A REVIEW OF THE HYDROLOGY OF LAKE VICTORIA AND THE VICTORIA NILE

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1. THE BACKGROUND TO THE PRESENT STUDY

The problem of the hydrology of the Lake Victoria basin may be expressed briefly: can the components of the balance be assessed, not only in average terms but also over the historic record, and was the rise in the lake in the years 1961-64 a temporary or a longer-term change in the regime?

The problem is complicated because the two major items in the balance are rainfall and evaporation over the lake surface, which can only be estimated indirectly. The average rainfall and evaporation are almost equal, and the lake balance completed by tributary inflows, lake outflows and level changes, is therefore very sensitive to changes in rainfall. This sensitivity is illustrated by the rise in lake levels and outflows in 1961-64 in response to an increase in rainfall of about 20%. The lake level rose 2.5 m in 3 years, which is equivalent to a storage increase of 170 milliard m^3 or over 8 years of lake outflow at the 1960 rate. The outflow increased 2½ times between 1960 and 1964 in response to this rise in lake level. The lake levels and outflows have fluctuated since 1964 but at a higher level.

The main studies have been those of Hurst (1938) and the Egyptian Irrigation Service and the WMO Hydrometeorological Survey (1974, 1981) of the lakes, but useful information has also been provided by Morth's (1967) study of the meteorological aspects, Grundy's (1964) analysis of the floods of 1961-62 and de Baulny and Baker's (1970) analysis of the water balance of Lake Victoria. Supplementary information is given by the WHO (1978) study of the surface water resources of Kenya, while a longer time scale is provided by Nicholson (1980).

1.1 RELEVANT STUDIES OF THE HISTORIC REGIME OF THE NILE

Much of the early survey of the Nile basin was carried out by the Egyptian Irrigation Service and Physical Department, and the current knowledge was described by Hurst and Phillips (1938) in The Nile Basin, Volume V, The hydrology of the Lake Plateau and Bahr el Jebel. They pointed out that data were scanty, comprising lake levels for

20-30 years and rainfall observations at some stations for the same period. The balance is estimated as lake rainfall 1151 mm, tributary runoff 276 mm, mean outflow 311 mm and the evaporation is therefore 1116 mm. Although Hurst measured the flow of the Kagera as early as 1926, the estimates of the runoff of the rest of the Lake Victoria basin are described as "rough guesses based on a knowledge of the character of the country and the streams"; nevertheless they are remarkably accurate.

In discussing the outflows from Lake Albert which date from 1904, they point out that the average discharge at Aswan from 1871 to 1898 is much greater than the average from 1899 to 1936. They quote evidence of a qualitative nature about the levels of Lakes Victoria and Albert from which one might "infer that from 1870 to 1900 high floods seem to have been more common than in the period following 1900". They conclude that the ordinary theory of sampling cannot be applied to the discharge of the Nile at Aswan to determine how long the low series which began about 1898 is likely to persist and that similar conclusions apply to determining a long period average for the discharge out of Lake Albert. These observations are very pertinent to the present problem of predicting how long the present high Lake Victoria outflows might persist.

Lamb (1966) describes the evidence for high Lake Victoria levels 10-20 years before the lake gauges were installed in 1896 (Figure 1.1). Catholic missionaries in Buganda reported that around 1876-80 the average water level was about 8 feet (2.4 m) higher than in 1898 or, as Lamb points out, about 0.5 - 0.7 m above the 1964 peak. He also quotes further details; the lake was high in 1878-9 and was falling from 1880 to 1890, then recovered somewhat to higher levels between 1892 and 1895, followed by a steady fall of 2 feet (0.76 m) in seven years to 1902.

This account is amplified by Lyons (1906) who draws on a number of travellers observations of the very high level in August 1878 and fall of 8-9 feet (2.5 m) by 1891, followed by the rise in 1892-95. He even quotes a farmer's account of a rise of about 1850 which inundated plantations which were uncovered about 1890. The 1878 peak is

Monthly Lake Victoria levels, 1896—1979

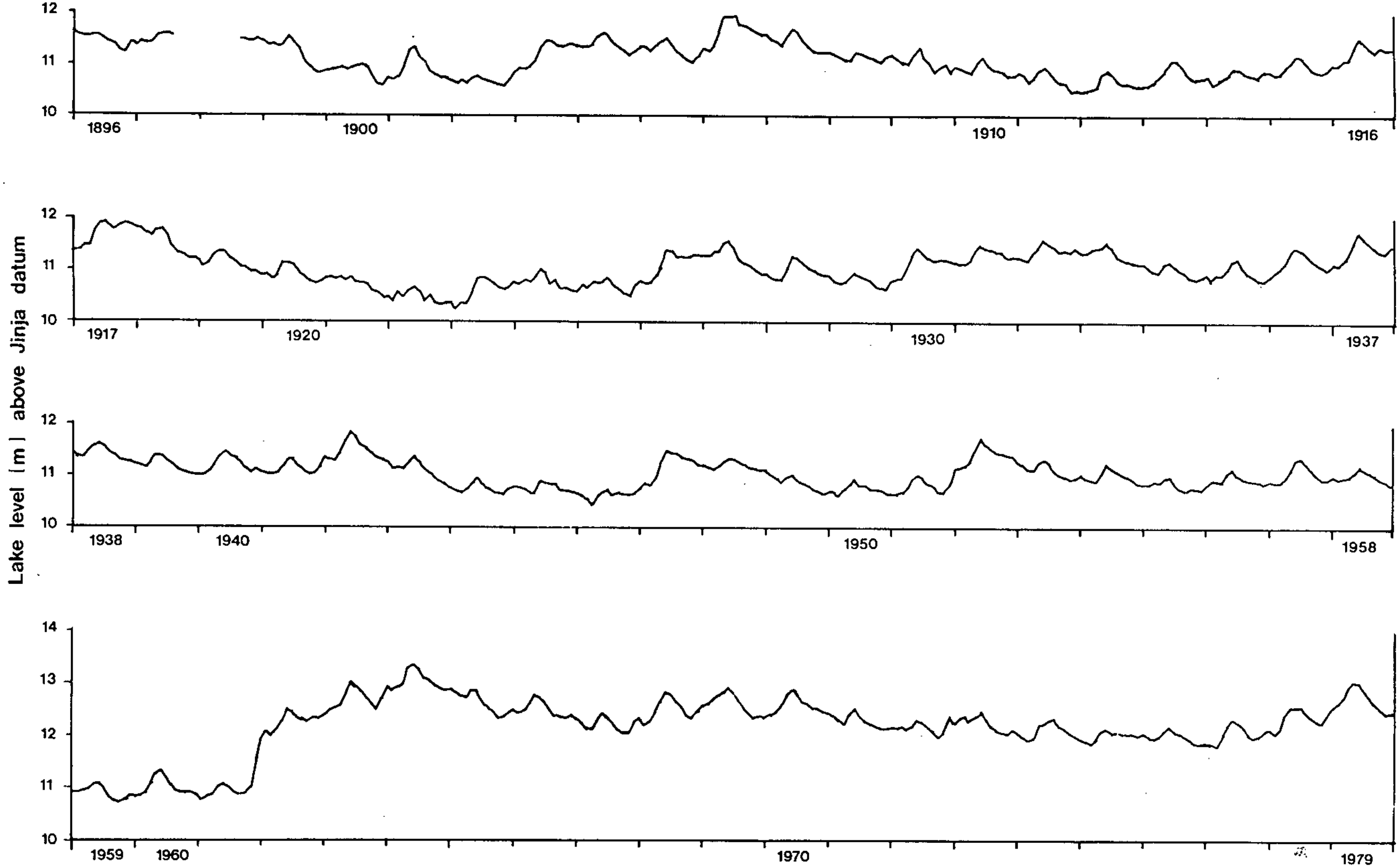


Figure 1.1

supported by observations of the Bahr el Jebel at Lado (Lyons, p103) which reached a maximum in August 1878 but was still very high in December 1878, pointing to an unusually high level of Lake Albert and therefore Lake Victoria.

Another source of information supports the evidence that outflows from the East African lakes were high in the period before 1895. The areas flooded in the Sudd are directly related to flows in the Bahr el Jebel and thus to the outflows from Lake Victoria (Sutcliffe and Parks, 1982). Early accounts (1870-85) describe the immense herds of cattle above Mongalla, where in the 1950s there were few cattle and little grazing (Jonglei Investigation Team, 1954). Sutcliffe (1957, 1974) suggested that the discrepancy could be reconciled if the high flows of the last century had provided grazing in this area; he observed (March 1982) that the present high flows have indeed provided grazing for large herds above Mongalla.

Evidence from a wider area and a longer time-scale is summarised by Nicholson (1980), who presents lake levels, Nile flows and rainfall information derived both from measurements and historical evidence. From long-term Nile levels at Cairo, a number of fluctuations in river flow from the East African lakes are deduced. The return to wetter conditions in the late 19th century is also supported by variations of the levels of East African lakes. Evidence is presented of a number of climatically anomalous periods, including above normal precipitation from about 1875 to 1895; however, studies have not yet led to a meteorological explanation of the changes.

These studies show that the rise in lake levels in 1961-64 was not a unique event and that similar fluctuations have occurred in the past in association with fluctuations in rainfall. In the absence of fundamental explanations the method of study must be a statistical analysis of the records.

1.2 STUDIES OF RECENT CHANGES IN LAKE REGIME

The lake rise of 1961-64 led to several studies of the available data. Morth (1967) concentrated on the meteorological records and specifically on the relationship between monthly rainfall and changes in lake level. He used average rainfall over all the available stations in the lake catchment area, which increased from 150 stations in 1938 to 300 in 1963. The coverage was very uneven with more than half in the northeastern Kenya corner of the lake catchment and none in Rwanda or Burundi. Neverthless, he obtained reasonable linear relations for each calendar month between the rainfall on this catchment network and lake level change. He tabulated the monthly rainfall series for the period 1938-64. This series is a reasonable indication of the rainfall on the important Kenya tributaries.

Another study of the available data was carried out by de Baulny and Baker (1970). They deal with each item of the balance in turn. On lake rainfall, they argue that rainfall should be constant over most of the lake, with sharp gradients near the shore. They compile mean monthly isohyets using 17 long-term stations near the lake, and deduce a mean annual rainfall of 1650 mm. To derive monthly lake rainfall, they used the records of 8 stations (Jinja, Entebbe, Kalangala, Bukoba, Kagondo, Mwanza, Musoma, Kisumu) to reconstruct a consistent record for the period 1925-1969. From a comparison of the monthly isohyetal map with monthly averages for the eight long-term stations, coefficients were drawn up for each calendar month which gave a weighted mean of the 8 records to represent monthly lake rainfall. This record, reproduced in Appendix A, gives an overall mean annual rainfall of 1674 mm, with a maximum of 2201 mm in 1961 and a minimum of 1281 mm in 1949.

Tributary inflows into the lake are taken by de Baulny and Baker from an analysis by the Hydrometeorological Survey, and the annual discharges of 17 selected streams for the period 1959-67 are reproduced as Annexe IV. This table is noted as "extracted from unpublished report - HYDROMET 1970", but no further details are given. As most of these streams were not measured until 1969, a number of these annual flows must have been based on comparison, perhaps of catchment rainfall, with the streams which were measured. The Kagera flows were available from 1940, and it was noted that the 1959-67 period was particularly wet. The average total inflow is estimated as 17.90 milliard m^3 or 260 mm over the lake.

Changes of storage are computed from the gauge records at Entebbe for 1900-1912 and at Jinja for the period 1913-1969; Jinja level is chosen to represent lake level as it controls the outflow.

Outflows were calculated according to a relationship between Jinja levels and flows over the Ripon Falls, which was obtained by model rating to extend the earlier agreed curve on which the dam was operated to reproduce natural river outflows.

Evaporation was estimated from the water balance for the period 1925-1959, omitting the exceptional period after 1959. Evaporation is estimated by de Baulny and Baker as:

J	F	M	A	M	J	J	A	S	O	N	D	Total
151	130	133	118	113	142	142	115	119	127	144	138	1572 mm

A study of the water balance for the years 1960-1969, when the average rainfall is estimated as 1826 mm, suggests that the evaporation was reduced by about 10%. A curve is given which suggests that evaporation increases with rainfall to a peak of 1700 mm when rainfall reaches 1650 mm and then decreases; however, this evaporation includes all the errors and uncertainties of measurement.

1.3 THE WMO HYDROMETEOROLOGICAL SURVEY

The gaps in information in all these studies have been the lake rainfall and tributary inflow, measurement of which became the immediate task of the WMO Hydrometeorological Survey which started work in August 1967. The objectives of the Survey were to study the water balance of the Upper Nile and to plan development and co-operation in the regulation and use of the Nile. A large number of stations were established (WMO, 1974) including 25 meteorological stations, 200 raingauges, lake stations, tanks and lysimeters, and 60 hydrometric stations including 45 stream gauging stations. A Data Centre was established and a series of Yearbooks were compiled for meteorological, rainfall and river flow data. Seven small index basins were selected for intensive study of rainfall-runoff relations.

The four volume report of Phase I of the Survey (WMO, 1974) described the objectives of the study and the observational network. It summarises the characteristics of the area and the climate. The influence of the inter-tropical convergence zone and its migration is complicated by low pressure over Victoria. The resulting wind system strongly affects the distribution of rainfall around the lake, with land and sea breezes playing a significant role.

A network of 22 rainfall stations was selected for statistical analysis of the period 1931-70. Analysis of the seasonal distribution of rainfall during extreme rainfall years showed that excessive rainfall years (eg 1951, 1961) are associated with abnormally heavy rains in the October-December season, while during dry years the deficits occur in the October-March period. Monthly and annual rainfall series were compiled for Lake Victoria and its land catchment using weighted means of 10 and 17 stations. The annual rainfall series are tabulated for 1931-1970 as departures from average. We have compared these series with those of de Baulny and Baker and Morth; the annual rainfall on the lake is well related to the land catchment rainfall.

Measurements of evaporation from Class A pans were compared with estimates made using the Penman, Kohler and Dalton approaches. In a normal year the different estimates range from 1473 to 1496 mm, but the monthly patterns differ.

The measured inflows from 21 tributaries in 1969 and 1970 are the first contributions of the investigation programme and these are tabulated, with estimates of the ungauged inflow in these years. We have used these inflows in our analysis.

Comparisons of outflow computed from the agreed curve, with measurements at Namasagali and at Mbulamuti are discussed. Outflows for the period 1946-70 are tabulated, and the 1946-61 mean outflow of 20 milliard m^3 is compared with the 1962-70 mean outflow of 44 milliard m^3.

The changes of storage are tabulated and water balances are drawn up for 1969 and 1970 and for a normal year. They conclude that rainfall over the lake exceeds the land rainfall by 50% in a normal year, that rainfall exceeds evaporation by about 10% and that rainfall is about six times the inflow and three times the outflow.

Following the completion of Phase I of the survey, the network of measurements continued, and Phase II of the survey was funded from 1975 to 1981. The survey included the formulation of a mathematical model representing the Nile system, evolution of various alternative patterns of regulation of the East African lakes, as well as continuing hydrological studies and training. The study was described in a single volume report (WMO, 1981) and the hydrological aspects have been described by Kite (1981, 1982).

A major component of the survey was the development of a mathematical model of the system by the Snowy Mountains Engineering Corporation, comprising a catchment model to estimate tributary inflow, a lake model for water balance accounting and a channel routing model. It was used to evaluate control plans, and could be used to examine the effects of proposed projects on the whole system.

In the continuation of earlier hydrological studies, evaporation was studied by water balance and heat budget methods, and was estimated as 1594 mm for the 1970-74 period; it is argued that annual changes should be small. Various models of isohyetal distribution for the lake were studied, but the choice of model is less critical than the availability and accuracy of basic data. The measurements of tributary flows continued and were compiled in annual yearbooks.

A monthly water balance of Lake Victoria was run for the years 1950-80 using lake rainfall, evaporation and tributary inflow data to estimate lake levels and lake outflows (Kite, 1981). Because this did not duplicate the observed rise in lake level, it was considered necessary to reconsider the basic data. Whereas the Hydrometeorology Project used shore and island stations for the years after 1970, the data were scarcer before 1970 and no island stations were available. The tributary inflow data were also scarce and were estimated from Kagera flows in the early years. A detailed study of the period 1977 to 1980, when the lake rose by 1.5 m, showed that the rise could have been caused by rainfall between 25 and 30% higher than those recorded.

The lake balance can be deduced either from lake rainfall, tributary inflow and evaporation, or by adding lake outflow to changes in storage to derive net basin supply. Because the lake levels could give a longer series of records, these were used as the basis of time series analysis.

The basic data are presented in Annex 3 of the Phase II report, in particular monthly lake levels and outflows; a lake area-capacity table is presented in Annex 5. Recent changes in level of Lake Victoria are discussed in Annex 7 and the monthly rainfall and tributary inflow data used in the mathematical model are listed.

The concluding paragraphs of this annex summarise the hydrological findings of the survey. The rises of 2.5 m in 1961-64 and of 1.5 m in 1977-80 are unusual but are confirmed by independent gauges and by similar rises at the same time on other lakes in East Africa. The only possible man-made cause is the Owen Falls dam, but it was found that this dam was the cause of only 0.03 m of the total rise over 1957-80. Most of the observed rises in lake level must therefore be due to natural causes. However, neither a simple water balance nor use of a mathematical model have been able to pinpoint the exact cause; this is believed to be due to inaccuracy of data on over-lake rainfall and evaporation. Use of the model has shown that increase in precipitation of 25-30% above the long-term mean could have caused the observed rise in lake level in 1977-80.

A number of time series analyses have been carried out on Lake Victoria records. Hurst's early researches on storage range were based on Nile flows, and showed that these and other natural phenomena contained groups of high and low years which resulted in a larger range of storage than would result from random variations.

Kite (1982) analysed monthly Lake Victoria levels and showed that the series contained large linear trend components, largely caused by the step in lake levels in 1961-64, which could only be modelled by incorporating a random jump component.

A variety of stochastic models have been proposed for the study of the Lake Victoria records, and a review is presented by Salas et al (1982). A posible model for the outflows is the autoregressive moving average (ARMA) model, but the historical series might require a nonstationary model. A realistic alternative suggested is an autoregressive model with a highly skewed random component. Another model incorporates a pulse input attenuated to produce a gradual decay in the output, but for prediction these pulses should occur at random. The complexity and ease of application of these models vary, and a reasonable aim might be a simple model which adequately reflects the historical information and can provide realistic predictions.

1.4 AIMS OF THIS STUDY

This summary is a useful point to recapitulate our knowledge of the lake system and to describe the aims of the current study. Although the rainfall on the lake area (69,000 km^2) is the most important source of supply, it is supplemented by tributary inflow from a much larger catchment (194,000 km^2). This tributary flow is sensitive to increases or decreases in rainfall and is therefore more variable from year to year than the rainfall itself. Because the average rainfall is almost balanced by lake evaporation, which is likely to vary little from year to year, the net basin supply is unstable and extremely sensitive to variations in rainfall. Moderate variations are highly damped by the very large lake storage without marked changes in lake level or outflow, but the sensitivity of the system means that extreme rainfall years have a disproportionate effect on the net basin supply. There is indirect evidence from the Nile downstream and from other information that similar fluctuations in lake level and outflow have occurred in the past.

Because analysis of individual hydrological components is more likely to lead to an understanding of the underlying causes and persistence of the apparent change of regime in 1961-64 than a study of the net basin supply alone, we decided to examine the basic data for each component and attempt a new synthesis of the water balance. If the changes in lake level and outflow could be related to rainfall and the tributary inflow, and the latter could also be related to rainfall, then time series analysis and the prediction of future rainfall and lake balance can be based directly on the rainfall series.

In the scale of this study, we have relied heavily on earlier studies and investigations. We have relied particularly on the large programme of field measurements of the WMO Hydrometeorological Survey. Most of the basic data collected in Phase I of the study were presented in the report (WMO, 1974). The report of Phase II (WMO, 1981) is supplemented by Yearbooks currently covering the period 1970-1979 in terms of river flows. The available data were kindly made available to us by the WMO Hydrometeorological Survey at the request of the Uganda authorities. Other sources of information have been reports of the hydrology of the Kagera basin, and a summary of river flows measured in Kenya in the years up to 1970 (WHO, 1973). Some of the records used in other studies are also available in de Baulny and Baker (1970).

2. THE COMPONENTS OF THE WATER BALANCE

2.1 INTRODUCTION

The various studies which have been carried out on the hydrology of Lake Victoria have been described. In this chapter we discuss the basic data which we have used, their sources and their assembly. Because the records are by no means straightforward, we have had to describe them in more detail than usual.

The major source of data was the WMO/UNDP Hydrometeorological Survey of the East African lakes. During the two phases of this survey a large programme of field measurements was established and two reports were prepared. In the first of these, which contained four volumes, most of the basic data collected were published; the second report, in a single summary volume, is supplemented by Yearbooks currently covering the period 1970 to 1979 in terms of river flow measurements.

Other sources of information have been various reports on the hydrology of the Kagera basin, the major tributary of Lake Victoria, and a summary of river flows measured in Kenya in the years up to 1970 (WHO, 1973). Some of the records used in this and other studies are drawn from de Baulny and Baker (1970).

2.2 RAINFALL

The records for eight long-term rainfall stations were used by de Baulny and Baker (1970) to reconstruct a consistent monthly rainfall record for the lake surface for the period 1925-1969. Coefficients for each calendar month gave a weighted mean of the records to represent monthly lake rainfall. This record, reproduced as part of Appendix A of this report, gives an overall mean annual rainfall of 1674 mm, with a maximum of 2201 mm in 1961 and a minimum of 1281 mm in 1949.

As a result of the installation by the WMO Project of additional gauges around the lake and on island sites, subsequent records were compiled for the period 1970-1977 by isohyetal analysis of monthly rainfalls (WMO Phase II Report, Annex 7, Table 5). For the period 1978-1979, when the network was not complete, monthly figures were derived (WMO) from the averages of data from Kisumu (2 stations), Rusinga Island, Nyakach Bay, Bukoba (2 stations), Mwanza and Musoma.

Although the total rainfall record compiled by WMO takes account of the records available in each year, and in particular takes advantage of the additional gauges installed during the project study, it is not compiled in an identical manner over the whole period. A detailed study of the recent years suggests that even in 1977 a 25% underestimate of the lake rainfall is possible. One must therefore agree with WMO (Kite, 1981) that over-lake precipitation is extremely difficult to estimate accurately.

In statistical extrapolation from past records to the future, using as long a period of records as possible, it is perhaps preferable to use a homogeneous set of records than to have early records compiled by one method and recent records estimated by a quite different method, even if the recent records should be more precise because more stations were available.

Because the de Baulny and Baker rainfall series covers the longest available period, 1925-1969, their method of estimation was carried forward to 1970 and subsequent years using the same eight stations and coefficients. In the later years, 1978 and 1979 in particular, the Uganda records were incomplete and the estimates are less reliable. Also, Kalangala was unavailable and Bumangi was substituted, while Kagondo was estimated from Bukoba. Nevertheless, the record, which is reproduced in Appendix A, is intended to be continuous with the earlier record.

It is interesting to compare this record with the WMO estimates. The means for the period 1970-1977 are comparable, 1692 mm against 1759 mm. However, the annual estimates range from 83 to 115% of the corresponding WMO estimates. This illustrates the problems of estimating rainfall over a large lake from a small number of gauges around the shore. The WMO estimates take into account a model proposed by Datta (1981) of rainfall over the lake. This is based largely on observations of the timing of rainfall on the east and west shores; the interaction of lake and shore breezes and the prevailing easterly winds, gives rise to convection storms in the morning on the west shore and in the evening on the east shore.

Before accepting the de Baulny and Baker rainfall series as representative of lake rainfall over the historic period it is possible to compare it with the Morth series of average basin rainfalls. Figure 2.1 shows the comparison of annual calendar year rainfalls from the two series and indicates that 1962 rainfall is a significant outlier to the general trend of agreement. We do not have the basic records to examine this discrepancy in detail and we must make a broad judgement about lake rainfall in 1962 on the basis of this evidence and the knowledge that the lake response in that year was consistent with a much higher rainfall than that given in the de Baulny and Baker series. Accordingly and pending detailed review we have increased the 1962 rainfall in the lake series by 22%, and the revised values appear in the listing in Appendix A.

