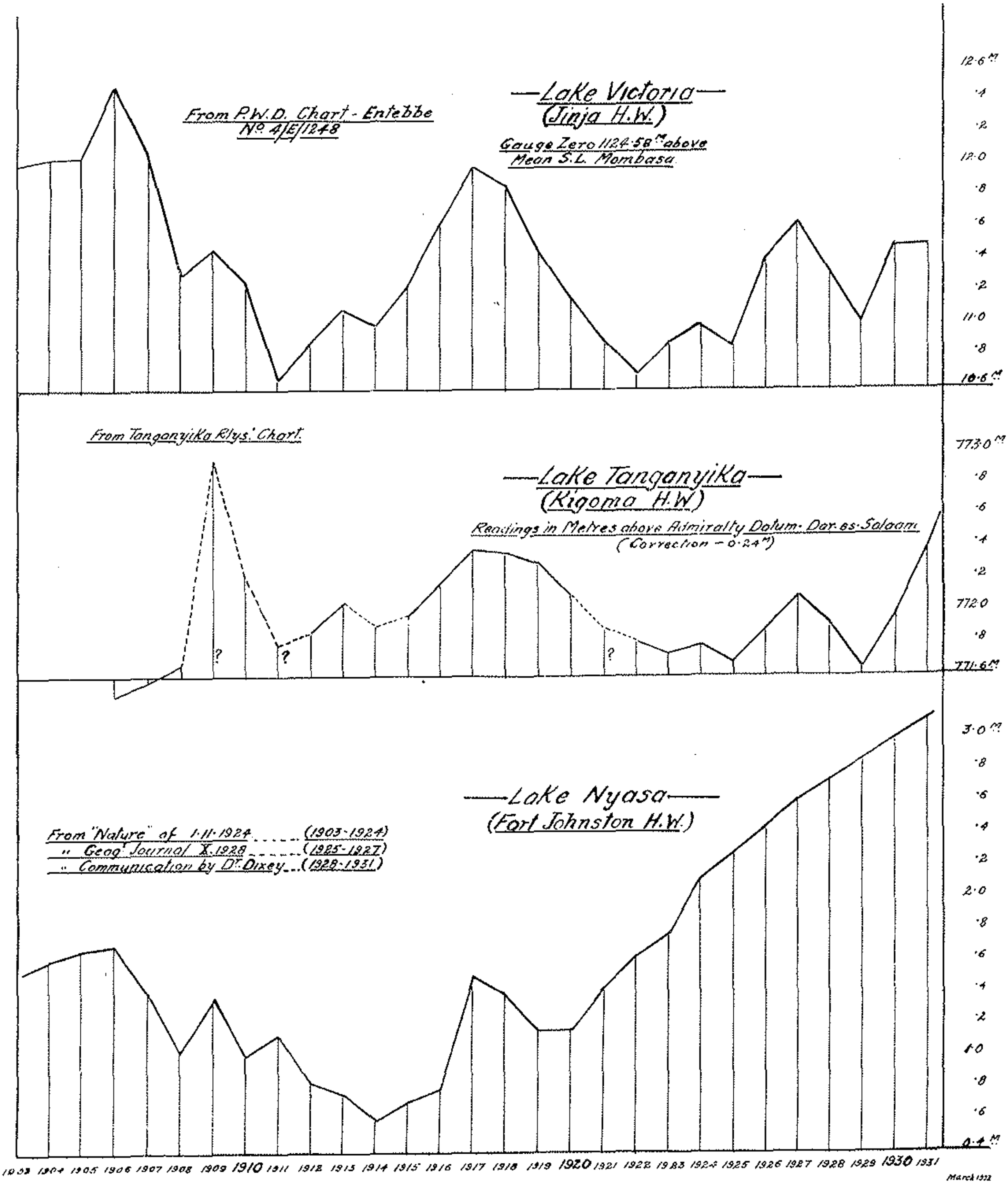
Thus the Admiralty datum is 0·45 ft. or 0·1219m *above* the German datum and it will be seen that the value of 770·00 now used for the Kigoma gauge Zero does not tally with either of these Dar es Salaam datums, the corrections to be applied being 0·12m for German and 0·24 for Admiralty datum respectively.

As this gauge Zero has the advantage of a full metre (without decimals) and thus of easier computation it is proposed to retain the same in future.

As regards *Belgian Records at Albertville* (covering the years 1922 to 1931) as well as those given in Belgian literature prior to that date, investigations have thus far been unsuccessful to find out what gauge Zero they are working to. As, however, one of Mr. Theeuws' figures (for 1912) definitely refers to and tallies with the German Kigoma reading it seems plausible that they have merely transferred the German value to their shore of the lake which, though of course not strictly correct, is better than any other method under the circumstances. A comparison between the continuous observation from 1922-1931 at Albertville and Kigoma furthermore shows good co-ordination. The Albertville records, therefore, where used, are expressed in Kigoma Gauge Zero. As they refer to the German railway values they must be reduced by 2·84m to obtain true sea levels above Dar es Salaam Admiralty datum.

COMPARISON OF LEVELS - EAST AFRICAN LAKES





—Lake Victoria—
(Jinja H.W.)
From P.W.D. Chart - Entebbe
No. 4/E/1248
Gauge Zero 1124·58 M above
Mean S.L. Mombasa
12·6 M
·4
·2
12·0
·8
·6
·4
·2
11·0
·8
10·6 M
From Tanganyika Rlys.' Chart.
—Lake Tanganyika—
(Kigoma H.W)
Readings in Metres above Admiralty Datum · Dar-es-Salaam
(Correction − 0·24 M)
773·0 M
·8
·6
·4
·2
772·0
·8
771·6 M
?
?
?
—Lake Nyasa—
(Fort Johnston H.W.)
From "Nature" of 1·11·1924 .... (1903-1924)
" Geog' Journal X.1928 .... (1925-1927)
" Communication by Dr. Dixey ... (1928-1931)
3·0 M
·8
·6
·4
·2
2·0
·8
·6
·4
·2
1·0
·8
·6
0·4 M
1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931
March 1932

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Note.—Halbfass [12,p.516] mentions two dissertations on Lake Tanganyika, written in 1920, which are unfortunately not available.

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