2.3 EVAPORATION

Evaporation estimates are given in the WMO Phase II Report, and we have largely accepted the findings of their investigations. Although pan evaporation measurements are available for a number of sites around the lake, the evaporation estimates were made after comparing a number of methods. A simple water balance approach gave an average open water evaporation for the 5 year period 1970-1974 of 1583 mm, while a heat budget method gave a corresponding estimate of 1594 mm; models using global solar radiation estimates gave a similar total (1625 mm) while the use of sunshine duration measurements gave a rather higher figure. Although there was good agreement in total, the comparisons between monthly figures was poor. The study of evaporation on a lake of this size is complicated by heat storage and the difficulty of estimating evaporation from changes of storage.

Comparison of annual lake and basin rainfall for 1938 - 1963

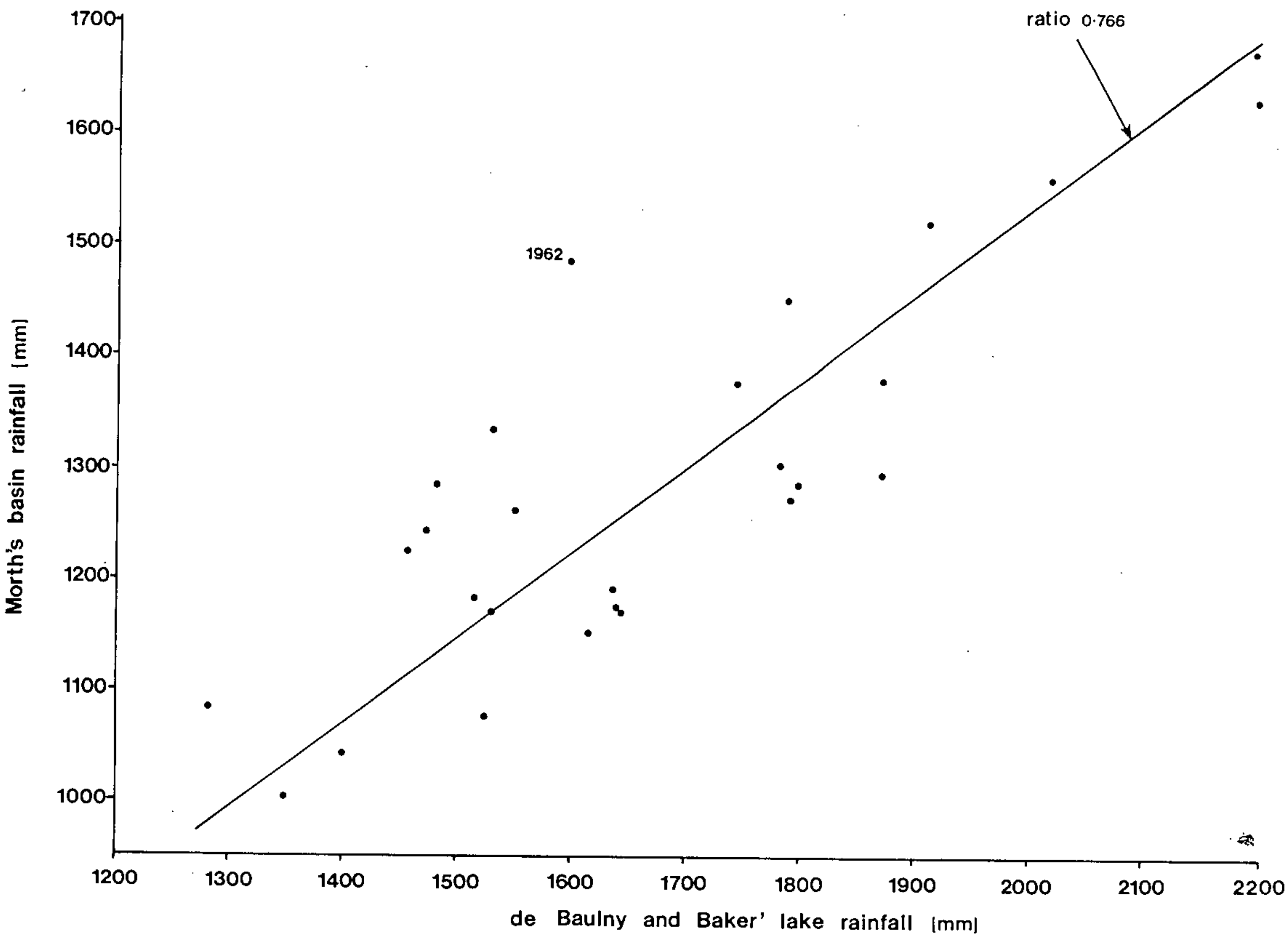


Figure 2·1

Monthly mean evaporation estimates for the period 1970-1974 are presented by WMO (1981) and Kite (1981) as being the most reasonable estimates of lake evaporation.

As it is not possible to distinguish easily between underestimates of rainfall and overestimates of evaporation, we have accepted these estimates, shown below, with some reservation about the seasonal distribution, which is somewhat out of phase with other estimates of open water evaporation (eg WMO 1974).

J	F	M	A	M	J	J	A	S	O	N	D	Total
119	112	134	154	151	166	175	137	109	114	107	110	1593 mm

It is argued that variations in evaporation from year to year are likely to be relatively small, and the evaporation from a lake of this size must be relatively conservative. A study of the open water evaporation estimated by the Penman method for Kericho for the years 1958 to 1974 shows a range from 1392 to 1547 mm, or from 6% below the mean of 1476 mm to 5% above. The standard deviation of annual estimates is only 3%.

It might be argued that the net energy supply would have been reduced by cloud cover during the wet years 1961-1964. We have obtained a 50 year record of temperatures at Kisumu, comprising mean maxima and minima for each month from 1931-1982. From these we have calculated annual mean maxima and minima and annual mean temperatures. The decade means are 22.8, 23.3, 23.3, 23.0 and 23.1°C. Although Kisumu is not an ideal site to reveal changes in lake temperature, as it is situated at the end of the Kavirondo Gulf, these records give little evidence of change.

It seems reasonable to assume that the 1970-1974 mean gives a reasonable estimate of annual evaporation.

2.4 LAKE LEVELS

Although the compilation of monthly lake levels and changes in level would seem simple, it does in fact present some problems with a large lake and a long period.

A comprehensive account of the early history of the lake gauges is given in "The Nile Basin", Vol. III, Cairo, 1933. The Jinja gauge was established in July 1912; although earlier gauges existed near the site from 1896 onwards, their readings cannot be connected with the later gauge. A masonry gauge was erected at Entebbe in March 1912, but earlier readings at Port Alice from January 1896 and at Entebbe from March 1900 have been reduced to the basis of the masonry gauge. Gauges were erected at Kisumu in October 1900, January 1904 and in 1928, but these and earlier readings at Port Victoria from January 1896 have been converted to corresponding readings on the 1928 gauge, which is, however, situated at the head of a long shallow gulf.

These readings are published in Nile Basin as 10-day and monthly means, whereas end of month readings are needed for a study of monthly changes of storage. For the period 1900 - 1969 de Baulny and Baker (1970) deduced end of month levels as the average of the last 10 day mean for one month and the first 10 day mean of the next month. They then tabulated (Annexe VIII) monthly changes of storage from this series calculated by this method which they attribute to the Egyptian Irrigation Service. For the period 1900-1912 they deduce Jinja levels from those measured at Entebbe.

WMO (1981, Annex 3) lists lake levels measured at Jinja for the period 1900-1977, and these are given in metres above MSL datum, with the gauge zero taken after relevelling as 1122.95 m against the old datum level of 1121.65 m, which was based on an arbitrary datum of 360.00 m at Khartoum (Nile Basin, Vol. III). The early levels correspond with the changes of storage calculated by de Baulny and Baker, and therefore must constitute the same series. The later levels also represent the beginning of each month.

The WMO 1981 report also contains (Annex 7, Table 4) a summary hydraulic statement for Owen Falls. This includes mean monthly lake levels for the period 1957-1979, and these provide a useful comparison with the beginning of month levels. Several inconsistencies arise in the period 1957 to the end of 1976 some of which appear to be transcription errors in the relevant tables in the WMO (1981) report. Without access to the original records we have made the following adjustments to the lake levels:

end of Jun 1962	12.45 m	for	12.49 m
end of Aug 1965	12.42 m	for	12.47 m
end of May 1967	12.41 m	for	12.14 m
end of Dec 1972	12.35 m	for	12.27 m
end of Dec 1976	11.82 m	for	11.70 m

After 1976 the comparison becomes poor suggesting that the method of estimation of end of month or average levels has changed. We do not have sufficient detailed data to substantiate this and we have used the data from the WMO reports which we reproduce in Appendix A, in terms of end of month levels in metres above the Jinja datum.

2.5 TRIBUTARY INFLOW

Although runoff from the land area contributing to the lake is considerably smaller than the direct rainfall on average, its importance should not be underestimated. The total area of tributary catchments is 194,000 km^2 or three times the area of the lake (69,000 km^2). Although the percentage runoff from the rainfall around the lake is low, the rainfall-runoff process is very sensitive to changes in rainfall. Therefore the runoff is more variable than the rainfall itself. Thus although average runoff into the lake is small in total volume compared with direct rainfall on the lake surface, its variability from year to year is greater and its impact on the water balance is significant.

Therefore, considerable attention was paid to obtaining the basic runoff measurements and in using these records to develop monthly runoff series covering as long a period as possible. The basic records comprise flows for the Kagera, the main tributary, which have been measured at Kyaka Ferry since 1940 and at Nyakanyasi since 1970. Flow records have been measured by the WMO Project for nearly all the tributaries and are available from 1969. Flows for 1969 and 1970 were presented in the Phase I report and estimates were made of the contribution of ungauged areas from rainfall. For subsequent years records are available in Project Yearbooks for the years 1970 to 1979.

TABLE 2.1 Summary of tributary inflows

No.	River	Area Km^2	Mean Flow m^3x10^6	mm	SD m^3x10^6
1	Sio	1080	348	323	119
2	Upper Nzoia	8420	1395	166	593
3	Nzoia	11900	2486	209	906
4	Upper Yala	2390	876	366	335
5	Yala	2650	1068	403	294
6	Kibos	490	68	139	
7	Nyando	2650	450	170	213
8	Cherongit	560	59	106	29
9	Sondu	3230	1383	428	447
10	Awach	508	246	483	204
11	Awach Kaboun	610	189	310	56
12	Migori	3050	396	130	229
13	Gucha Migori	6840	1599	234	622
14	Mori	590	137	232	87
15	Mara	10830	1125	104	880
16	Suguti	1020	63	62	46
17	Rwana Grumeti	11430	377	33	225
18	Mbalageti	3730	144	38	79
19	Simyu Dima	10790	735	68	442
20	Mgogo	1200	55	46	43
21	Moame	2090	65	31	46
22	Isinga	4780	135	28	
23	Kagera (R Falls)	30200	6708	222	1299
24	Kagera (Nyak)	55800	6279	113	2031
25	Ngono	2611	753	288	148
26	Ruizi	5670	272	48	172
27	Katonga	13020	114	9	51

Note: The table summarises the annual flows given in the Appendix. The mean and SD are calculated for the whole period of record in each case.

WMO (1981, Annex 7) derive annual discharges of the lake tributaries from de Baulny and Baker (1970) for the period 1959-67, but they in turn quote these as "extract from unpublished report - HYDROMET 1970". During this period flow from 35% of the area was measured, and flow from ungauged areas was estimated on the basis of rainfall, catchment characteristics, and similarity with other rivers (Krishnamurthy and Ibrahim, 1973). Because we now have about 10 years of measured flows from which to extend the record by considering the long-term measured flows, we have preferred to reassess these early flows in monthly terms.

The basic flow records are flows of the Nzoia, Sondu and other tributaries in Kenya which are available from 1956 (World Health Organisation, 1973), flows of the Kagera (Norconsult, 1975; WMO, 1981) and flows of nearly all the lake tributaries (WMO Phase I Report and Yearbooks, 1970-1979). Useful information is also available in Grundy (1963) for the floods of 1961-62 in Kenya.

Firstly, there were in these sources a number of occasions in which records were incomplete with one or more monthly records missing. These gaps were filled by interpolation during periods of flow recession or by comparison with adjacent gauges when higher flows were missing. There were too many gaps in 1979 for completion in this way. The annual totals for the available records are given in Appendix A with a key and summary in Table 2.1.

The process of deriving a complete set of records for the total inflow was as follows. First, missing years for the Ruizi (1971), Mgogo (1974) and Sondu and Awach (1978) were filled by assuming that these river flows were the same ratio of the other gauged tributaries (excluding the Kagera and Ngono) in the missing months and years as over the whole common period.

The flows of the Kibos, Isinga and estimates for the ungauged areas are available for 1969 and 1970 in the Phase I Report. Estimates for the months and years in the period 1971-78 were made on the assumption that the flows were the same fraction of the gauged tributaries as in the period 1969-70.

The total tributary inflow to the lake has now been estimated from measured flows for the period 1969-78. The flows of the Kagera and Ngono have to be added to these tributary inflows.

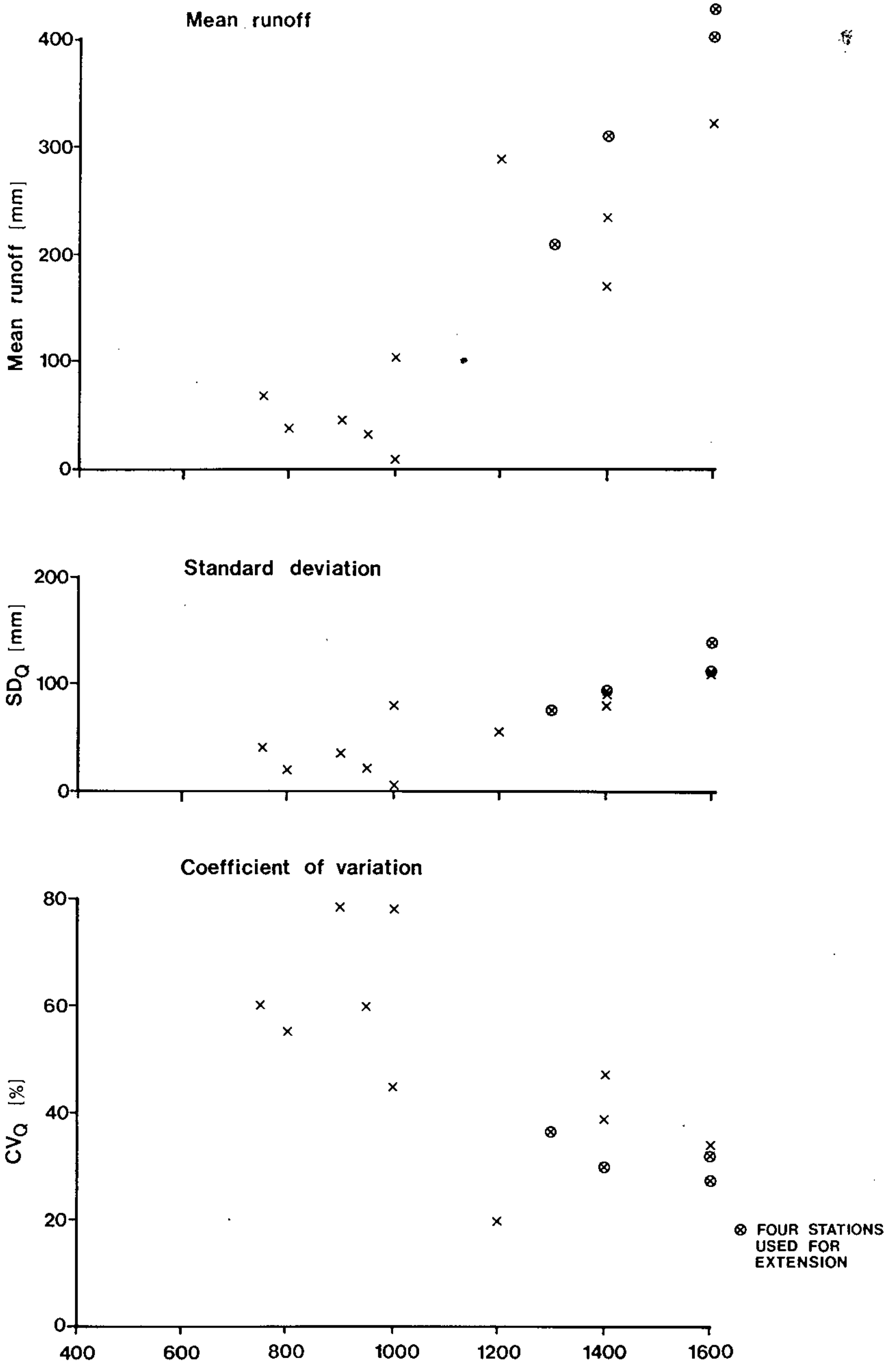
In order to extend the tributary inflows to the period before 1969, records are available for the Upper Nzoia (8420 km^2) for the period 1956-70 and for the Nzoia (11900 km^2) for May 1963-1979. The Upper Nzoia flows were multiplied by the ratio of flows in the common period to give Nzoia flows for the period 1956 to April 1963.

The Upper Yala (2390 km^2) flows are similar to the Yala (2650 km^2) for the common period, so they were accepted as the Yala flows for 1956-58 and 1961. The flows of the Awach near Genda (508 km^2) were also accepted as those for the Awach (610 km^2) for the period 1956-68. The Sondu flows (3230 km^2) are available for 1956-79.

The total annual flows for these four rivers were compared with the total lake tributary inflow (excluding Kagera and Ngono) for the common years 1969-77, and the four rivers provided consistently slightly less than half the total runoff. The mean annual runoff and its variability for individual tributaries were compared with mean annual basin rainfall estimated by SMEC (Brown et al, 1979, Table 3). Although the rivers from the southern and drier parts of the lake catchment contribute a smaller depth of runoff (Figure 2.2) and the variability of runoff is therefore higher, there is the compensating effect of the sum of a number of imperfectly correlated variables. In Figure 2.3 the sum of the four rivers is compared with the remainder of the tributary runoff (except the Kagera and Ngono). (The year 1978 has been included in this comparison, but two of the four rivers were themselves estimated in this year.)

The comparison suggests that during the period 1969-77 the flows of the four north-eastern tributaries were well related to and representative of the other tributaries and the total runoff. There is some indication that the total tributary flow is slightly more variable than the sum of the four rivers. The mean monthly distribution is also slightly different. However, the monthly flows of the four tributaries have been multiplied by 2.24, the ratio of flows in the common period, to extend the total tributary inflow back to 1956.

Comparison of tributary runoff statistics with mean catchment rainfall



Comparison of total flows of four tributaries [Nzoia, Yala, Sondu, Awach] with remainder of tributary inflows [except Kagera, Ngono], 1969 - 78

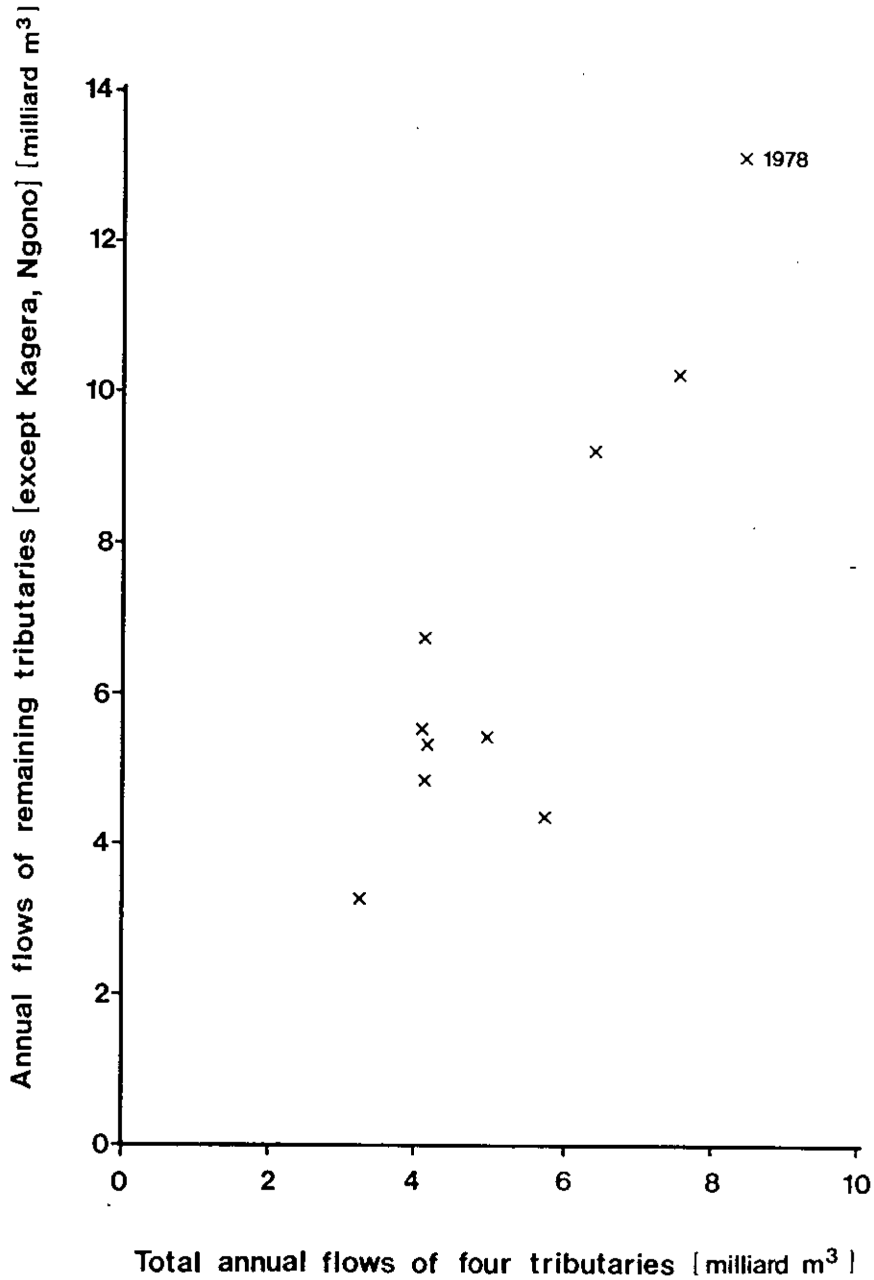


Figure 2·3

The Kagera flows and the Ngono contribution (estimated as 10% of the Kagera in the early years) have to be added to give the total monthly and annual inflow given in Appendix A expressed as million m^3. It is possible that this approach may underestimate the runoff in the extreme wet years following 1961, but it takes account of all the measured records.

It is necessary to point out that the annual flows in this table are comparable with those used by WMO (1981, Annex 7) in the years 1959-70, but do not correspond well in the years 1956-58 when WMO used data derived from regression on the Kagera, or in the years 1971-77 when both sets of flows are derived from the WMO Yearbooks. We have checked our derivations for the last few years carefully, and can find no reason for this discrepancy.

The total tributary inflow (less Kagera) has been compared on an annual basis with the Kagera flows (Figure 2.4) and the lake rainfall (Figure 2.5). It is evident that the tributary inflow is far more variable than either the Kagera flow or the lake rainfall. The Kagera runoff is less closely related to lake rainfall, but this reflects the lag caused by the lakes and swamps in the Kagera basin.

2.6 LAKE OUTFLOWS

Before the construction of the Owen Falls dam, lake outflows were controlled by the Ripon Falls and were therefore related to lake levels. They were measured at the gauging station at Namasagali and more recently at Mbulamuti. However, an agreed curve between lake levels at Jinja and outflows was revised and extended in 1978, and historic monthly outflows have been computed from lake levels for the period 1900-78.

Since construction outflows have been controlled by the Owen Falls dam to give, on average, natural outflows corresponding with lake levels according to the agreed curve. For this purpose flows through the sluices are estimated from measurements of upstream water levels and ratings based on model tests. Flows through the turbines are estimated from power output alone using a rating table; this implies a constant operating head and it is not clear whether this has been revised to take account of the rise in lake level after 1961.

Annual tributary inflows [except Kagera, Ngono]
related to Kagera / Ngono inflows August–July

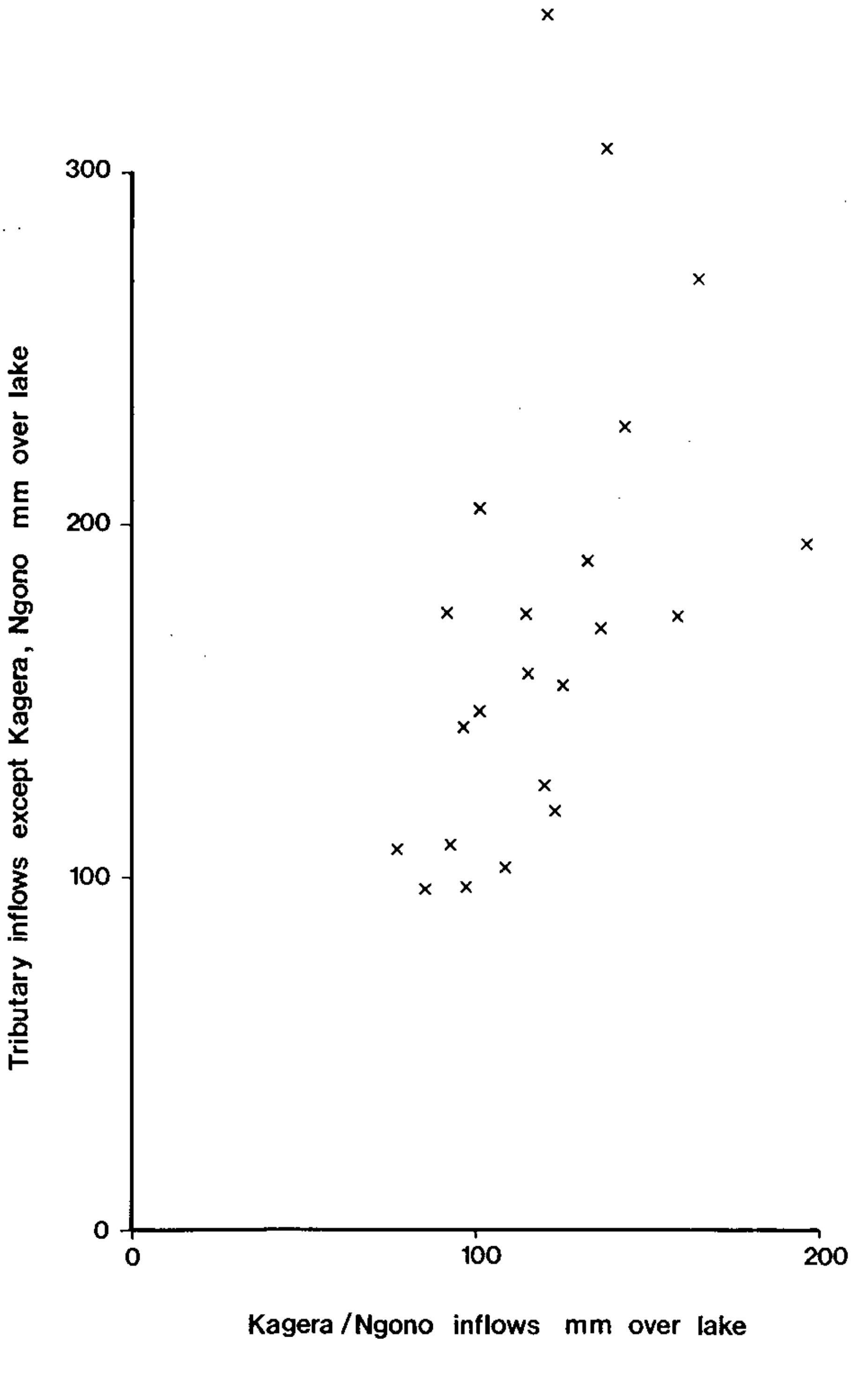


Figure 2.4

Annual tributary inflows (except Kagera, Ngono) (August-July) related to lake rainfall

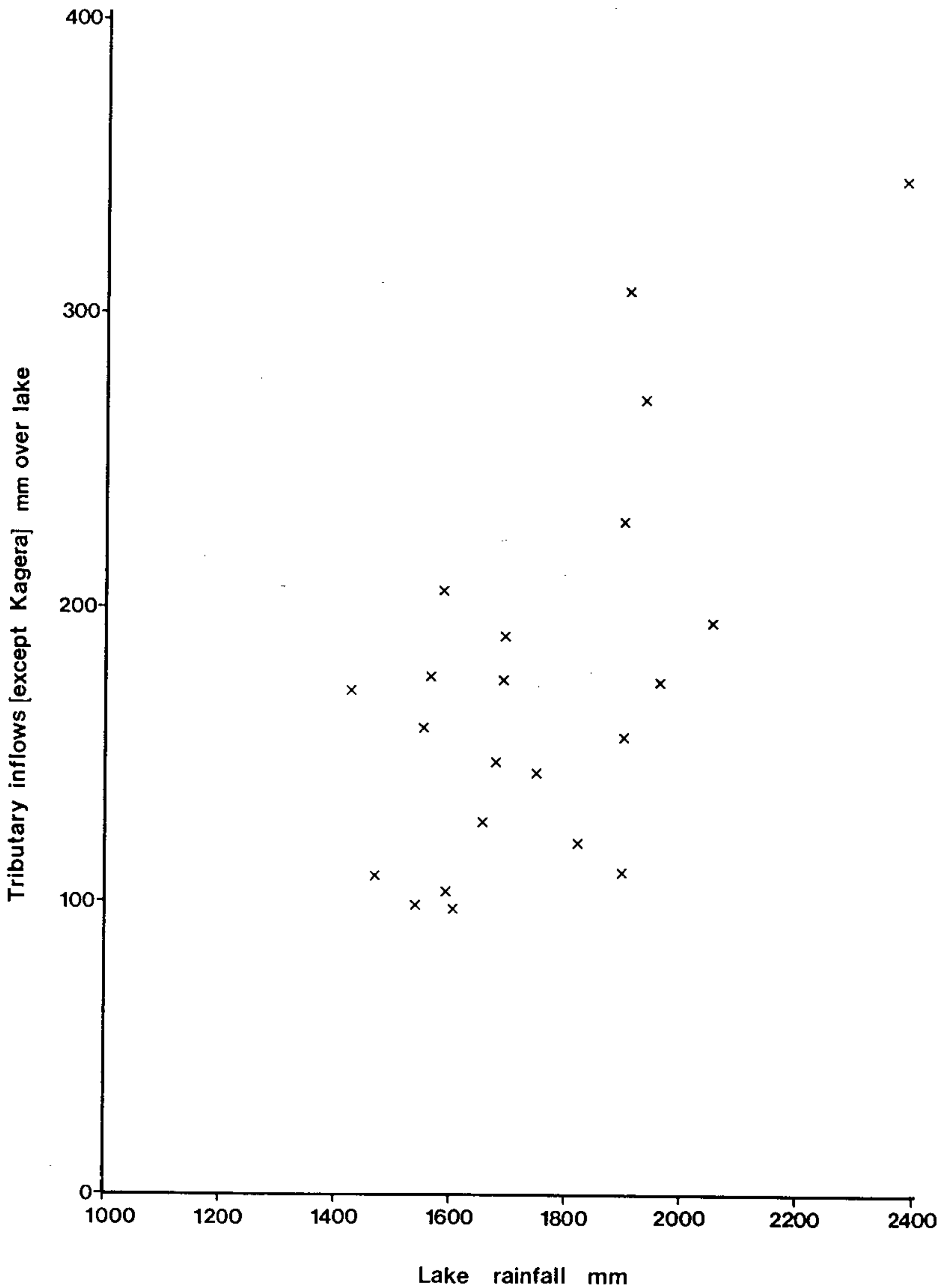


Figure 2·5

The current rating table implies an overall efficiency of 84% at recent operating heads of about 19 m. Hydraulic tests during the period 1956-59, before the rise in lake level, show that the head loss through the Ripon Falls was not great for discharges corresponding to the agreed curve. Thus allowing for tailwater levels being lower, the operating head would not have been much less than at present. As less than half the river flow passes through the turbines, any possible errors from this cause would be small compared with other factors.

The feature of the lake outflows has of course been the marked increase following the rise of lake level. The 1900-60 mean of 20.8 milliard m^3 contrasts with an annual average of 39.4 milliards m^3 over the period 1961-78.

In some parts of our analysis we have had to express the agreed curve in a form suitable for computer use. Ideally this could have been a set of cubic splines fitted to a number of data points, but as some extrapolation is necessary we have used an equation of the form used by Hurst.

$$VO = A * (VL - B)^C$$

where the outflow VO is in million m^3/day, lake level VL in metres above the Jinja gauge datum and A, B and C take values of 5.73, 7.96 and 2.01.

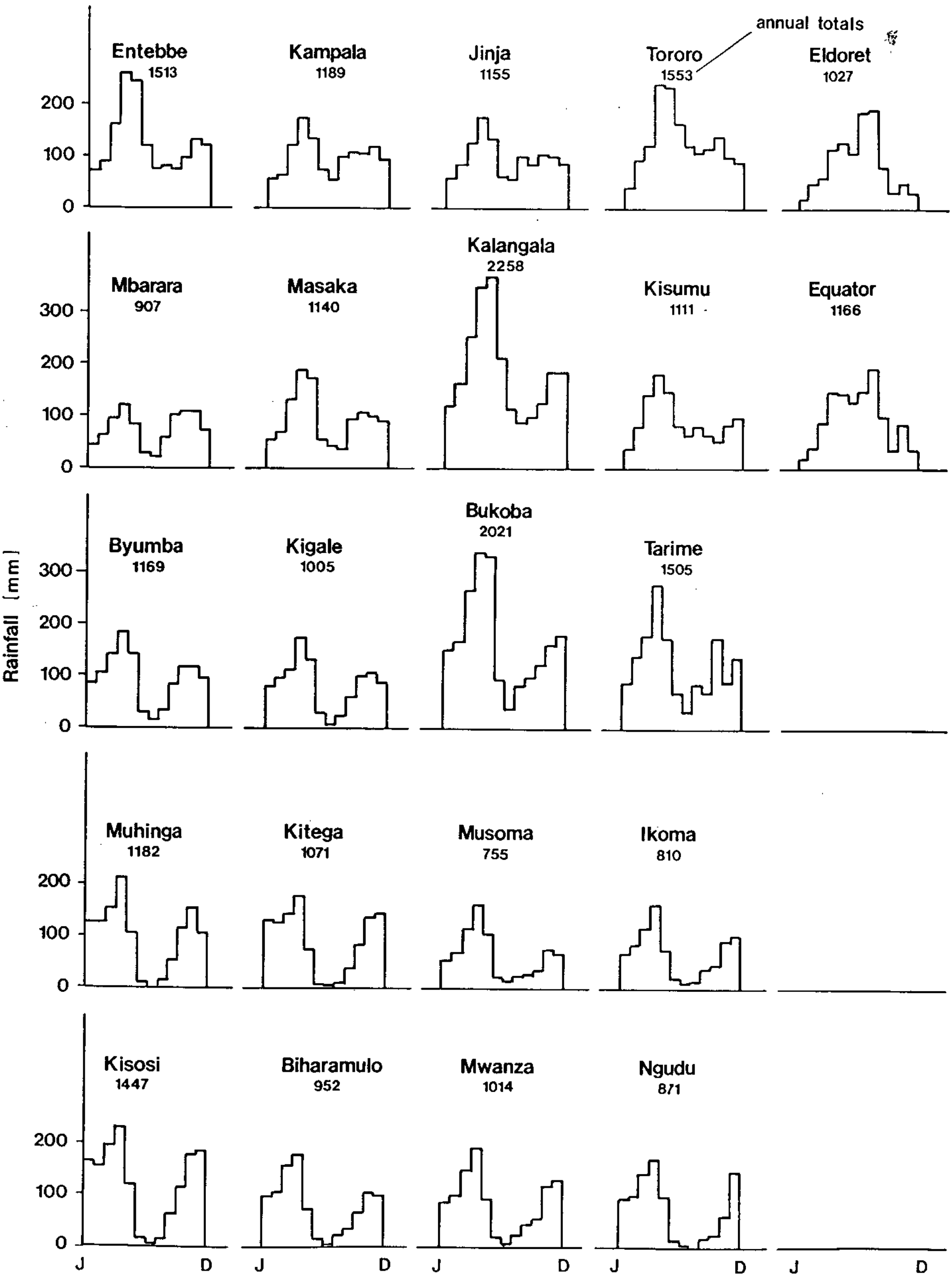
2.7 LAKE HYDROLOGY

This is a convenient point to summarise our knowledge of the hydrology of the lake and its catchment. The pattern of annual average rainfall over the area is given by the Mean Annual Rainfall Map of East Africa. There is heavy rainfall (over 2000 mm) on the western shore at Bukoba and over the Sese Islands south of Entebbe. The bulk of the higher rainfall belt is to the north and north-east of the lake, where there are areas with rainfall over 2000 mm north and south of Kisumu and a wide belt with rainfall over 1200 mm. To the south of the lake, on the other hand, rainfall is 800-1000 mm over a wide area, apart from Ukerewe Island where it is higher. To the west of the lake, the rainfall decreases to a minimum of about 800 mm in eastern Rwanda and then increases to about 1600 mm on the Nile-Congo divide. Thus the rainfall over the land catchment draining to Lake Victoria is lower than the estimated mean rainfall over the lake itself (1650 mm) except in isolated areas, most of which are to the northeast of the lake. However, as the catchment area is large, the tributary contribution resulting from this rainfall is likely to be significant.

The seasonal rainfall distribution is illustrated by Figure 2.6, where mean monthly rainfall for a number of stations around the lake is plotted in relative positions. The stations include not only lake-side sites but also a number in the tributary basins, including several in the important northeastern area and in the Kagera basin in Rwanda and Burundi. Both the similarities in these seasonal patterns and the differences are striking. Common to all are the two rain seasons, in March/May and November/December, corresponding to the annual march of the ITCZ. However, at the southern limits of the study area, the dry season in June/August is more marked, while the low rainfall separating the two seasons in January/February is missing in the south. The diagram also reveals an additional feature in stations to the northeast of the lake, particularly at Eldoret and Equator; there is a period of heavy rainfall in July and August which is not related to the normal seasonal pattern.

This additional rainfall is a feature of the area between the north of the lake and the escarpment, and may be related to an interaction between lake breezes and the topography (Sansom and Gichuiya, 1969; Datta, 1982). There is some evidence, particularly at Equator, that the diurnal variation of rainfall is different in this July/August period from other months, with maximum rainfall occurring about 1300-1500 hours compared with evening in other months. However, this rainfall to the northeast of the lake results not only in the higher annual total already described but ensures a reasonably continuous supply of water in this area and therefore a less seasonally variable runoff regime than in the remainder of the lake catchment.

Seasonal distribution of mean rainfall



The monthly tributary inflows are summarised in Figure 2.7 and reflect both the rainfall pattern and the characteristics of the individual catchments. All the runoff patterns are highly seasonal and accentuate the seasonal distribution of rainfall.

The Nzoia reflects more clearly than the other rivers the July/August rainfall to the north-east of the lake, superimposed on the other seasons. The Yala and the Sondu reveal a greater proportion of base flow; to the south, the Gucha shows much greater variability of flow and the preponderance of the March/April wet season in most but not all years. Further south in the drier region the Mara, Rwana and Simyu show similar seasonal patterns but even less flow in the dry season. The Kagera flows, on the other hand, have a later peak and very high base flow component because of the attenuating effect of swamps and lakes.

The effect of the 1961-62 rains shows up in all the measured tributaries, with the increase most marked in the Awach. The increase in the outflow from the Kagera basin is more persistent than the other rivers, with the base flow markedly higher in recent years.

The sensitivity of the hydrological system to changes in rainfall may be illustrated by the annual figures for rainfall and tributary inflow expressed as mm over the lake surface (69000 km^2). Taking the 22 years 1956-1977, the lake rainfall and tributary inflows have a mean and standard deviation as shown below:

	Lake rainfall	Tributary Inflow	Net Supply
Mean	1754	292	452
Standard deviation	225	85	290
Coefficient of variation (%)	12.8	29.1	64.2

The net supply is the sum of lake rainfall plus tributary inflow minus annual evaporation (1593 mm). Whereas the variability of lake rainfall is 13% and of tributary inflow 29%, the resulting net supply has a variability of 64%.

3. THE WATER BALANCE OF LAKE VICTORIA 1956-1978

3.1 INTRODUCTION

We have measurements or estimates of all the main variables involved in the water balance of the lake only for the period 1956 to 1978. Their origin and accuracy together with the correction of apparent errors and inconsistencies have been discussed already. In the absence of any relevant information and in line with previous studies, we have assumed that groundwater flow into or out of the lake is negligible.

The main question is whether the inputs (rainfall on the lake and tributary inflows) balance the outputs (evaporation from the lake, outflows and increases in storage). If there is not a balance using the data as they stand, can small adjustments be made in one or other of the variables so as to describe the behaviour of the lake over this historic period?

In this analysis we have chosen to define the hydrological year as August to July. There is no clear cut argument in favour of this definition as the region benefits from year round rainfall although June and July rainfalls are relatively low over the lake and much of its catchment area. Annual tributary inflows are better related to annual rainfalls if we use the August to July year and this could be important when we come to extend the tributary inflow series for the earlier years. Also the choice of an August to July year ensures that the annual minimum lake level occurs always before the annual maximum. This avoids some confusion when we come to relate end of year levels to annual maxima and minima.

All water balance studies described here have been done on a volume basis taking account of the small changes in lake area with level. Although the effect of change in area is insignificant from year to year, the cumulative effect can be significant when lake level changes are sustained for a period of several years. Over the range of lake levels of interest, the lake level - area curve can be considered linear and we have derived the following equation relating lake level and area from the data published in the WMO Phase II report.

$$\text{AREA } (km^2) = 58283 + 775. \text{ LEVEL (m above Jinja gauge datum)}$$

A useful summary of the data for the 22 year period, 1956/57 to 1977/78 is given by Figure 3.1. This shows annual values of the variables expressed as a depth over a constant lake area for the hydrological year August to July.

3.2 THE ANNUAL WATER BALANCE

We have expressed the error in the water balance in two ways; firstly as the annual difference between input and output and secondly in a cumulative sense by defining an implied series of end of year lake levels which can be compared with the series of observed levels.

Initial trials showed that a reasonable balance could be achieved only by increasing the input side by an amount equivalent to 7.5% of lake rainfall or 45% of tributary inflow. Alternatively the output side could be decreased by about 8% of evaporation or 25% of outflow. Over the 22 year period the accumulated error implied a decrease in lake level of nearly 2.9 m.

We cannot accept that such large errors are likely in the estimates of tributary inflows or the outflows measured at Owen Falls. However in terms of rainfall and evaporation the errors are relatively small. Both variables have to be estimated indirectly; rainfall is estimated from records at 8 stations around the lake, evaporation from short records from stations on the northern shore. In neither case do the available records necessarily represent conditions over the lake itself.

There is little evidence to suggest whether it is rainfall that is underestimated or evaporation that is overestimated. It is reasonable to argue that evaporation is reduced in months when rainfall is high as the increased cloudiness reduces the radiation reaching the surface of the lake. But any attempt to model a

Time series of water balance variables for 1956/57 to 1977/78

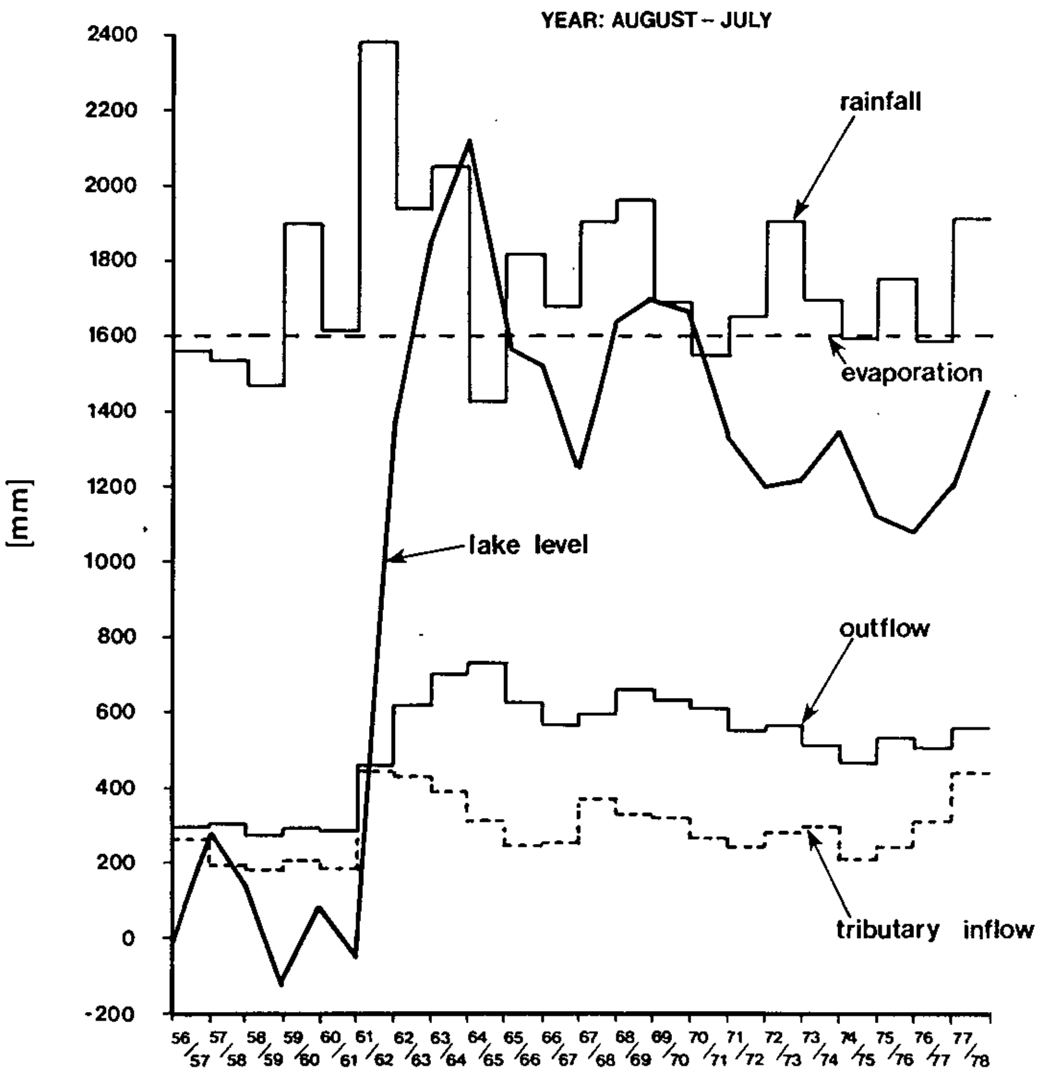


Figure 3.1

reduction in evaporation in linear terms relative to rainfall has the same effect on the water balance as a linear increase in rainfall itself. Thus the two alternative courses of action cannot be distinguished without additional evidence and no firm evidence is available.

On balance we marginally prefer to increase the estimate of lake rainfall directly. This course is supported to some extent by meteorological arguments (Datta 1981) which support the likelihood of there being higher rainfalls over parts of the lake than the uniform rainfall suggested by de Baulny and Baker (1970) would imply. Thus in all further water balance studies reported here we have increased monthly and annual rainfalls on the lake by 7.5%.

Figure 3.2 shows the series of end of year lake levels implied by the revised water balance. Comparison with the observed levels shows good agreement; the dramatic rise in levels in the early 1960s is almost fully described. No extraordinary explanations are necessary; the 7.5% increase in rainfall is needed throughout the 22 year period to achieve a good balance, not just in the few years of very high rainfall.

The effect of using the rainfall estimates for the 1970s prepared by the WMO project team is also illustrated on Figure 3.2. Their estimates do not seem to give as consistent a balance as the continuation of the series developed by de Baulny and Baker. Thus we have continued to rely on the de Baulny and Baker series in all further analyses.

The series of annual errors in the water balance now have a mean of zero and a standard deviation of about 160 mm when expressed as a depth of water on the lake. This is equivalent to about 10% of rainfall or evaporation and as such is within the expected range of error of estimation of either of these variables.

3.3 THE MONTHLY WATER BALANCE

Continuing to use the 7.5% increase in rainfall in a monthly water balance we can derive a series of monthly errors in the water

Comparison of implied and observed end of year lake levels

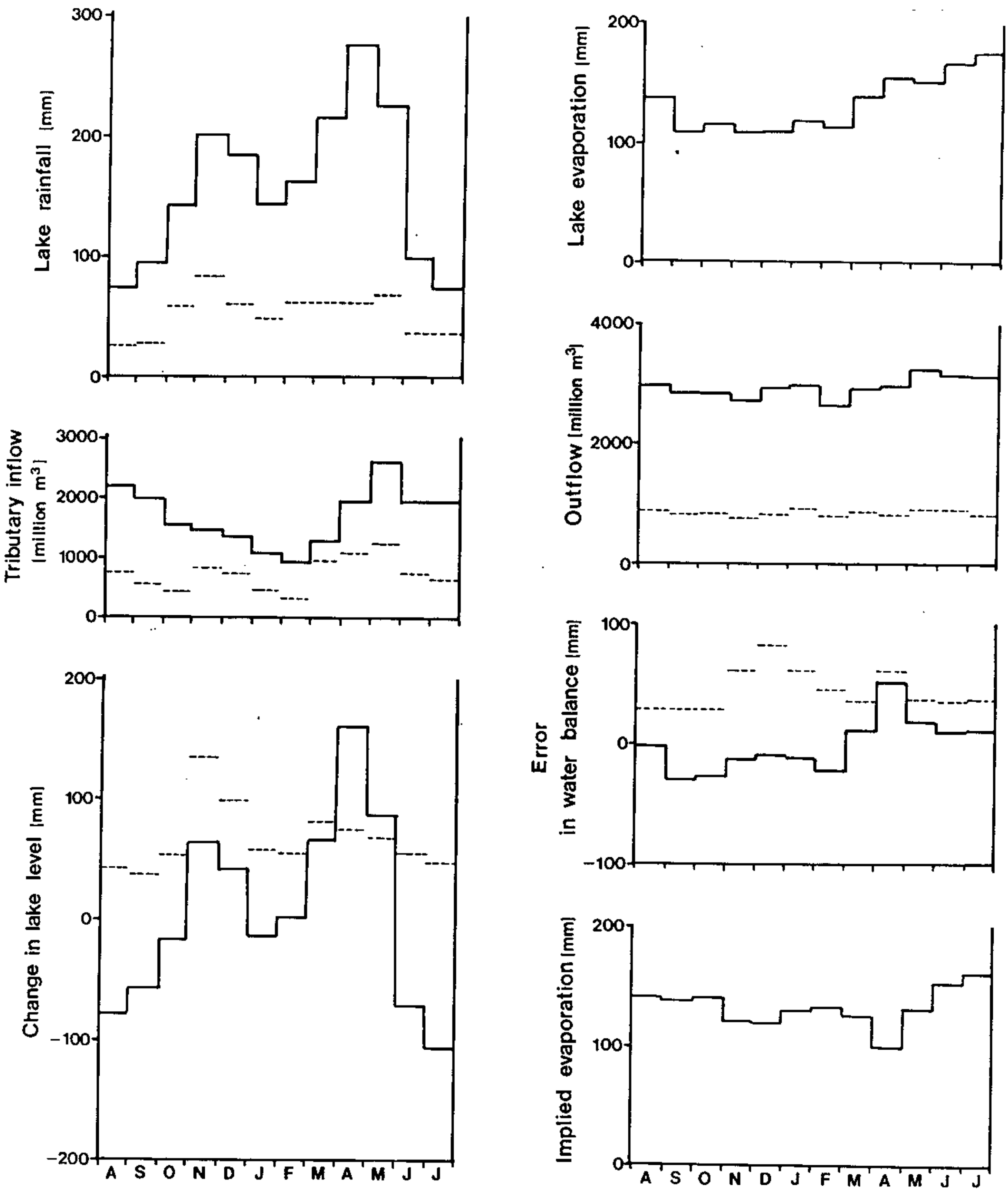
Figure 3.2

balance. Histograms of the monthly average errors and their standard deviations are compared with histograms showing the seasonal distribution of the main variables in Figure 3.3. All histograms refer to the 22 year period from 1956/57 and therefore they do not necessarily represent long term averages or seasonal distributions of these variables.

The average seasonal distribution of the errors is very similar to that of rainfall. Again we have the difficulty of explaining the seasonal bias in the water balance in terms of errors in the seasonal pattern of rainfall directly or indirectly through its possible influence on evaporation. The rainfall estimates could be seasonally biassed in view of the way in which they were derived using weighting factors that varied seasonally. However, systematic adjustment of monthly rainfalls, assuming that there was a rational basis for adjustment, would have a different effect in different years. On the other hand it seems reasonable to adjust the monthly evaporation distribution to give average monthly water balance errors of zero if such an adjustment gives a realistic monthly distribution of average evaporation.

Figure 3.3 shows the implied distribution of monthly evaporation required and we accept that it is realistic; it implies some suppression of evaporation during the wetter months balanced by a modest increase in the drier months. Thus we have adopted this revised distribution of evaporation which does not affect the annual total and therefore the annual water balance in any way. Arguably in the context of this study the detail of the monthly water balance is much less important than the medium and longer term trends in lake levels represented by the cumulative annual water balance, and we should not place too much importance on the adjustment of the evaporation distribution.

Monthly distribution of water balance variables



Monthly means and standard deviations

plotted refer to the period 1956/57 to 1977/78

Figure 3·3

4. EXTENDING THE LAKE WATER BALANCE BACK TO 1925

4.1 INTRODUCTION

We have shown that small adjustments to the estimates of rainfall and evaporation on the lake lead to a water balance which describes well the changes in lake level over the period 1956/57 to 1977/78. Total tributary inflows are not known for the period 1925-1955 for which all the other water balance components are known or have been estimated. Therefore to extend the water balance back to 1925 we must derive tributary inflows indirectly, preferably from rainfall. However the lake rainfall series is the only one immediately available; we are not aware of any monthly estimates of basin rainfall other than those of Morth (1965) referred to earlier. Monthly rainfall estimates for the Kagera basin have been derived back to 1940 but these are not available and would anyway cover only part of the period of interest.

Whether or not lake rainfall can be used as an index rainfall to estimate tributary inflows is of some importance to the later parts of this analysis. If successful we can be more certain of our interpretation of the water balance by simulating the lake level series over a much longer time scale than the 22 years considered so far. Also we can then look to extend the rainfall series by stochastic time series methods in the knowledge that we can derive the corresponding lake level series.

The main options available to relate tributary inflows and lake rainfall are forms of statistical model or a conceptual approach which might be defined as a net rainfall - soil moisture deficit model. Time did not permit investigation of all but the simpler options and we show that good results can be obtained by the net rainfall - soil moisture deficit approach. Trials based on a regression of annual tributary flow on lake rainfall for the 22 years of common data were not as successful. Severe attenuation of tributary flows in the Kagera basin means that tributary inflow in any year is related to current and past annual rainfalls.

4.2 THE NET RAINFALL - SOIL MOISTURE DEFICIT APPROACH

The monthly rainfall series and the monthly evaporation estimates used in the lake water balance are assumed to act as index variables for the catchment area of the lake. Net rainfall in each month is defined as:

$$NR = R - FE * E$$

where R and E are the lake rainfall and evaporation and FE is a factor which allows for any difference in representativeness of the variables.

The net rainfall series is accumulated month by month. Negative accumulations are interpreted as a soil moisture deficit which has a limiting value FS. Positive values are interpreted as runoff in the month they occur and the soil moisture deficit is set to zero when runoff occurs. Runoff is scaled by a parameter FT and the series of scaled runoff values is routed through a linear reservoir with a time constant PK.

The sum of lake rainfall and derived tributary inflow is the input side of the lake water balance. Subtracting lake evaporation we are left with a net input which must be distributed to outflows down the Nile and an increase (or decrease) in lake storage or level. Given the start of month lake level and the relationship between outflow and lake level, we have used an iterative method to distribute the net output so that outflow is consistent with the average of start and end of month levels.

4.3 FITTING THE MODEL

There is no single criterion against which the 'best' set of parameter values (FE, FT, FS, PK) can be defined. While our principal objective is to derive a model which can give a good representation of lake level trends, it is important to avoid bias in the simulation of year to year level changes. Also we need to reproduce the tributary inflows for the period 1956/57 to 1977/78 for which estimates are available.

Initial trials showed, as expected, that FE and FT are the most sensitive parameters. FE effectively controls the variance of annual tributary inflows although this effect can be modified to a limited extent by the routing parameter PK. The scaling factor FT is highly inversely interdependent with FE.

The parameters FS and PK are generally much less sensitive. In practice FS was set at a very high value so as to play no effective part in the model when it was found that soil moisture deficits only occasionally exceeded 300 mm, a value that should be within the range of available soil moisture storage. PK was held at 250 days giving a seasonal tributary inflow distribution broadly consistent with that estimated for the 22 year period from 1956/57. This apparently large value reflects the storage of the Kagera.

After a number of trials using combinations of FE and FT, values of 0.95 and 82.5 were chosen for these parameters. Table 4.1 shows some of the relevant statistics which led to this choice, and Figure 4.1 compares the simulated end of year lake levels with the observed levels for the 53 year period 1925/26 to 1977/78. We show in Figure 4.2 that the annual changes in level are a reasonably unbiassed representation of the observed values.

Comparison of the simulated and estimated tributary inflows for 1956/57 to 1977/78, illustrated in Figure 4.3 and Table 4.2, shows that the simulated series exhibits a significantly higher variance both by months and annually. We accept that the approach we have used to derive the estimated tributary inflows can cause some under-estimation of the variability of the total, but this is unlikely to explain more than 25% of the difference in question. However the very high rainfall and tributary inflows of the early 1960s have a disproportionate effect on the variance, and we suspect that flows could have been significantly underestimated during this period.

However there could be other explanations. Study of Figure 4.1 reveals a few years such as 1937/38 when the simulated lake level change is completely different from the observed change. It is possible that the lake rainfall was substantially overestimated in

TABLE 4.1 **Statistics used in fitting the net rainfall model**

FE	FT	SE (m)	SSY (m^3)	$\overline{VTP}$ (million m^3)	Lake level (m) at end of year: 1934/35	1941/42	1951/52	1958/59	1962/64	1976/77
0.85	40.0	-3	305	15675	10.80*	11.79*	11.66*	10.83*	12.80*	11.76
	42.5	48	310	16654	10.84*	11.85*	11.72*	10.87*	12.88*	11.82
	45.0	98	323	17634	10.88*	11.90*	11.77*	10.92*	12.95*	11.87*
0.90	52.5	-6	292	16379	10.73	11.78*	11.63*	10.74*	12.90*	11.79
	55.0	33	295	17159	10.76	11.82*	11.67*	10.77*	12.96*	11.83
	57.5	71	303	17939	10.79*	11.87*	11.71*	10.80*	13.02*	11.87*
	60.0	109	316	18719	10.81*	11.91	11.75*	10.82*	13.08*	11.91*
0.95	75.0	-26	290	17393	10.60	11.75*	11.54*	10.56*	13.05*	11.81
	77.5	1	291	17972	10.62	11.78*	11.56*	10.57*	13.10*	11.84
	80.0	27	295	18552	10.63	11.81*	11.59*	10.59*	13.15*	11.86
	82.5	53	301	19132	10.65	11.84*	11.61*	10.60*	13.20*	11.89*
	85.0	79	309	19712	10.66	11.87*	11.64*	10.62*	13.24*	11.92*
1.00	130.0	-80	376	19325	10.36	11.64*	11.30*	10.31	13.31*	11.82
	140.0	-23	387	20811	10.38	11.70*	11.34*	10.33	13.34*	11.88*
	150.0	32	407	22298	10.40	11.76*	11.38*	10.35	13.57	11.95*
	Observed values			20171	11.08	11.60	11.55	10.85	13.09	12.17

Note: * indicates that the simulated level was within 0.3 m of the observed level.

FE and FT are the parameters of the model.
In all tests shown, PK = 250 days, FS is ineffective.

SE is the sum of annual differences in level (simulated - observed)
SSY is the root mean square annual difference.

$\overline{VTP}$ is the average annual tributary inflow over the period 1956/57 - 1977/78

Year: August - July.

TABLE 4.2 Comparison of observed and simulated tributary inflows for 1956/57 to 1977/78

	Observed inflow (million m^3)		Simulated inflow (million m^3)	
	mean	sd	mean	sd
Aug	2151	749	1758	1349
Sept	1964	563	1558	1196
Oct	1534	450	1382	1061
Nov	1498	806	1286	942
Dec	1341	721	1242	941
Jan	1061	462	1159	893
Feb	913	323	1088	867
Mar	1267	984	1198	898
Apr	1918	1045	1737	1310
May	2617	1261	2310	1734
Jun	1968	705	2337	1702
Jul	1937	649	2076	1506
Total	20171	5833	19132	12258

Comparison of simulated and observed end of year lake levels

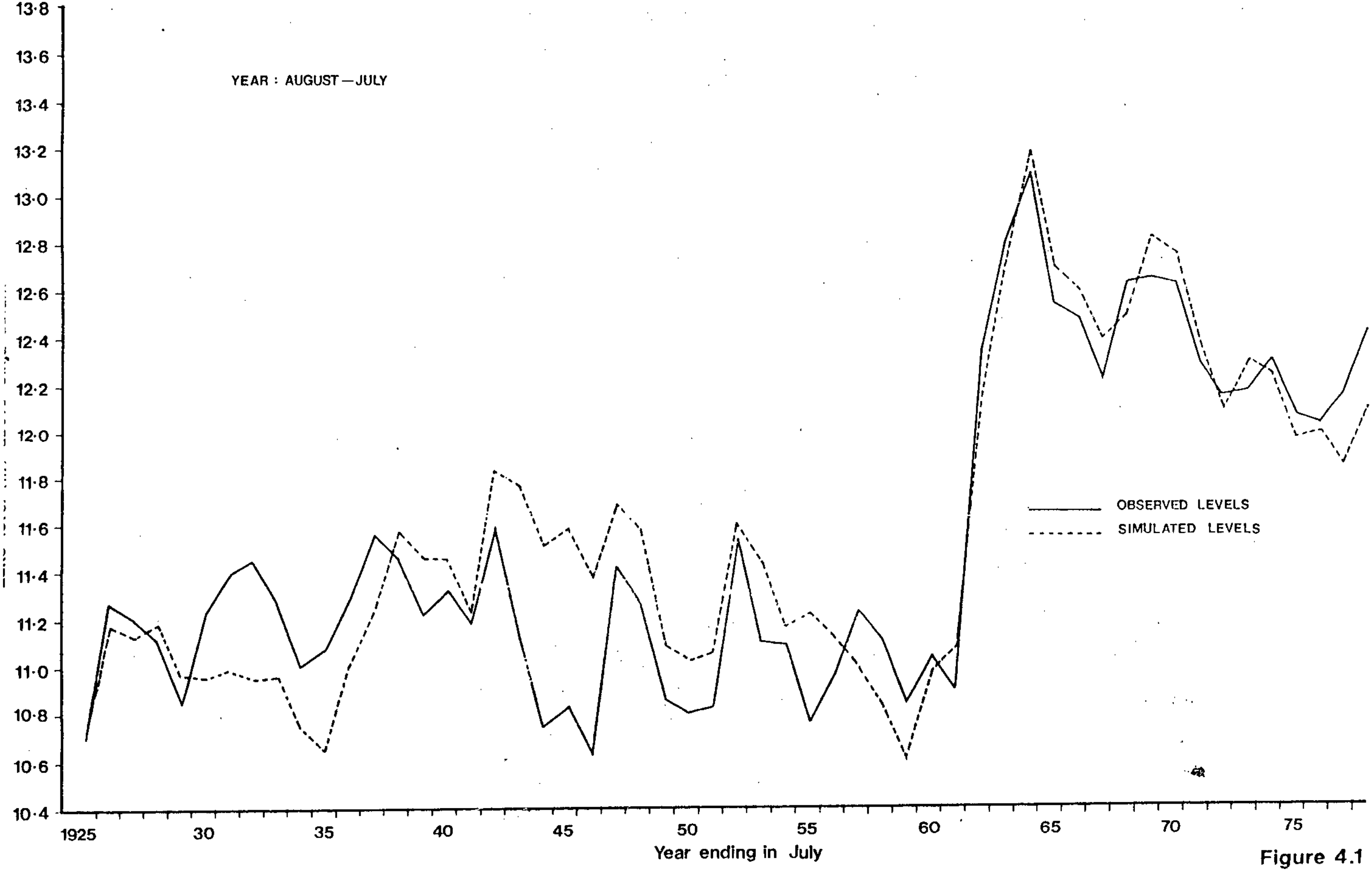


Figure 4.1

Comparison of simulated and observed annual changes of lake level

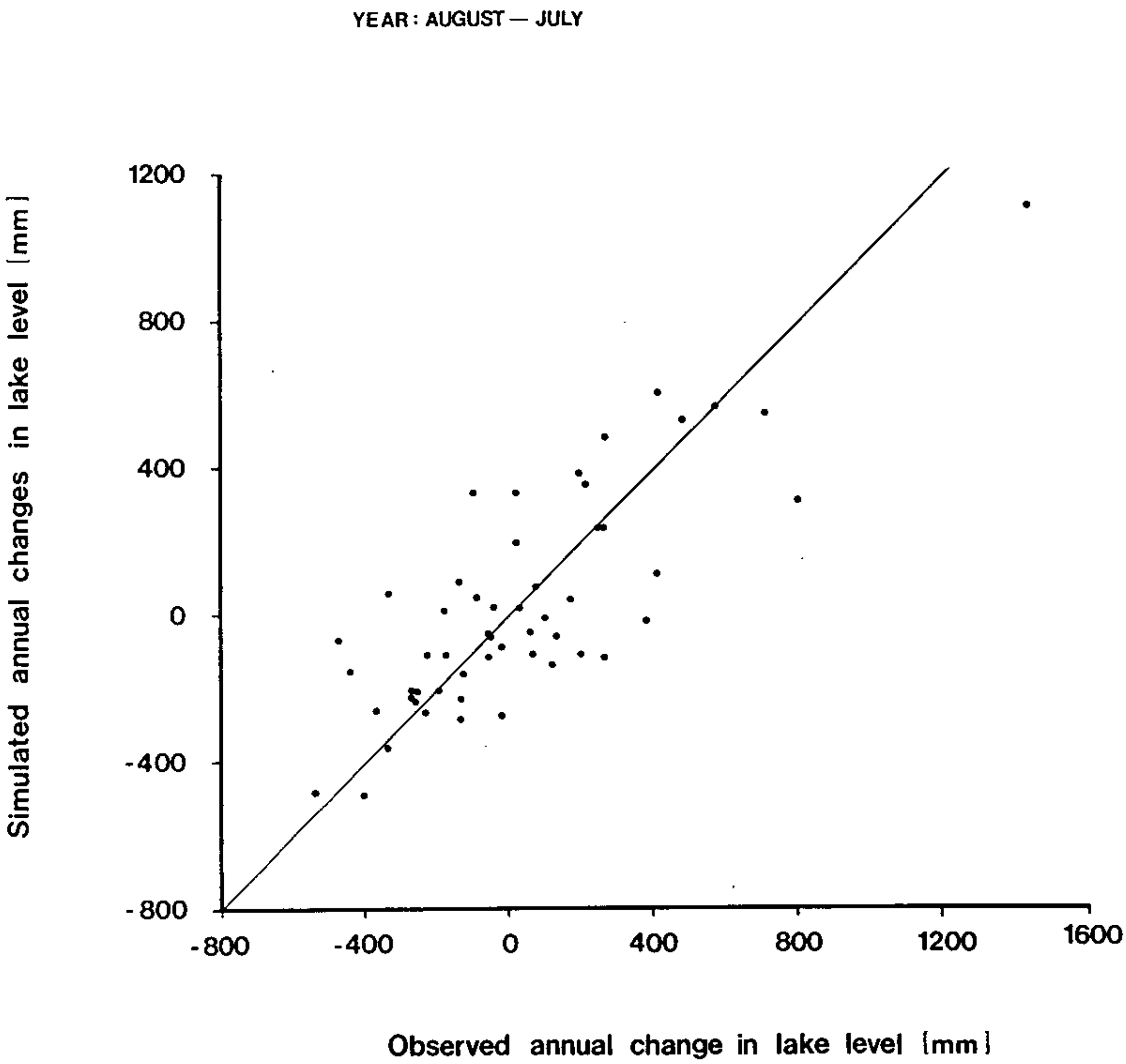


Figure 4.2

Comparison of simulated and estimated annual tributary inflows 1956/57 to 1977/78

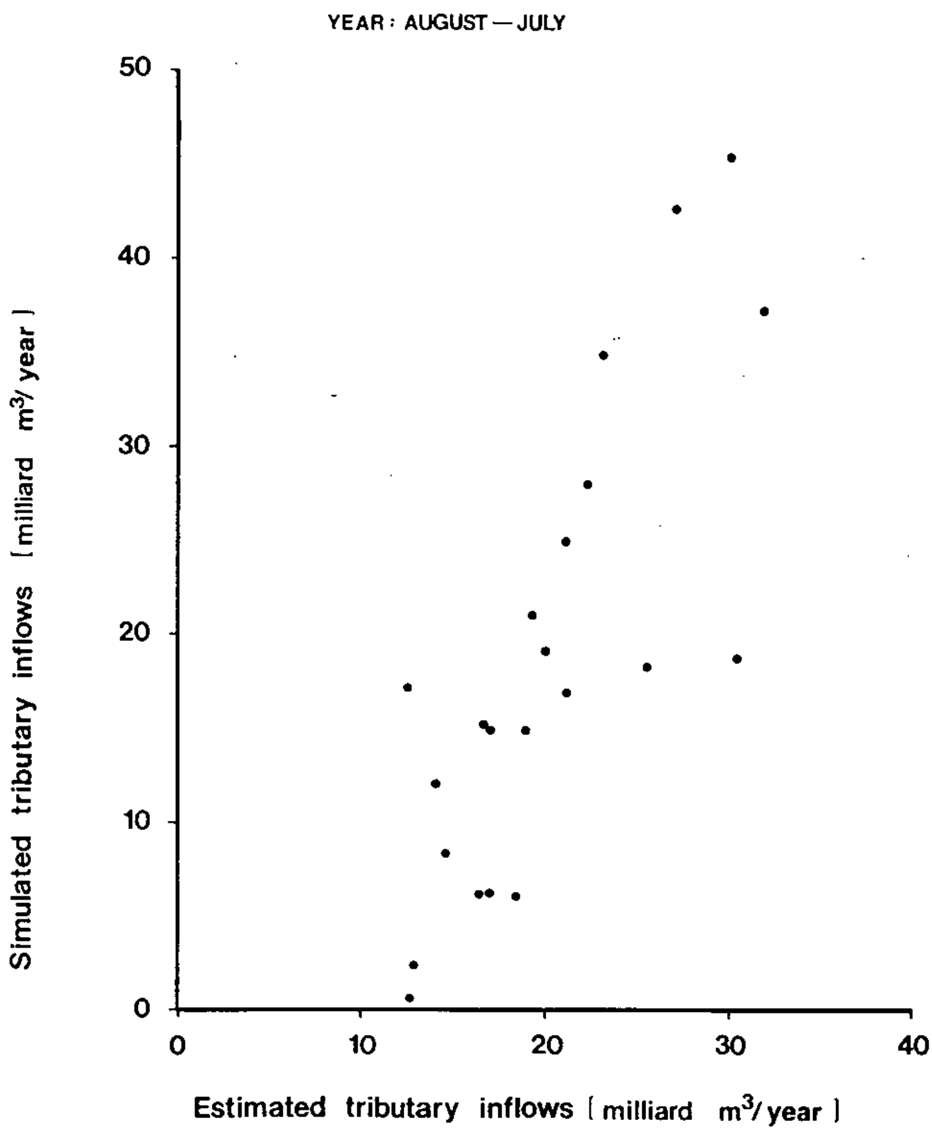


Figure 4.3

that and a few other of the early years. Indeed it would be surprising if a network of only 8 gauges produced consistently good estimates of rainfall over an area of 69000 km^2. But any overestimate during the early period of stable and relatively low lake levels will force the model to try to produce low tributary inflows to compensate. As the total tributary inflow for the later, 22 year, period is constrained to be consistent with that estimated from the records, correspondingly higher tributary inflows will be associated with the higher rainfalls in this period. Thus the variance of tributary inflows could well be exaggerated by the model in response to a few particular errors in the rainfall estimates.

Subject to some uncertainty about the variance of tributary inflows we have shown that the history of lake levels since 1925 can be reproduced reasonably well using a model which develops tributary inflows from the series of monthly lake rainfalls. But too much should not be read into this model. In the long run it amounts to scaling up a slightly adjusted difference between lake rainfall and open water evaporation. In the short term it provides a means of taking account of the varying monthly distribution of rainfall and the attenuation of runoff in the lake basin. However it is the trends of lake levels that are our main concern and therefore we have given less emphasis to the short term simulation of the lake balance.

4.4 ANNUAL MAXIMUM AND MINIMUM LAKE LEVELS

The analysis so far has been concerned with end of hydrological year levels and with the average seasonal distribution of lake levels. It is useful now to consider the maximum and minimum lake levels each year and how they could be estimated from the end of hydrological year levels.

The annual maximum lake level occurs almost always in May, occasionally in April, June or July. The minimum however can occur in any of the months August to March. The frequency of occurrence of the annual minimum in these months suggests that it is likely to occur in September to November if there is substantial rainfall in October to December, and in January to March otherwise. This frequency of occurrence of the maximum and minimum levels in the different months

TABLE 4.3. **Frequency of Occurence of Maximum and Minimum Lake Levels by Months**

	A	S	O	N	D	J	F	M	A	M	J	J
Maxima in observed series									2.5	46.5	3	1
Maxima in simulated series									5	47	1	0
Minima in observed series	2	7	10.3	6.1	2.3	5.3	11	8.9				
Minima in simulated series	3	6	13	6.5	1.5	4.5	13	5.5				

Note: Period of record is 1925/26 to 1977/78. Joint occurrence of extreme values in 2 or 3 months of the same hydrological year has been scored 0.5 or 0.3 respectively.

TABLE 4.4. **Differences Between End of July Lake Level and the Previous Maximum or Following Minimum Level**

	Difference in level (m)			
	End of July and previous maximum		End of July and following minimum	
	(observed)	(simulated)	(observed)	(simulated)
Mean	0.17	0.18	0.23	0.22
Standard deviation	0.07	0.05	0.12	0.08

was closely matched by the simulated lake level series described above as shown by Table 4.3.

We have examined the series of differences between the end of July lake level and either the previous maximum level or the following minimum level. The relevant statistics are summarised in Table 4.4. The observed and simulated lake level series gave similar results and both series showed a mean annual range of lake level of about 0.4 m. Simple tests show that for practical purposes the differences are normally distributed. Thus extreme levels can be deduced from the predicted end of July levels described later in this report, using the statistics in Table 4.4.

4.5 THE EFFECT OF STORAGE IN LAKE VICTORIA

We have already noted that the increase in storage in the lake in the period 1961-1964 is equivalent to 8 years of outflow at the pre 1961 rate. Yet the outflow increased by a factor of only about 2.5. Therefore the lake is capable of attenuating the inputs very strongly.

We can use the model already described to examine this attenuation by postulating a constant annual rainfall of any chosen magnitude and deriving the lake response starting from any chosen lake level. The annual rainfall is assumed to have a seasonal distribution given by that of the mean monthly rainfall in the 1925/26 to 1977/78 period. Because we are looking at an equilibrium condition in terms of tributary inflow simulation, the inflows are governed by the annual rainfall chosen and their seasonal distribution plays a minor part in determining the time series of lake levels or outflows.

Figure 4.4 shows the equilibrium lake levels and outflows corresponding to the chosen annual lake rainfall. While the gradient of the lake level - rainfall graph is lower at higher rainfalls, the reduction is not so marked as to suggest that there is a practical upper limit to lake level within a few metres of present levels.

As an example of the large range of conditions which could be illustrated, Figures 4.5 and 4.6 show the time series of levels and

Equilibrium lake levels and outflows for a given mean rainfall

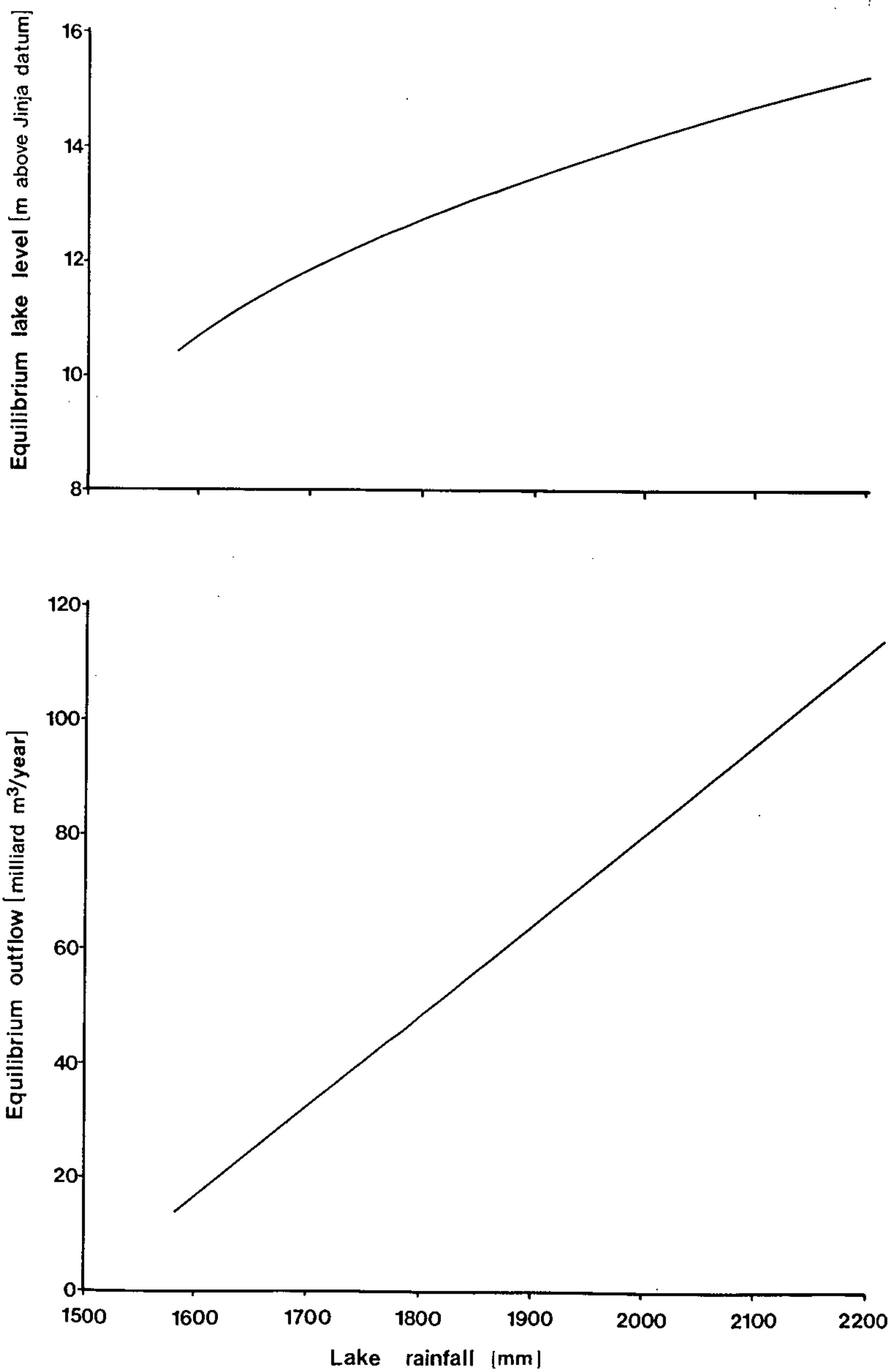


Figure 4·4

Transition lake levels for an assumed rainfall of 1700 mm

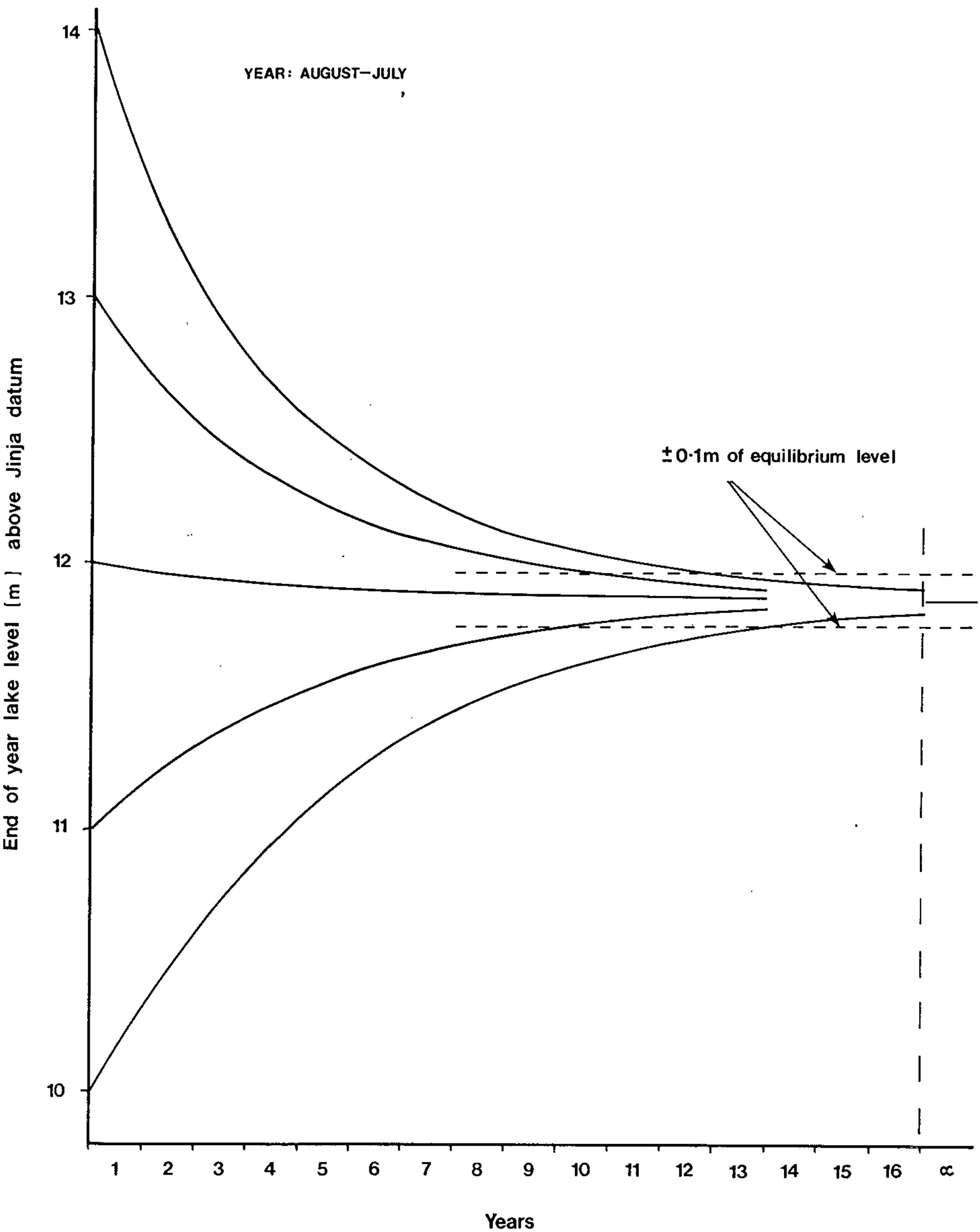


Figure 4.5

Transition annual outflows for an assumed rainfall of 1700 mm

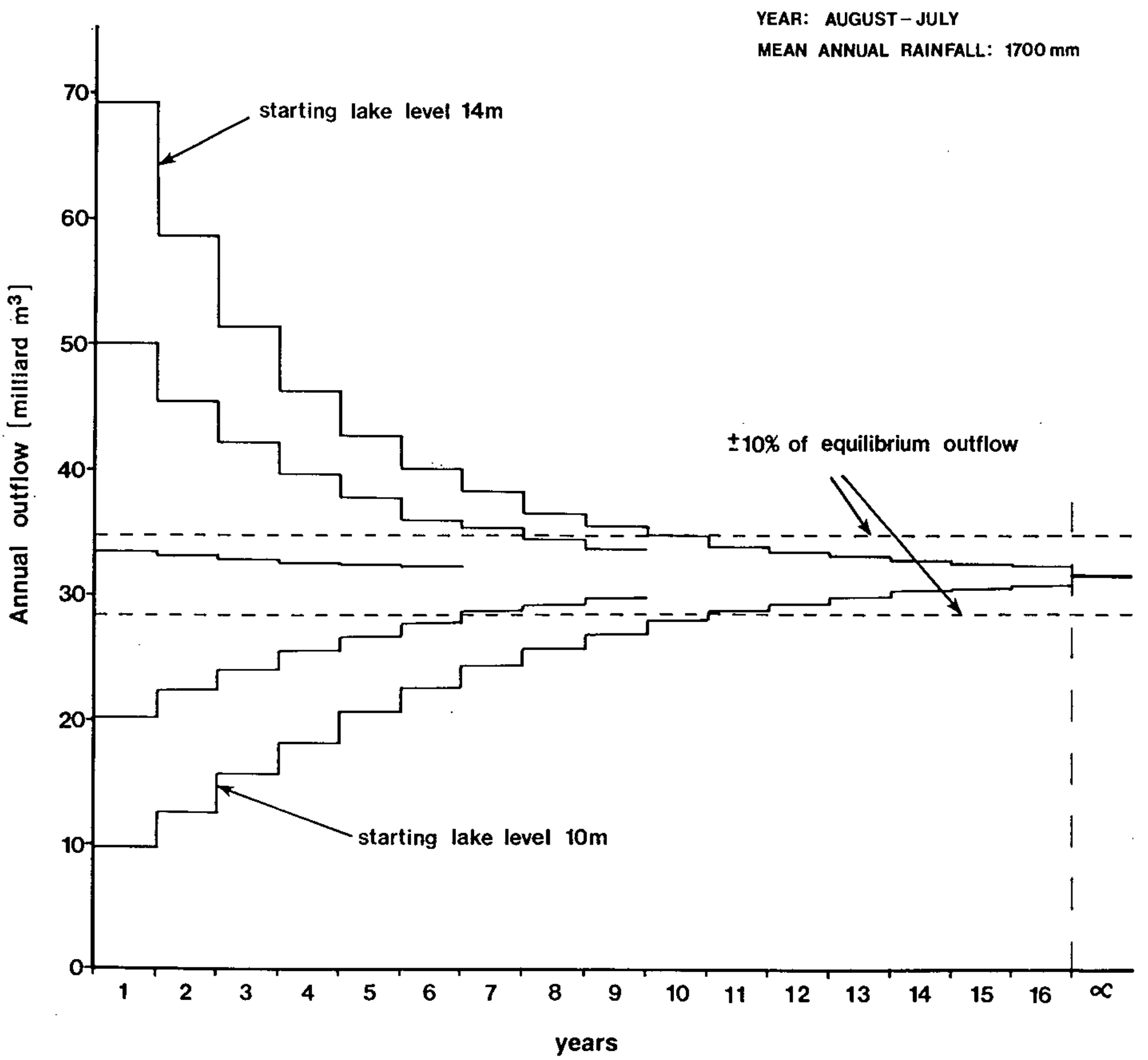


Figure 4·6

outflows respectively during the transition period given a mean annual rainfall of 1700 mm and a range of initial lake levels. It can be seen that if the lake is perturbed by only 1 m, it can take 10 years for levels to return to within 10 cm of the equilibrium level. For outflows, 8 years is required for the outflow to be within 10% of the equilibrium value.

It is interesting to apply these results albeit approximately to the period 1956/57 to 1972/73 to gain further insight into the dynamics of the lake. The mean annual lake rainfall for 1956/57 to 1960/61 was 1620 mm which would lead to an equilibrium lake level of 11.0 m and outflow of 19800 million m^3/year plotted on Figures 4.7 and 4.8 for this 5 year period. The observed end of year levels and outflows are plotted for comparison, and we can conclude that the lake was in equilibrium with the inputs at this time.

Imposing an average 2100 mm rainfall for the next three years, similar to the 2124 mm actual lake rainfall, gives the transition path for level and outflow plotted on the graphs; in both cases a reasonable representation of what occurred. It is interesting to note is that the lake response over the 3 year period is only a fraction of the change to an equilibrium level of 14.7 m and an outflow of 95000 million m^3/year which would have occurred had the rainfall been sustained at 2100 mm annually.

In fact the average rainfall in the next period was much lower; 1733 mm over the 9 year period to 1972/73. Figures 4.7 and 4.8 show the transition paths for level and outflows which would be followed for a range of mean annual rainfalls. A number of useful observations can be made: the time series of levels and outflows is very sensitive to small changes in the mean annual rainfall, the observed levels and outflows are consistent with the predicted transition curve for a mean rainfall of about 1700 mm, and outflows continued to rise in 1964/65 irrespective of the mean rainfall applied as did the observed outflow.

While it is evident that the mean rainfall after the events of 1961/62 to 1963/64 was significantly higher than the pre 1961/62 rainfall, the difference (110 mm/year) is small relative to the sharp increase in rainfall (500 mm/year) in the 3 years of rapid lake rise. Yet the lake levels and outflows decline slowly because of the attenuating effect of the lake storage.

Transition lake level curves applied to the 1956/57 — 1972/73 period

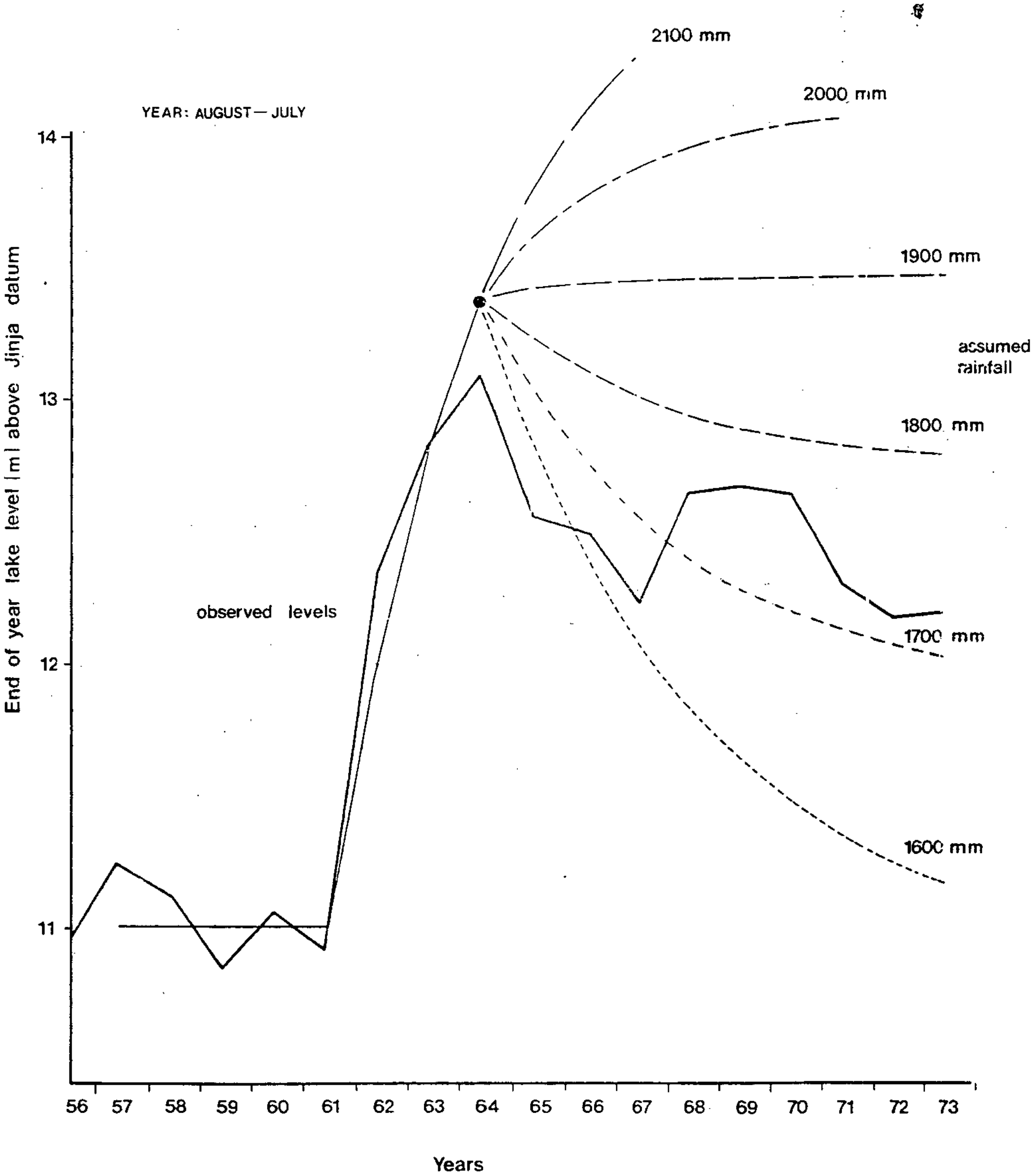
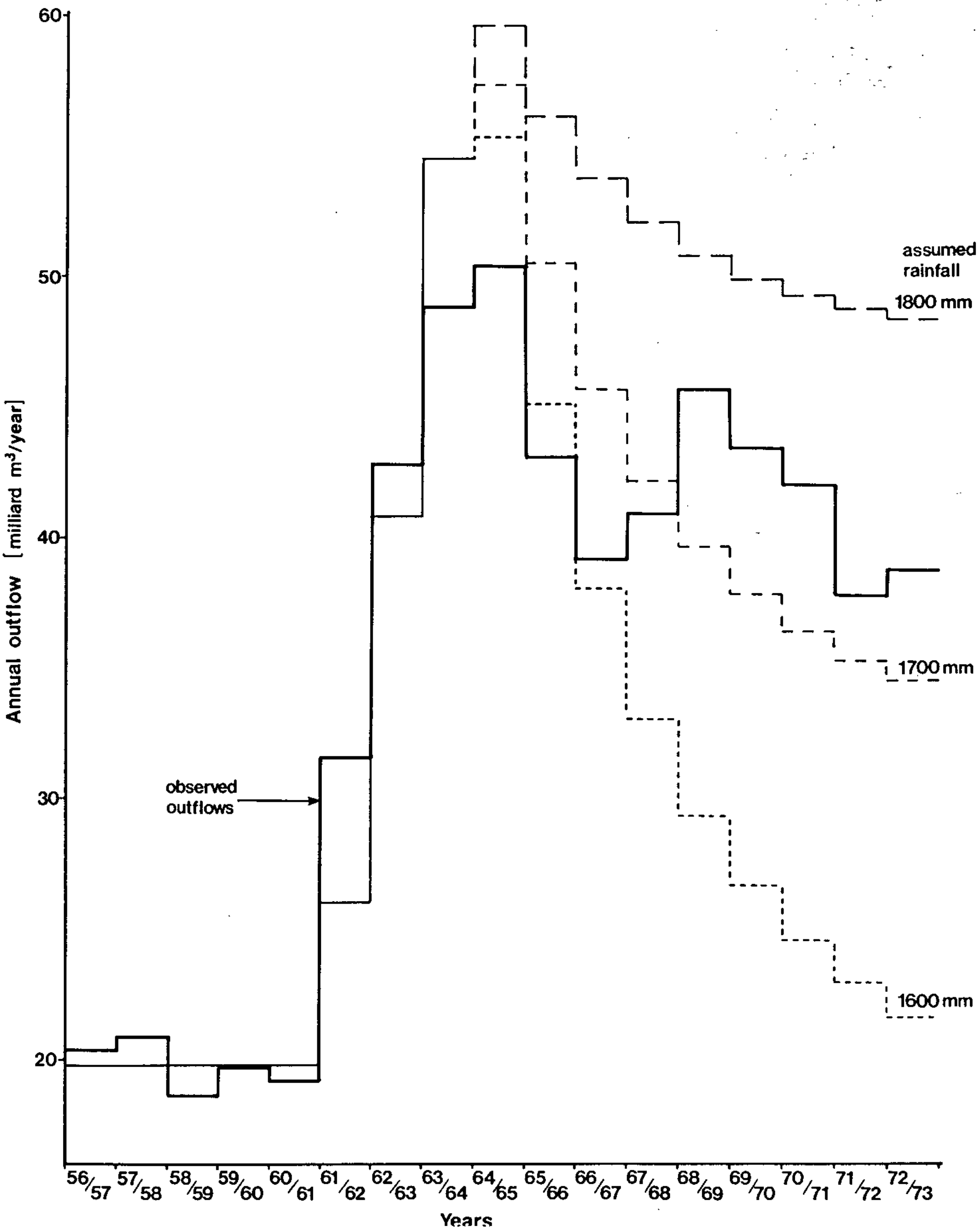


Figure 4.7

Transition outflow curves applied to the 1956/57 - 1972/73 period



5. TIME SERIES MODELLING OF RAINFALL

5.1 INTRODUCTION

In an earlier chapter, the historical record of the levels of Lake Victoria has been shown to be well explained by the lake rainfall series when the runoff from the land area of the catchment is handled by a simple rainfall-runoff model. The length of the rainfall series is much longer than any of the individual tributary flow records, which in any case represent only part of the surface runoff for most of the period. It is therefore natural to base a simulation study of the likely behaviour of the levels of the lake on a suitable stochastic model for the lake rainfall series alone coupled with a rainfall-runoff model. A different approach might have been possible had sufficiently long rainfall series for separate sites been readily available, as then it might have been possible to develop and include specific rainfall and runoff models for different regions of the catchment. Further, had rainfall records for separate sites been available, a joint stochastic model for these might have been used in simulations to form a single series representing the rainfall on the lake, for example by using the same set of weights as de Baulny and Baker (1970). Thus the choice made here has been at least partly dictated by the data readily available to us.

5.2 STATISTICS OF THE LAKE RAINFALL SERIES

Tables 5.1 and 5.2 present some simple statistics calculated from the lake rainfall series for the period 1925-1979, which was the longest period available. The mean rainfalls for the separate months of the year have peaks in April and December: the season of high rainfall which occurs in August in the north-east of the catchment is not reflected in the monthly means of this series, although it is often true that this month is a local maximum in individual years. March, April and May are the months of lowest year-to-year variability, as represented by their coefficients of variation. One feature of great interest in the data is the apparent increase in rainfall over the period of record, which is reflected by the rise in

TABLE 5.1 Statistics of monthly and annual lake rainfall

	mean (mm)	standard deviation (mm)	skewness	coefficient of variation	trend (mm/year)
Jan	135	55	0.65	0.41	0.29
Feb	140	56	0.20	0.40	0.49
Mar	191	54	-0.14	0.28	-0.01
Apr	252	51	-0.03	0.20	0.26
May	212	59	0.13	0.28	0.01
Jun	89	34	1.24	0.38	0.16
Jul	69	27	1.07	0.39	0.05
Aug	70	24	0.66	0.35	0.08
Sep	84	25	0.15	0.29	0.11
Oct	115	43	1.37	0.38	0.77
Nov	167	65	0.92	0.39	0.82
Dec	168	72	1.16	0.43	0.46
Total Jan-Dec	1690	201	0.38	0.12	3.48
Total Aug-Jul	1693	209	0.74	0.12	3.35

TABLE 5.2 Correlations of monthly and annual lake rainfall

Correlation with the month k months before

k =	1	2	3	4	5	6	12	24
Jan	.12	-.05	-.13	-.06	-.06	.03	-.29	-.05
Feb	.06	-.05	-.03	.07	-.23	-.03	-.09	-.15
Mar	.09	.13	.14	.36	.16	.01	.00	.17
Apr	.28	.02	-.02	-.04	.25	.19	-.26	.11
May	.00	.03	-.05	.01	.06	.04	-.02	-.13
Jun	-.16	.02	-.18	.11	-.10	-.09	-.07	.11
Jul	-.09	.03	-.06	-.06	-.13	-.06	-.15	-.09
Aug	.02	-.08	.26	-.16	-.03	-.22	-.10	-.14
Sep	-.15	.15	-.10	-.06	-.01	-.03	.28	-.06
Oct	.28	.01	-.07	-.02	-.00	-.07	.20	.01
Nov	.60	.17	-.06	-.23	-.04	.09	.04	.18
Dec	.20	.20	-.18	-.07	-.20	.20	-.20	.00

	Previous year	2nd last year
Annual totals Jan-Dec	.09	-.07
Annual totals Aug-Jul	-.05	.15

(sampling standard error of correlations is 0.14) lake levels: this is summarised here by quoting a figure for the average increase per year. It can be seen that October and November are the months which account for almost all the overall increase. Of the sample correlations between rainfalls in different months, shown in Table 5.2, that between November and October rainfalls is largest with a value of 0.6. Otherwise there is little pattern in these correlations beyond a suggestion that March and April rainfalls are related to the previous October and November.

The sample statistics of the rainfall show that the historical series has two features which distinguish it from a simple seasonal series of independent random variables, and a stochastic model for generating synthetic series must account for these in some way. The first of these features is the high correlation between October and November rainfalls with the correlation extending to the following March and April. It is difficult to assess the statistical significance of the features seen, but given that the sampling standard error of a correlation whose true value is zero would be about 0.14 for this sample size, a value of 0.36 for the second largest correlation observed is not too unexpected. Nevertheless, if a stochastic model is to generate data for which the year-to-year variances of both monthly values and yearly totals agree with that seen in the historical data, there must be some correlation between monthly values besides that of October - November: otherwise the variance of the yearly totals would be substantially smaller than that observed.

The second and probably most important feature of the data is the apparent increase in rainfall over the period of record. If the yearly totals were in fact independent, then there would be only a 1 in 25 chance of as large an increase or decrease over the period being observed in similar series. Among the individual months, the increase seen in October is equally significant; the increase for November is less unusual with a 1 in 7 probability. The apparent increases in the other months are not statistically significant. This assessment is based on the standard Student t-test and is substantiated by the related distribution-free test based on Normal scores. It follows that the year-to-year behaviour of the lake rainfall series cannot be explained by a model in which different years are generated two parameters: α and β in standard notation. In the model used here α and β are not only different for the different months of the year but α is allowed to vary from year to year. Once the parameters for the different months have been fixed, independent random variates are generated to obtain the synthetic rainfalls. By allowing the parameters α to vary randomly in an appropriate way, correlation both between months and between years can be built into the generated series. An interpretation of the parameters α and β is that the Gamma variate represents the sum of α separate random contributions each exponentially distributed and of average size β. Thus the model can be thought of as allowing the "raininess" in adjacent months and years to be related. The model is one type of doubly stochastic process.

It is convenient to describe the model by working with August to July years, since it includes an explicit connection between October, November and the following March and April. For any year y, a background random variable X_y and its transformation Z_y are defined to to represent "raininess": each has zero mean and unit variance and values of zero represent normal conditions, positive values representing wet conditions. The process $\{X_y\}$ is a second order autoregression with both lag one and lag two correlations equal to 0.3: specifically the two processes are simulated using the formulae

$$X_y \;=\; 0.231\,(X_{y-1} + X_{y-2}) + 0.928\,\varepsilon_y$$

$$Z_y \;=\; (\exp\,(0.413\,X_y + 1.875) - 7.73)/3.33$$

where ε_y are independent standard normal random variables. This between-year model is used to introduce a small amount of correlation between the monthly values in adjacent years. The one parameter here (0.3) was set at the smallest value such that the observed trend coefficients of monthly and yearly totals were judged to be adequately represented.

Synthetic rainfalls $R_{m,y}$ for month m of year y are generated as

$$R_{m,y} \;=\; c_m + G_{m,y}$$

where

independently. There is no implication that a model incorporating a linear trend must be used and indeed a stationary model incorporating correlation between years is probably more realistic in view of the high rainfall and lake levels experienced towards the end of the nineteenth century (Nicholson, 1980).

5.3 SIMULATION MODEL FOR LAKE RAINFALL

There are many possible approaches that one might take to formulating a stochastic model to represent the lake rainfall series, each predicated upon one's interpretation of the behaviour of the historical data. One such approach would be to describe the data as shifting between two otherwise stable mean levels in 1961. While such a shift is apparent in the yearly total rainfalls, it is not so clear in the series for individual months taken separately. The major difficulty with this approach is how the likely future behaviour of the rainfalls is to be modelled. The lake level record, even if incomplete for the late nineteenth century, could be brought in to argue for several shifts up and down having occurred within the past 120 years, but this would still leave the problem of specifying (in statistical detail) how often such shifts might occur in future, even assuming that only two possible levels for the mean was thought reasonable.

In fact, the sharp rise of the lake levels in 1961-64 is entirely explained by the occurrence of three consecutive years of relatively high rainfall coupled with the nonlinear response of the land catchment, rather than depending on a sustained increase in the overall amount of rainfall. Thus we argue that the rainfall series can be modelled without including explicitly changes between fixed mean levels; instead we have adopted a model which has been chosen to be as simple as possible while providing an adequate representation of the features observed in the data. In particular we have sought a model under which the statistics of correlation and trend calculated from the data are reasonably likely to have been observed.

The model for rainfall that has been adopted here is based on the Gamma distribution. This is a well-known distribution and has

$G_{m,y} \sim$ Gamma $(a_m + d_m Z_y,\ b_m)$.

That is, each monthly rainfall value is generated independently from the Gamma distribution with parameters $\alpha = a_m + d_m Z_y$ and $\beta = b_m$. Final values of the parameters are given in Table 5.3. The parameters d_m introduce correlation between months and are zero for those months not judged to be significantly correlated with the pivotal months October and November. For other months, values of d_m are fitted jointly with the set of parameters a_m and b_m using the method of moments based on the sample means, variances and between-month correlations. The parameters c_m are fixed on an ad hoc basis: while they do form a lower bound to the values of rainfall that can be generated, they have been used in this case to adjust the skewness of the marginal distributions: the parameter α of the Gamma distribution is always greater than one here, so that the probability density is zero at the lower bound and hence the values generated will be substantially greater than the bounding values.

To begin simulating from the model, initial values of the yearly process $\{X_y\}$ can readily be generated from the stationary distribution of the process. This is the approach taken here, and it is appropriate for situations where the generated rainfalls are to represent possible realisations where there is no information about the immediately preceding rainfalls. However, when trying to simulate rainfall sequences following the historical data, a more appropriate way of starting up is required. Unfortunately there is no direct way of imputing the current values of the background process $\{X_y\}$ and so a more empirical approach might be taken. Since the decline of the lake levels over the final 15 years of the record accords closely with a rainfall input of about average, the initial values for the $\{X_y\}$ process could be taken to be zero, corresponding to average conditions. Similarly, the initial values could be set to 1 or 2 to represent different degrees of above average rainfall.

5.4 ASSESSING THE FIT OF THE MODEL

Because of the way the model has been fitted it is necessarily true in the long term that the means and variances of the separate

TABLE 5.3 Parameters of the model for generating synthetic rainfalls

	a_m	b_m	c_m	d_m
Aug	8.15	8.58	0	0
Sep	13.42	6.23	0	1.47
Oct	8.73	9.72	30	3.33
Nov	9.47	14.43	30	3.33
Dec	4.59	32.37	20	0.60
Jan	5.95	22.67	0	0
Feb	6.10	22.88	0	0
Mar	16.48	11.58	0	2.28
Apr	27.12	9.29	0	1.90
May	12.92	16.42	0	0
Jun	3.57	17.80	25	0
Jul	4.83	12.19	10	0

monthly distributions generated by the model are exactly equal to the sample means and variances of the historical data. The extent to which the other statistics of the historical data are explained by the model has been investigated in the following way. The question is whether the observed statistics could reasonably have arisen from the population of similar statistics defined by the model. One measure of this is to calculate the difference between the observed statistic and the population mean divided by the standard deviation. The population mean and standard deviation are readily calculated by using the rainfall simulation model to generate a large number (400 in this case) of synthetic series of the same length as the historical data and calculating the statistic for each sample. Table 5.4 presents the results of this analysis for a number of different statistics. When considering the degrees of fit measured in the above way, an absolute value of below 2 for any individual statistic would probably be regarded as indicating no serious lack of fit. The values of the degree of fit are largest for the correlations between-months in adjacent years and many of these large values are associated with negative sample correlations: no attempt has been made to build negative correlations, either between-months or between-years, into the model.

The model chosen here seems to be reasonably good at reflecting the observed behaviour of lake rainfall series. The synthetic series generated by the model have long-term monthly and yearly means identical to the means of the historical record of 55 years and the variation over years of the monthly and yearly totals is also preserved.

5.5 UNCERTAINTY OF PARAMETER ESTIMATES

The model was adjusted to produce positive correlation between months so as to preserve exactly the variance of the yearly totals, and thus the variance should probably be interpreted as a parameter of the model even though it does not appear explicitly as such. It is probably this variance together with the annual mean which will have most effect on the simulation study of lake levels performed here,

TABLE 5.4a Analysis of fit of rainfall simulation model, for mean and standard deviation statistics

	MEAN				STANDARD DEVIATION			
	Obs	mean	st dev	degree of fit	Obs	mean	st dev	degree of fit
Jan	134.8	134.7	7.5	0.0	55.3	55.2	6.4	0.0
Feb	139.5	139.8	7.7	0.0	56.5	55.8	6.4	0.1
Mar	190.8	191.3	8.8	-0.1	53.9	53.4	6.5	0.1
Apr	251.8	252.2	7.9	-0.1	51.5	51.3	5.3	0.0
May	212.2	211.3	8.3	0.1	59.0	58.2	6.2	0.1
Jun	88.6	88.6	4.2	0.0	33.7	33.2	4.0	0.1
Jul	68.8	68.9	3.4	0.0	26.8	26.6	3.1	0.1
Aug	70.0	70.0	3.5	0.0	24.5	24.1	2.8	0.1
Sep	83.6	84.1	3.7	-0.1	24.6	24.3	2.6	0.1
Oct	114.8	115.0	8.5	0.0	43.3	42.3	6.3	0.2
Nov	166.6	166.9	12.2	0.0	65.5	63.7	9.1	0.2
Dec	168.5	168.3	10.7	0.0	72.0	70.6	8.5	0.2
Total								
Jan-Dec	1690	1691	42	0.0	201	200	24	0.0
Aug-July	1693	1691	42	0.1	209	216	26	-0.2

TABLE 5.4b Analysis of fit of rainfall simulation model, for skewness and inter-month correlation

	SKEWNESS				CORRELATION WITH PREVIOUS MONTH			
	Obs	mean	st dev	degree of fit	Obs	mean	st dev	degree of fit
Jan	0.65	0.70	0.36	-0.14	0.12	0.0	0.13	0.98
Feb	0.20	0.66	0.38	-1.22	0.06	0.0	0.12	0.45
Mar	-0.14	0.53	0.39	-1.70	0.09	0.01	0.14	0.59
Apr	-0.03	0.38	0.35	-1.17	0.28	0.16	0.14	0.90
May	0.13	0.46	0.32	-1.03	0.00	0.0	0.14	0.0
Jun	1.24	0.92	0.41	0.78	-0.16	0.01	0.13	-1.27
Jul	1.07	0.76	0.38	0.82	-0.09	0.0	0.13	-0.66
Aug	0.66	0.56	0.36	0.28	0.02	-0.01	0.13	0.23
Sep	0.15	0.49	0.32	-1.05	-0.15	0.0	0.14	-1.04
Oct	1.37	0.88	0.42	1.19	0.28	0.26	0.14	0.14
Nov	0.92	0.83	0.45	0.20	0.60	0.53	0.12	0.63
Dec	1.16	0.81	0.38	0.92	0.20	0.18	0.14	0.14
Total								
Jan-Dec	0.38	0.36	0.34	0.04				
Aug-July	0.74	0.49	0.37	0.68				

TABLE 5.4c Analysis of fit of rainfall simulation model, for inter-year correlation and coefficient of trend

	CORRELATION WITH PREVIOUS YEAR				COEFFICIENT OF TREND			
	Obs	mean	st dev	degree of fit	Obs	mean	st dev	degree of fit
Jan	-0.28	-0.03	0.13	-1.94	0.29	0.00	0.45	0.64
Feb	-0.09	-0.01	0.13	-0.60	0.49	-0.04	0.50	1.06
Mar	0.0	0.04	0.15	-0.24	-0.01	0.04	0.52	-0.09
Apr	-0.25	0.02	0.13	-2.03	0.26	0.04	0.49	0.44
May	-0.02	-0.02	0.14	0.02	0.01	0.01	0.47	0.01
Jun	-0.07	-0.02	0.12	-0.44	0.16	-0.01	0.28	0.60
Jul	-0.15	-0.02	0.13	-0.97	0.05	-0.03	0.24	0.34
Aug	0.10	-0.02	0.12	0.98	0.08	0.01	0.21	0.34
Sep	0.28	0.01	0.14	1.86	0.11	0.01	0.22	0.47
Oct	0.20	0.12	0.14	0.60	0.77	0.0	0.49	1.56
Nov	0.04	0.11	0.15	-0.48	0.82	0.07	0.74	1.02
Dec	-0.20	0.01	0.13	-1.59	0.46	0.03	0.64	0.67
Total								
Jan-Dec	0.09	0.20	0.14	-0.82	3.48	0.12	2.38	1.41
Aug-July	-0.05	0.11	0.15	-1.01	3.35	0.09	2.45	1.33

although all of the other parameters have a separate effect, not least because of the non-linear rainfall-runoff model that is included.

An adequate indication of how well the long-term mean and variance are determined by the available 55 years of data can be obtained by applying the standard theory for independent Normal random variables to the yearly totals. This is because the skewness and between-year correlations are small. Treated in this way approximate 95% confidence intervals for the long term mean and year-to-year standard deviation are (1636, 1744) and (170, 249) for the central estimates of 1690 mm and 201 mm, respectively. These intervals are likely to underestimate the uncertainty about the parameters.

The sample standard deviations of various statistics calculated from the synthetic rainfall data (Table 5.4) give a good insight into the sampling variability of the simple moments, on which the estimates of the parameters have been based. Because of the ad hoc way in which the model parameters were fitted it is impossible to give an objective assessment of the uncertainty inherent in the entire set of formal parameters. Table 5.4 indicates the extent to which 55 years of data are sufficient to determine the mean, standard deviation and skewness for each month, and the correlations between months.

6. STOCHASTIC SIMULATION OF LAKE LEVELS

6.1 RISK OF EXTREME LEVELS

The three components of the overall model for the levels of Lake Victoria have been described in earlier chapters: the stochastic model for rainfall, the rainfall-runoff model for tributary flow and the water balance model for the lake itself. A probabilistic assessment of the future behaviour of the levels and of outflow for the lake can therefore be obtained and this is now described.

In practice one would like to have information about the likely behaviour of the future lake levels making maximum use of data about current conditions. This would involve using recent data of rainfalls to compute values of catchment storage and soil moisture deficit with which to start the rainfall-runoff model, as well as using the most recent lake level to start the simulation of the lake itself. However, a consistent series of lake rainfall is available to us only up to the end of 1979. Hence, in order to provide information about future levels not tied to an out of date starting condition a more objectively determined initialisation has been used. Specifically, using the fitted rainfall-runoff model, the end of December catchment conditions were determined for each year of 1925-1979 using the historical record of rainfall. From these, average values of implied catchment storage and soil moisture deficit were determined: these values have been used as initial conditions for all of the simulations reported here. The range of catchment conditions seen in the historical data has been found in trials to make a difference in levels of the lake of as much as 0.65 m in the first two years, with the difference becoming slowly smaller in subsequent years as seen in Chapter 4. Thus by using the average conditions an error of less than 0.3 m in the first two years should be incurred.

When calculating future levels of the lake for a given inflow series, we take as our basic case the assumption that outflow from the lake will be according to the agreed "natural flow" curve. As the outflow from the lake is in practice limited by the physical constraints of the Owen Falls Dam, we have also looked briefly at the effect that this limitation would have: for this case, a maximum outflow of 216 million m^3/day has been assumed. In all cases an unlimited lake level has been allowed as, although this is unrealistic, it has itself no effect on the calculation of the probability of reaching a given high level.

The results reported here are based on 1000 sequences of synthetic rainfall each representing 30 years of monthly values. The same set of sequences was applied for each of the initial lake levels considered as this gives a better indication of the sensitivity to initial lake levels of the probabilities investigated. Because only a limited sample is used there is clearly some statistical uncertainty in the probabilities calculated: this uncertainty can be expressed by the following 95% confidence intervals applied to the quoted probabilities.

lower limit	estimated probability	upper limit
0	0.0	0.003
0.0003	0.001	0.005
0.002	0.005	0.01
0.005	0.01	0.018
0.04	0.05	0.065
0.08	0.1	0.12
0.47	0.5	0.53

Results for a number of different initial lake levels are presented here: these correspond to beginning of January levels. To reduce computation costs only levels for the end of July have been examined. We have found empirically that reasonable estimates of maximum and minimum lake levels can be derived by using the mean differences given in Table 4.4.

Some examples of the simulations are presented in Figure 6.1 and these show that large variations in lake level are quite likely to occur in future. Figure 6.2 shows one case in which the simulated lake levels reached the point where the constraint on the outflow would come into effect, and shows the different courses taken by the levels in the two cases.

Examples of 30 year simulations

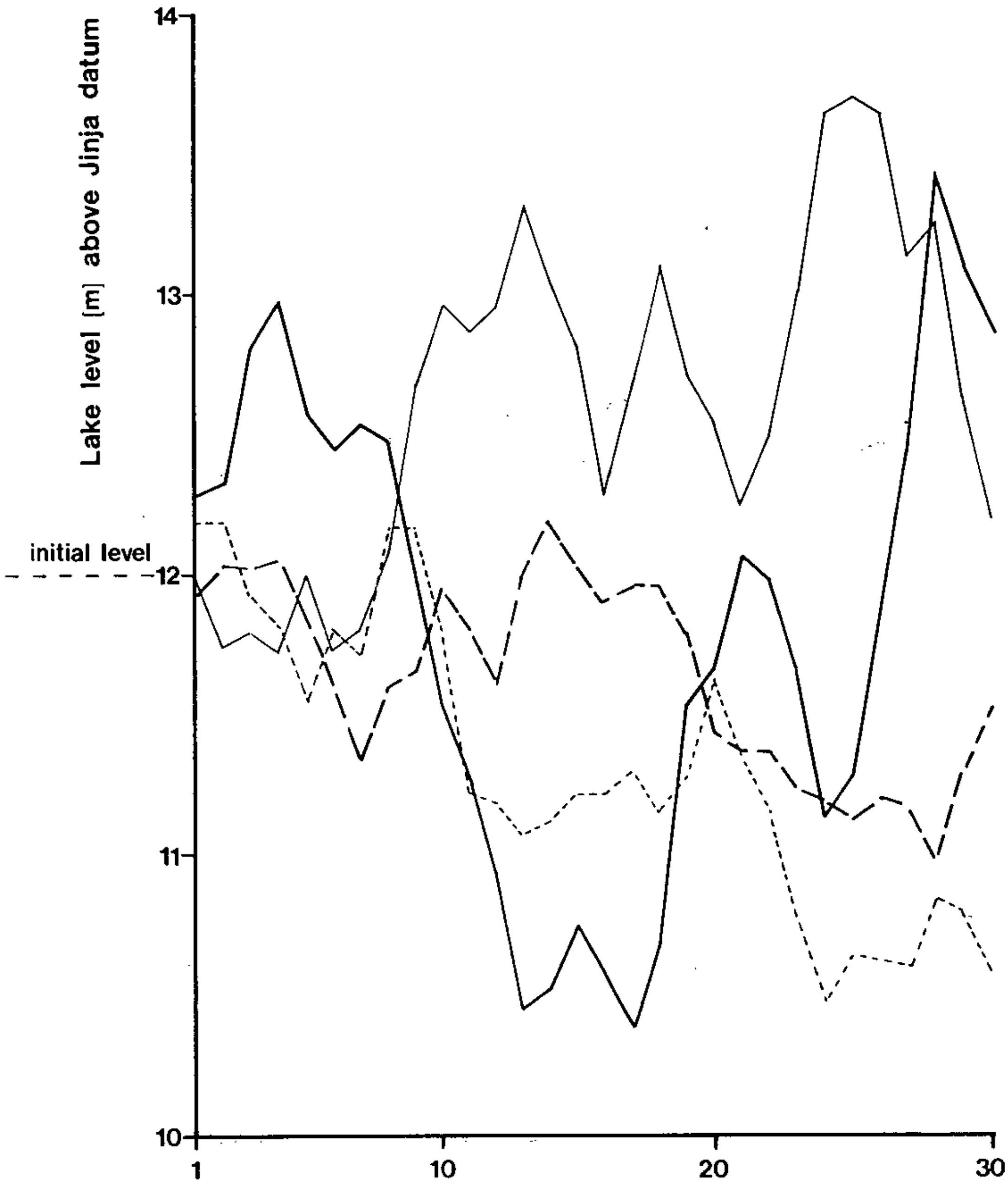


Figure 6-1

Example of the effect of the constraining lake outflow

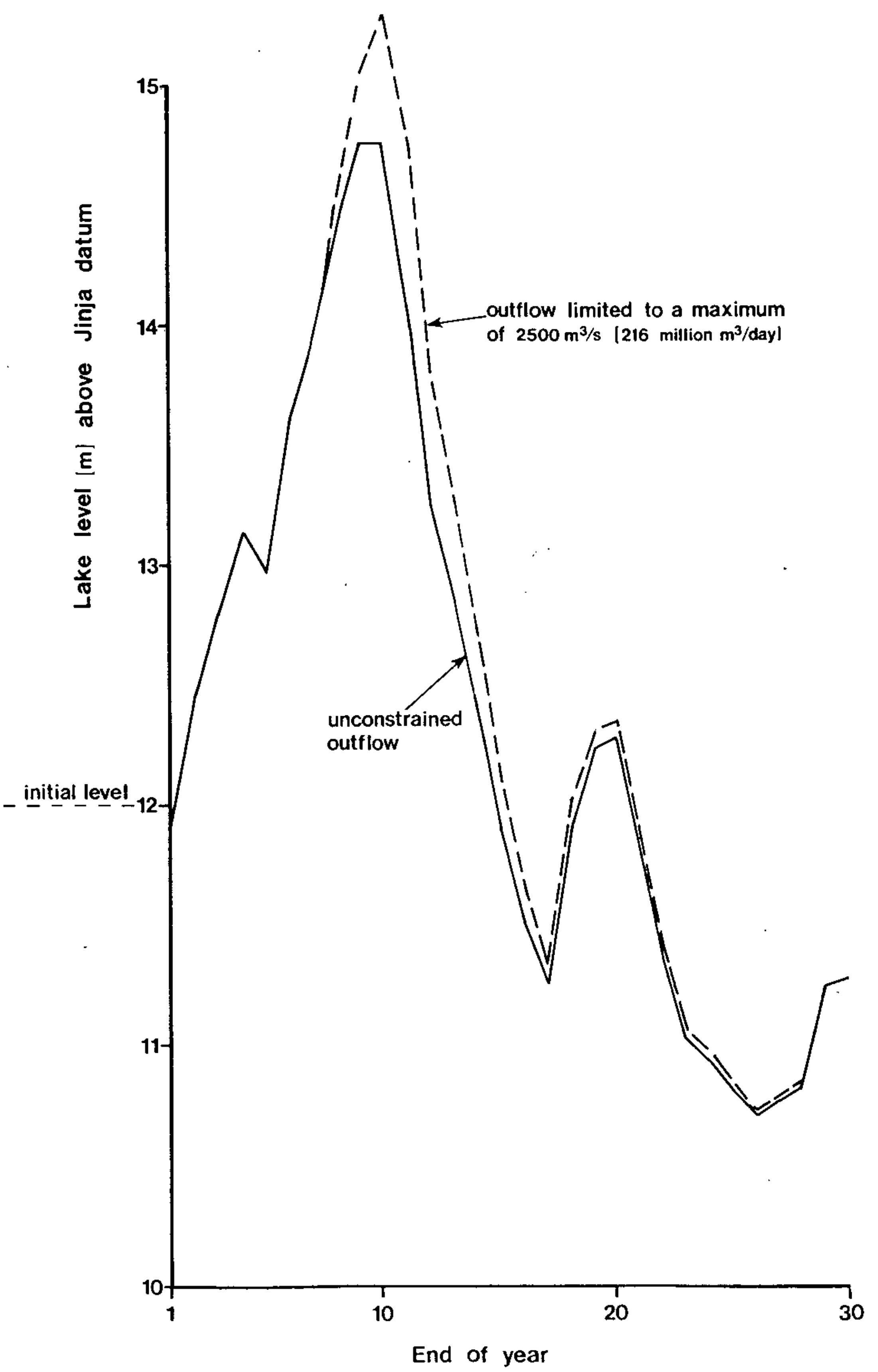


Figure 6·2

The development over time of the probability distribution representing possible lake levels for July of any given year is shown in Figure 6.3. It can be seen that the distribution reaches a stable condition fairly slowly with the median level approaching an equilibrium level in much the same way as seen earlier for the case of a constant rainfall. Figure 6.4 illustrates the evolution of the distributions for the other starting levels.

The lines in Figures 6.3 and 6.4 could have been smoothed to eliminate variations caused only by the use of 1000 simulations to estimate rare events. We have left the curves as they appear in order to illustrate the range of uncertainty pending the use of many more simulations when realistic operating conditions are devised.

The maximum and minimum levels achieved within time horizons of 30 and 15 years from a given starting level are the subject of Figures 6.5 and 6.6 respectively. Here it can be seen that the initial starting level of the lake has only a little effect on the levels which are reached in only 1 out of 10, or fewer, of the simulations. Thus it is clear that the long-run probabilities of levels exceeding or falling below the levels shown in any period of 30 or 15 years will be little different from the values given in these Figures, at least for probabilities of less than 0.1. In particular, in 1 out of 100 periods of 30 years levels of the lake will reach or exceed 14.65 metres: an adjustment of this figure to 14.82 metres would be appropriate to convert to annual maximum levels, rather than July levels. The effect of the practical limitation on the releases from the dam would lead to a further increase of 0.25 metres in the levels reached with this probability: the limitation on releases comes into effect at 14.04 metres, a level reached in only 1 out of 20 periods of 30 years.

The limited number of stochastic simulations reported means that the rarest extreme levels are estimated only rather imprecisely: thus levels given as being reached in only 1 out of 1000 simulations may have a true probability of recurring between 3 in 10,000 and 1 in 200. However, since these higher lake levels are beyond the present capacity of the dam, it has not been thought worthwhile refining these estimates by increasing the number of simulations.

Probability of end of July lake levels not being exceeded in any one year

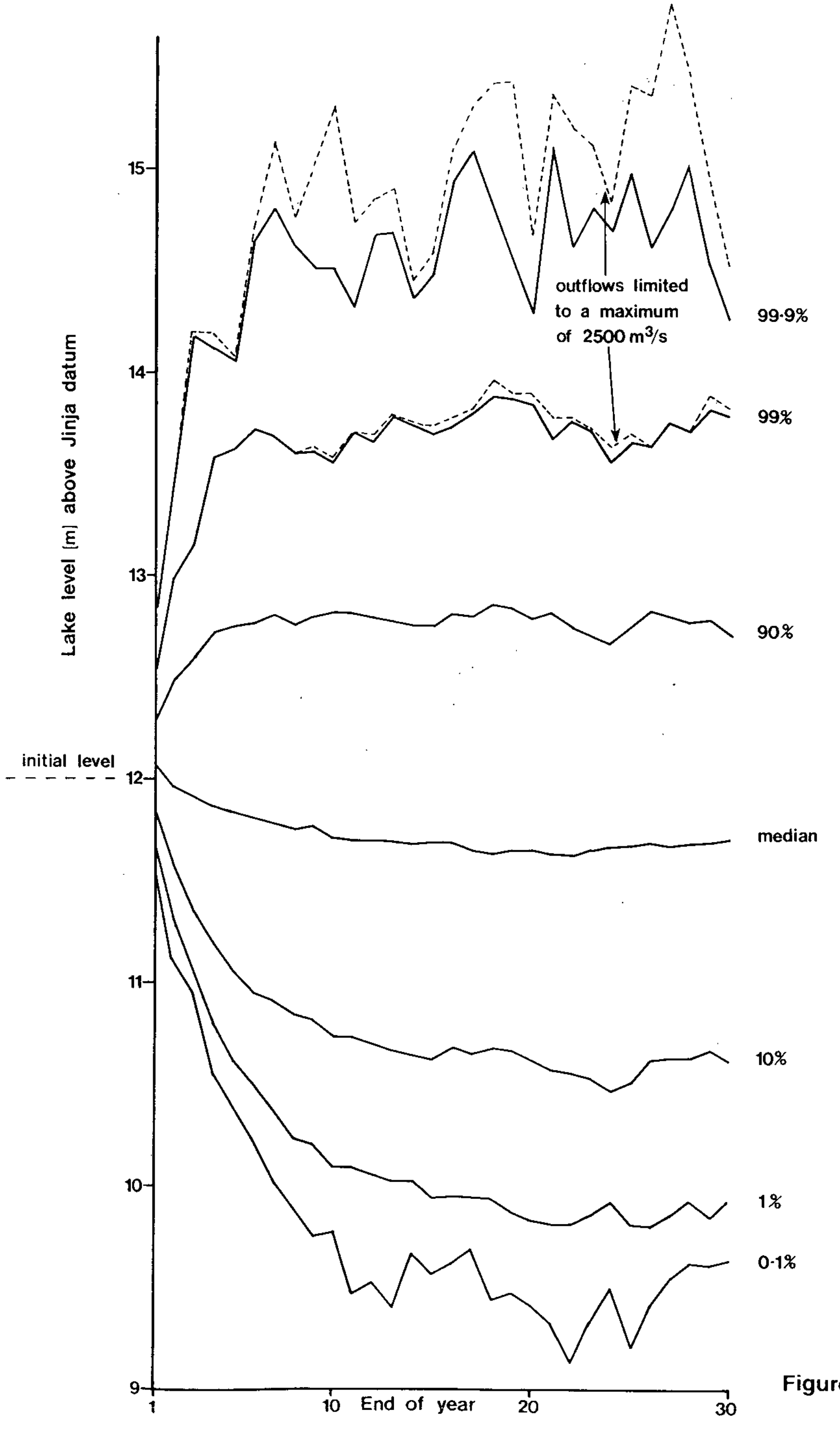


Figure 6·3

Effect of starting level on probability of end of July lake levels not being exceeded

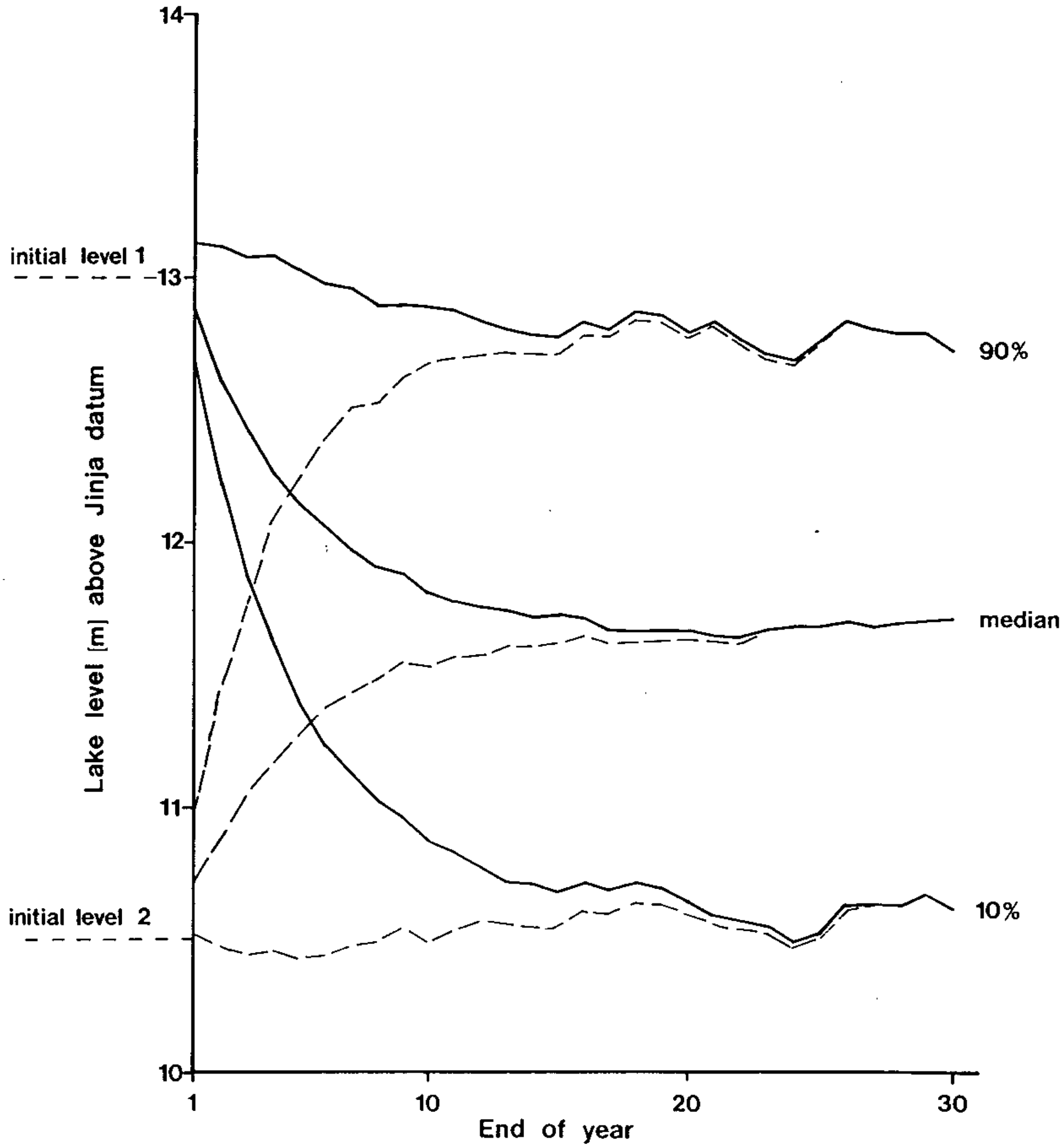
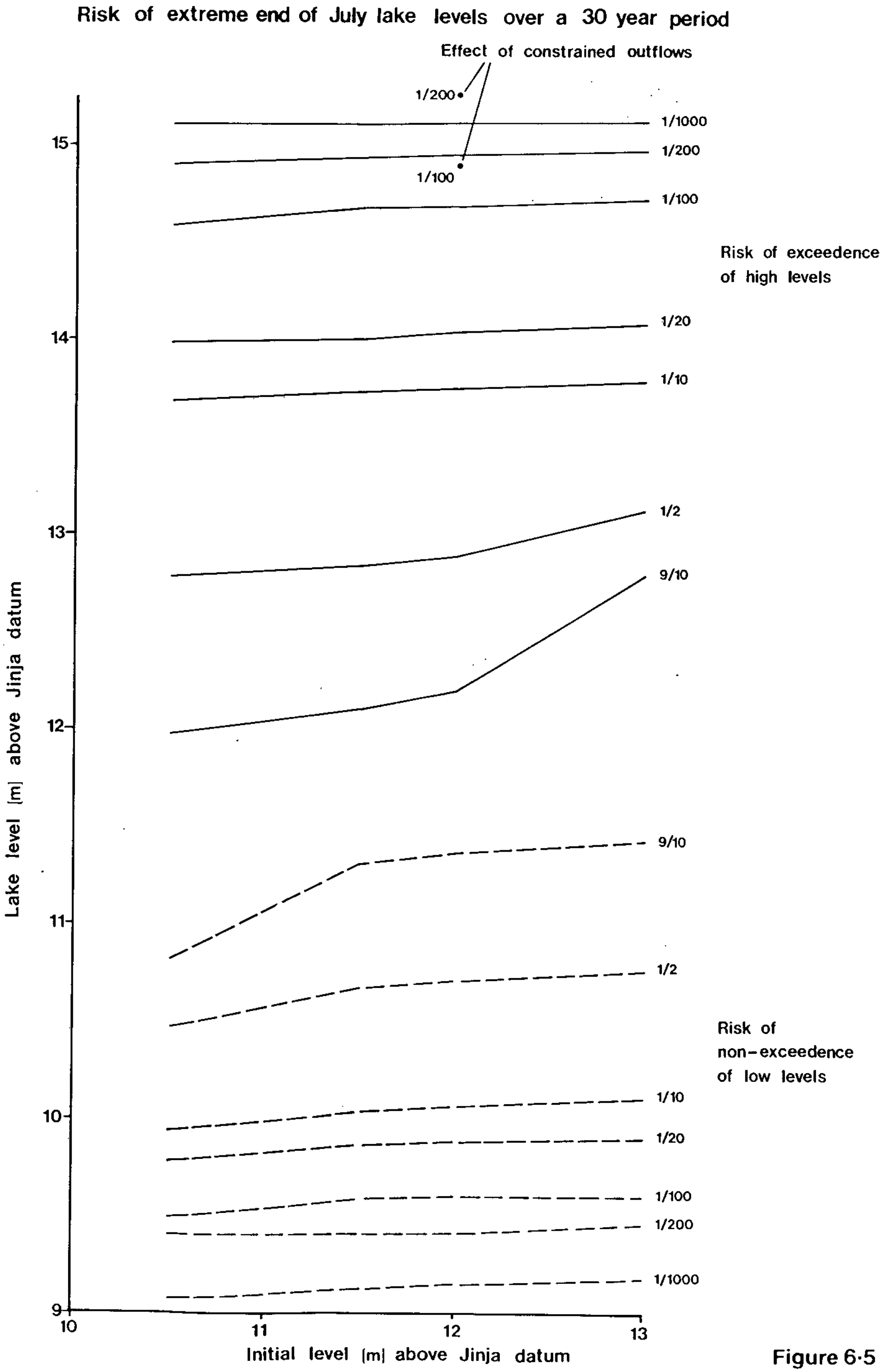


Figure 6·4



Risk of extreme end of July lake levels over a 30 year period
Effect of constrained outflows
1/200
1/100
1/1000
1/200
1/100
Risk of exceedence of high levels
1/20
1/10
1/2
9/10
9/10
1/2
Risk of non-exceedence of low levels
1/10
1/20
1/100
1/200
1/1000
Lake level (m) above Jinja datum
15
14
13
12
11
10
9
10
11
12
13
Initial level (m) above Jinja datum

Figure 6·5

Risk of extreme end of July lake levels over a 15 year period

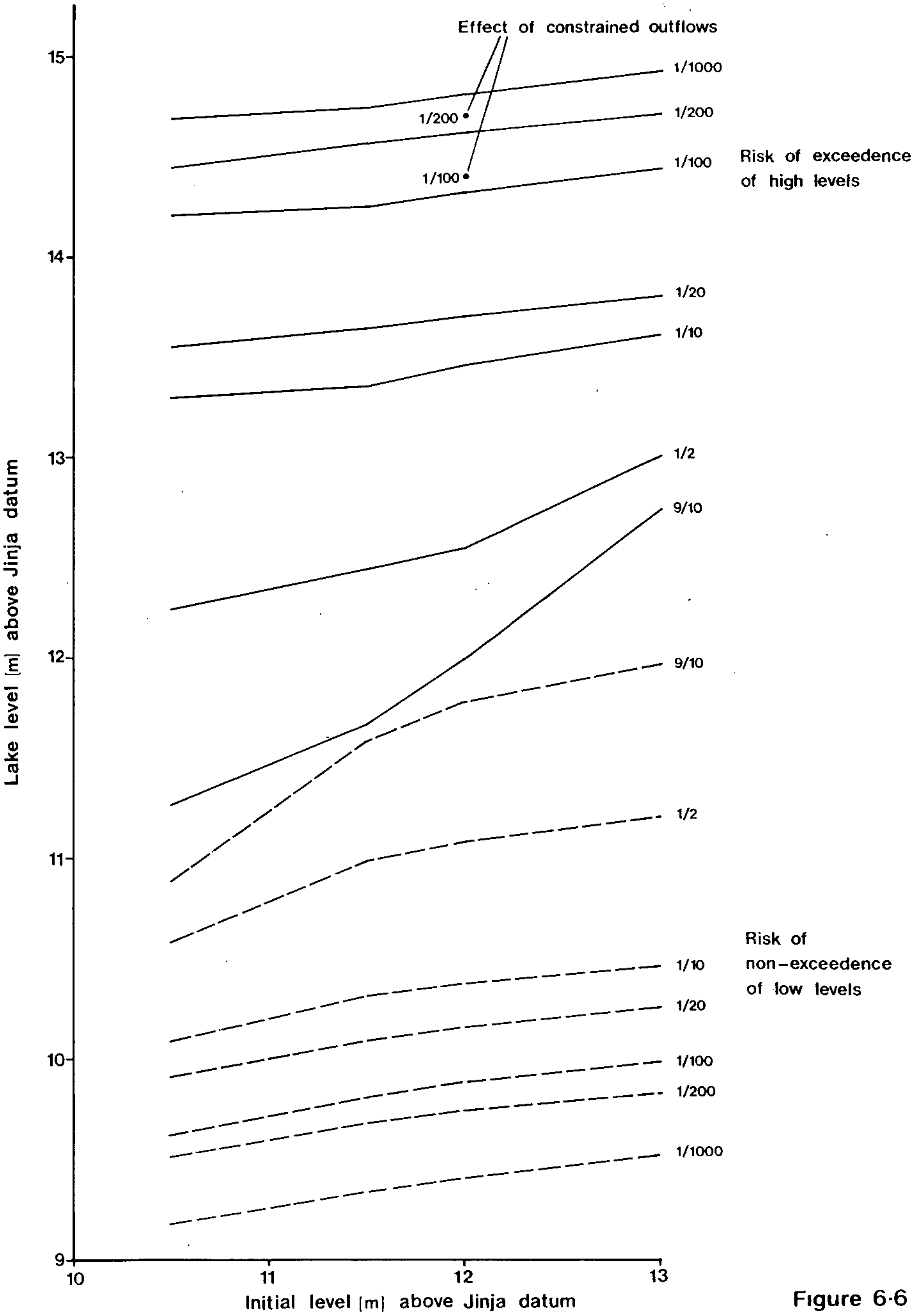


Figure 6·6

During the period 1925 to 1977, the highest and lowest end of July lake levels observed were 13.09 and 10.70 metres respectively. The simulation results suggest that, given the current lake levels, each of these records has roughly a 1 in 2 chance of being broken within a time horizon of 30 years.

6.2 ASSESSMENT OF THE OVERALL MODEL

The stochastic model for rainfall has been shown to be an adequate representation of the historical data of lake rainfall, and the rainfall-runoff model and lake water balance model together with the rainfall record have been shown to explain the observed variations in lake level. However it has become apparent from the simulation of lake level that the long period of relatively stable low lake levels observed from 1900 to 1960 might be regarded as rather anomalous if compared with similar sets of simulated data. There has not been time for a full analysis of this point but Figure 6.7 is indicatory: this shows the probability distribution of the range of end-of-July lake levels observed in the simulations over time periods of 15 and 30 years. For lake levels generated by the simulation model, a period such as that of 1925-1960, during which the range of lake levels was less than 1.5 metres, is clearly fairly unlikely to occur. A better way of assessing the overall model would be to consider the low period of 1900 to 1960 as being the longest period of low levels observed in the extended record of levels from about 1860 to 1979 and to see how unusual such a period would be.

Two possible explanations of this apparent anomaly might be either that the rainfall-runoff model coupled with the lake model may be producing simulated lake levels that are too variable, for which there is perhaps some evidence in Figure 4.1, or that the distribution of simulated rainfalls is not skew enough. Actually the implication would be rather that the combined model does not produce effective inputs to the lake balance which have the right distribution. It will be recalled from Section 3.2 that the error of the annual lake water balance given best estimates of tributary flow was equivalent to a standard deviation of 160 mm: by comparison with the year to year standard deviation of observed rainfalls of 200 mm, this indicates a

Probability distribution of the range of lake level in 15 and 30 year periods

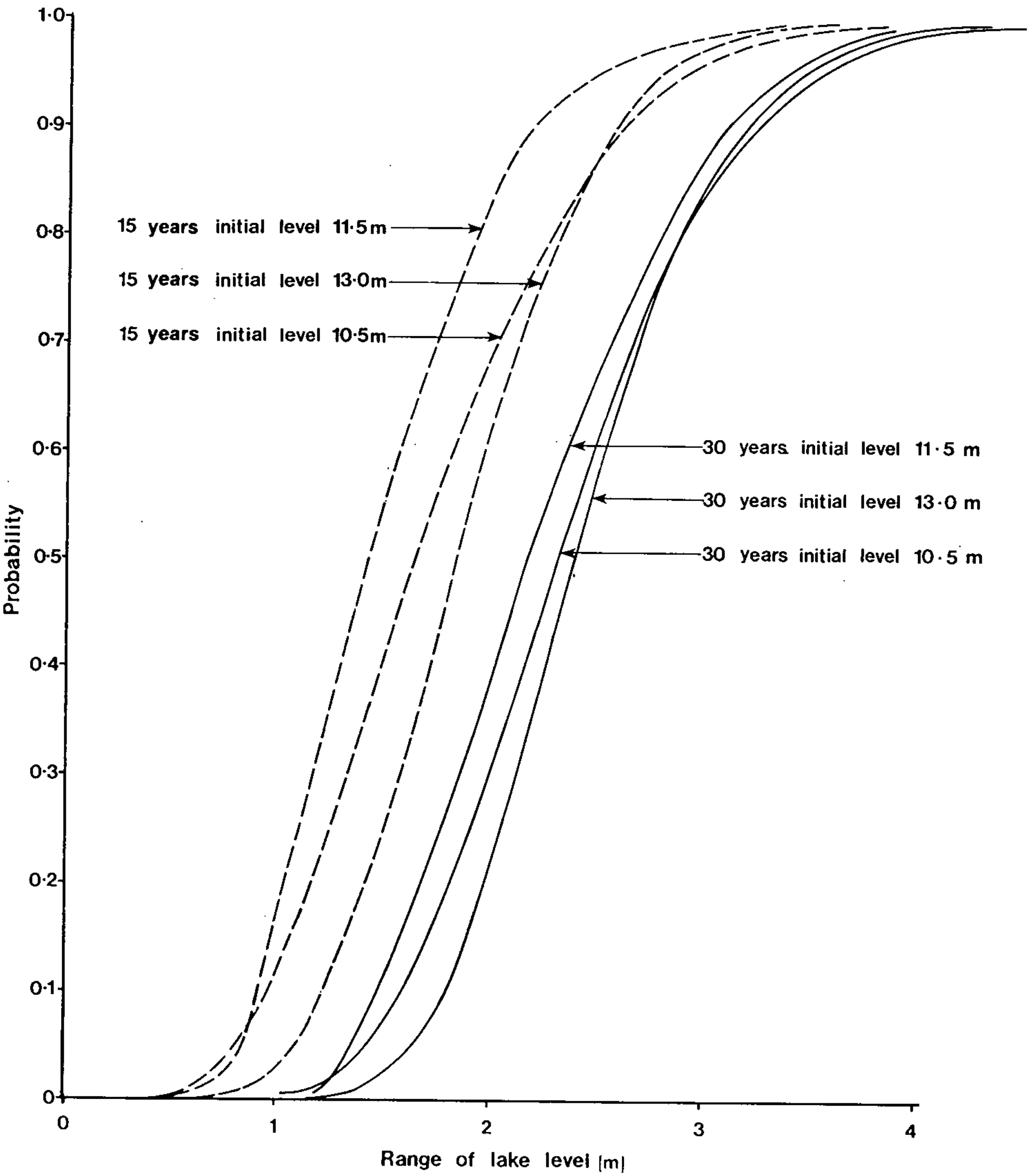


Figure 6·7

large estimation error in the lake rainfall series which could be masking the true statistics of lake rainfall. While it would be possible to tinker with the models used here it may well be that substantial improvements can only be made by developing more complex models based on more extensive data.

The results concerning the risk of extreme lake levels described here have been based on the stochastic model for rainfall described in Chapter 5. This model is such as to produce simulated rainfall sequences whose overall mean and variances are based on the limited record of 55 years of data. An indication of the ranges within which the true values of the mean and standard deviation of yearly total rainfall might actually lie were given in Section 5.4, and these are quite wide. We have chosen to base the results in this chapter on the assumption that the future rainfall will have parameters agreeing with our best estimates. The extent to which the results would be affected by the uncertainty about the parameters can be judged in the following way. For the purposes here the overall model can be treated as being essentially linear, and uncertainty in the parameters of the rainfall model can be regarded as lumped into the uncertainty about the yearly means and standard deviations. With these assumptions, a reduction in the between-years standard deviation of rainfall would lead to a reduction by the same factor in the spread of the distribution of lake levels at any given time: the effect on the equilibrium median level of a change in the mean rainfall would be given by the curve in Figure 4.4.

7. FLOWS IN THE VICTORIA NILE

7.1 INTRODUCTION

The outflows from Lake Victoria enter Lake Kyoga without significant change over the monthly time scale that we are considering. However the water balance of Lake Kyoga and its catchment area including the Kafu has a seasonal effect on the flows at Masindi Port just below the outlet from the lake. For practical purposes we can assume that there are no further significant gains or losses from Masindi Port to the inlet to Lake Albert.

Rainfall, evaporation and tributary flow data for the Lake Kyoga area are less complete and less fully analysed than those for Lake Victoria. Thus the net effect of the Lake Kyoga balance is best examined by comparing the outflows from the two lakes. As the annual differences are small, generally about 10% of the total annual flow, it is evident that the accuracy of measurement of these flows is more important than the precise determination of the other factors in the Lake Kyoga water balance.

The sources of outflow data for Lake Victoria have been described earlier in this report. Outflows from Lake Kyoga are derived from river level measurements and rating curves at a number of stations covering different periods. Historically the principal station was Masindi Port where river level data were collected from 1912. The flow record for the period 1912-1937 was derived from a single rating curve based on gaugings carried out in 1922-1923 and 1932-1936. This record was extended to 1939. From 1940 Victoria Nile flows were derived from river levels at Kamdini using regularly updated rating curves. We understand that the record from 1912-1978 published in the WMO Phase II report is a composite of these separate basic records. In general we should expect the accuracy of the records after 1940 to be significantly better than that of the earlier records.

7.2 THE WATER BALANCE OF LAKE KYOGA

Given the inflows, outflows and change in level of Lake Kyoga we can derive a net balancing term which is the difference between rainfall and evaporation over the lake and swamp areas plus the inflow from the surrounding catchment area. Using the lake level - area relationship (WMO 1981) and an estimate of annual evaporation we can refine this calculation to give an implied rainfall plus tributary inflow expressed as a volume or as a depth over the lake and swamp area.

The results are presented in Table 7.1 as mean values over decades to reduce the large scatter associated with the annual values. Even so there is a large variation in the implied balancing term and in the mean implied rainfall plus tributary inflow. Furthermore the latter estimates for the 1920s and 1930s are substantially less than the average rainfall on the lake without including an amount for tributary inflows. Thus we can conclude that while the average effect of Lake Kyoga seems to be to cause a small net loss of flow in the Victoria Nile, the results for several decades are unrealistic and cast doubt on the overall conclusion.

An alternative approach is to synthesise a water balance by making reasonable assumptions about rainfall, percentage runoff and evaporation. The net inflow to the Victoria Nile from a range of assumptions is shown in Table 7.2. For simplicity we have assumed that lake level remains constant at the level chosen.

These calculations suggest that for a high rainfall decade there would be a substantial contribution to flows in the Victoria Nile irrespective of lake level. During a low rainfall decade there would be a small net loss of flow at low lake level and a higher loss at high levels. But at high lake levels the loss would tend to be mitigated by release of water from lake storage if Lake Victoria releases were also falling at the same time. On average we should expect the net effect of Lake Kyoga to be a small gain in flow in the Victoria Nile.

TABLE 7.1 **The implied water balance of Lake Kyoga by decades**

(million m^3/year)

	1912-1919	1920s	1930s	1940s	1950s	1960s	1970-1977	all years
Mean annual inflow (Nile)	21662	17898	23305	20712	19967	39116	37496	25504
Mean annual outflow (Nile)	22685	15570	20355	19697	18227	42958	38313	24849
Outflow - inflow	-977	-2328	-2950	-1015	-1740	3842	817	-655
Change in lake level over the period (mm)	710	- 420	250	- 360	580	1570	-370	1960
Implied rainfall + tributary inflow - evaporation	-667	-2478	-2862	-1141	-1533	4491	612	-541
Implied rainfall + tributary inflow (mm over lake area)	1251	864	833	1235	1144	2579	1710	1367
Rainfall on Lake Victoria (mm)			1636	1646	1627	1861	1692	

Notes: Lake and swamp area is estimated by the equation

AREA (km^2) = 1600 * (Level -6.85)$^{0.6}$

derived from data given by WMO (1981)

An evaporation rate of 1590 mm/year is assumed when computing the implied rainfall plus tributary inflow

TABLE 7.2 Estimated water balance of Lake Kyoga

	Low rainfall decade			High rainfall decade		
Mean annual rainfall (mm)		1000			1200	
Runoff coefficient (%)		2			5	
Runoff (mm)		20			60	
Evaporation from lakes and swamps (mm)		1590			1590	
Assumed lake level (m)	10.0	11.5	13.0	10.0	11.5	13.0
Corresponding area of lakes and swamps (km^2)	3185	4023	4758	3185	4023	4758
Contributing catchment area (km^2)	60215	59380	58640	60215	59380	58640
Volume rainfall on lakes and swamps (million m^3/year)	3185	4023	4758	3822	4828	5710
Volume tributary inflow (million m^3/year)	1204	1188	1173	3613	3563	3520
Volume evaporation from lakes and swamps (million m^3/year)	5604	6397	7565	5064	6397	7565
Net inflow to Victoria Nile (million m^3/year)	-675	-1186	-1634	2371	1994	1665

While on average Lake Kyoga should be a source of some additional flow in the Victoria Nile, there will be individual years when there is a significant loss of flow due to poor rains in the Lake Kyoga catchment area. Again we must make some assumptions about the rainfall in this region. If the mean annual rainfall is about 1100 mm and its year to year variability is similar to that given by the Lake Victoria rainfall series (coefficient of variation 0.124), a rainfall of 900 mm or less might occur at least once every 15 years on average. Assuming a runoff coefficient of only 1% and an average lake level of 11.5 m, we can derive a corresponding net loss of about 2250 million m^3/year or about 75 m^3/s on average.

The seasonal pattern of gains and losses is fairly stable; the biggest loss of flow in the Victoria Nile usually occurs in May, the smallest loss (or biggest gain) in flow can occur in September, October or November. Taking the average monthly gains or losses from the 1912-1977 records, the annual loss of 75 m^3/s derived above would imply a loss of 150 m^3/s in May and a gain of 2 m^3/s in October. These estimates assume that releases are made from Owen Falls according to the agreed curve; should the release pattern be altered, it is likely that a lake model would be needed to establish the net response of Lake Kyoga to the new regime.

7.3 FLOOD FLOWS IN THE VICTORIA NILE

In most years the flood flows in the Victoria Nile are determined principally by the outflows from Lake Victoria. However, occasionally there is a large flood contribution from the Lake Kyoga catchment as illustrated by Figure 7.1 covering the 1917-1918 perid. This event, due largely to the area of high rainfall extending further north than usual, shows the largest flood contribution from Lake Kyoga in the period of record.

An approach to the estimation of extreme floods based on analysis of the maximum flood in each year cannot be used for the Victoria Nile. Flows in successive years are far from being independent events as we have shown in section 4.5 of this report. The flood flows originating in the Lake Kyoga catchment are probably not subject to this same constraint. However we believe that they cannot be derived accurately by difference between the Masindi Port and Jinja flows particularly for the earlier years.

Monthly inflows and outflows for Lake Kyoga 1914-24

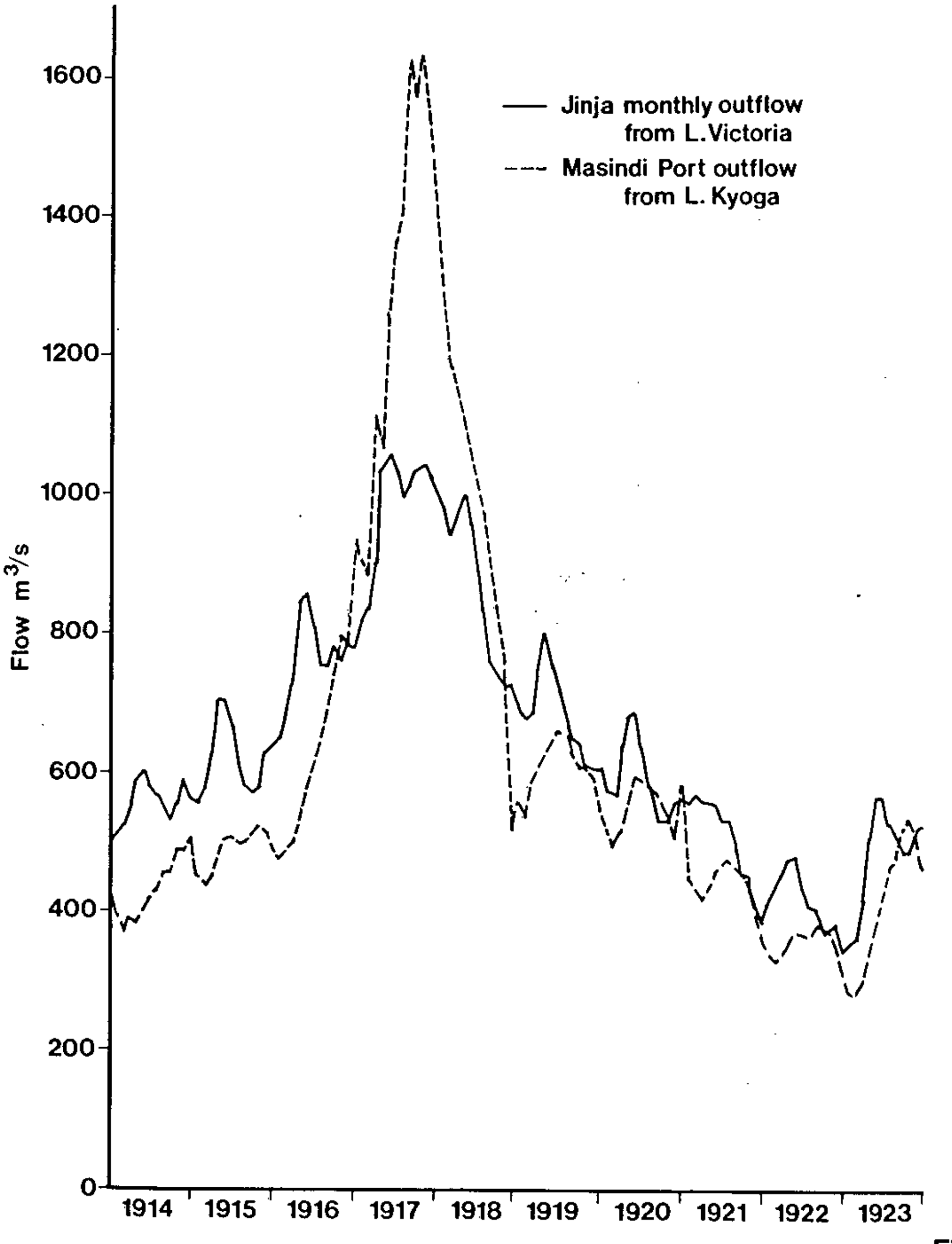


Figure 7.1

In fact, in most years the measured monthly outflows from Lake Kyoga are below the outflows from Lake Victoria. Whether these apparent losses are real or just the result of measurement errors, there is no series of annual maxima of the Lake Kyoga inflow which can be deduced by difference. On the other hand the rainfall and tributary inflows to Lake Kyoga are not available in the same way as they are for Lake Victoria. Thus it is not possible to carry out a statistical analysis of the Lake Kyoga inflows to deduce flows of given return periods or to investigate their cross-correlation with the Lake Victoria outflows in order to estimate total flows of the design frequency by combining the two frequencies.

The alternative is to develop an ad-hoc method of estimating a rare flood below Lake Kyoga which will be of comparable return period to the design flood below Lake Victoria. The method adopted is as follows. Measured outflows from Lake Kyoga and Lake Victoria show that there has only been a significant increase due to Lake Kyoga inflow on one occasion, 1917-18, during the period 1912-82. Allowing for the apparent underestimation of Masindi Port flows during this period, the peak of the Lake Kyoga contribution can be estimated at about 800 m^3/s. Using the unbiassed Gringorten formula for the frequency

$$F_i = (i - 0.44)/(N + 0.12)$$

for the i th smallest value in N years of records, and substituting $N = 71$ gives $F_i = 0.992$ or a return period T of over 100 years.

The combination of the Lake Victoria peak outflow and the peak Lake Kyoga contribution can be considered as the combination of two tributary flood series downstream of a junction. The combined probability or return period of two tributary floods will depend not only on the return periods T_1 and T_2 of the tributary floods, but also of the intercorrelation of the two series. Without a means of analysing the two series, or of generating Lake Kyoga contributions, it appears realistic to add 800 m^3/s, representing about a 100 year contribution from Lake Kyoga, to the design outflow from Lake Victoria to obtain a design flood of comparable rarity for the combined contributions.

8. SUMMARY AND DISCUSSION

In this section we summarise and discuss the important features of our investigations and conclusions. We have reexamined the basic data and have used these to reconstruct for as long a period as possible a complete and consistent hydrological record.

Although a number of rainfall series have been compiled for the lake itself and the land catchment, none have been derived for the whole record by a constant method. The longest homogeneous series was derived for the lake by de Baulny and Baker from the weighted means of eight long-term lakeside stations. We have carried this series forward to 1979 as a basis for lake balance and statistical analysis.

The tributary inflow, though small by comparison with direct lake rainfall, is nevertheless more variable and therefore provides an important contribution to variations in the lake supply. We have used the recent and almost complete measurements of tributary inflow, whereas previous estimates were based on comparisons with rainfall, to extend the inflow series back to 1956.

The lake evaporation is not expected to vary much from year to year, and we have used the estimates of this factor. The fact that evaporation is almost equal to mean lake rainfall increases the effect of annual variations in rainfall and tributary inflow.

Historical evidence shows that upward and downward variations in lake level and river outflow have occurred on several occasions before the lake records began in 1896 and thus that the 1961-64 rise was not unique. We have shown that for the longest period for which the historical hydrological series can be completed (1956-77), there is no great difficulty in reconciling the lake balance. We have found that either the rainfall derived from a weighted mean of lakeside gauges underestimates the lake rainfall by a small percentage or that evaporation is slightly overestimated. A simple adjustment to rainfall reproduces the lake behaviour quite well.

The longer term fluctuations can be reproduced by a simple rainfall-runoff model coupled to the historic rainfall series. Therefore a stochastic reproduction of the lake rainfall structure should present realistic predictions of probable future lake behaviour.

Complex models including trends, cycles and jumps have been proposed in the past to explain the rise in lake levels in 1961-64. Models incorporating steady trends are not suitable for extrapolation to the future because past evidence makes a steady rise in rainfall unlikely and unrealistic. Cyclical patterns raise similar objections and have not proved successful in the past. Random changes in the rainfall regime seem more consistent with the physical evidence, and might be linked with changes in global circulation or the intensity of meteorological processes; however, one change during the period of scientific records is insufficient to build a model to reproduce this effect.

Previous studies of the potential benefits of controlling the outflow of Lake Victoria have been based on the historic record and in the most recent study (WMO 1981) on some synthetic series about which we have little detailed information. We believe they were based on a time series model of 66 years of observed outflows plus change in lake storage. We agree that such model development is essential. However, while a 66 year record would be considered quite long in the design of a typical run of river hydropower scheme, the considerable inertia of the Lake Victoria system means that a representative range of lake levels may not be experienced in this time scale.

In the time available for this study we have been able to present the results of using one possible prediction model. Many such models could be defined although certain types of model that imply changes in the mean rainfall or basin supply cannot readily be fitted to data which exhibits only one such shift. All models must recognise the large uncertainty inherent in our present knowledge of the lake regime.

We have therefore put forward a relatively stable model with interrelated random components which appears to reproduce most of the features of the rainfall regime without requiring drastic changes in regime or an explanation of the underlying meteorological mechanism. The choice of model is perhaps somewhat arbitrary, but can be tested by its ability to reproduce the statistical features of the rainfall and the resulting lake levels. The model seems realistic in that it reproduces rises and falls in lake level with a frequency and range which are supported by the historical evidence. It has, however, less success in reproducing the relatively steady lake levels of the early historic record.

The implications of the model are that the relatively large changes of level of the 1961-64 priod are not unique and that their frequency can be reproduced by a rainfall-runoff model based on the 1925-79 records. The engineering implications are that the range of levels provided by the Owen Falls dam is barely adequate to contain the natural rises and falls of the lake and it is therefore premature to consider control procedures which would reduce the variability of the outflow by increasing the range of level.

We have no reason to doubt the implication that further engineering works to raise the dam level, increase its sluice capacity or provide spillway capacity are necessary in the medium or long term to ensure the continued safety of the dam. Even with quite large errors of estimation of the probabilities and risks presented in Chapter 6 the conclusions would be the same.

However we believe that as the model does not reproduce stable lake levels as readily as the historic record might lead us to suggest it should, further development or study will be needed before definitive tests of control procedures are carried out. It may be true that the stability of the lake from 1900 to 1960 was indeed anomalous. But while the historic record is arguably a weak basis for the definition of control rules, the stability of the early part of the record should not be understated to the extent that our model suggests.

ACKNOWLEDGEMENTS

We are most grateful to the WMO/UNDP Hydrometeorological Survey of Lakes Victoria, Kyoga and Mobutu Sese Seko for their help, in particular for providing us with information and records at the request of the Uganda authorities. We would in particular like to thank Mr Bushaijabwe, Project Director, Mr M Haddad in Nairobi and Mr J P Wambi in Entebbe.

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APPENDIX A

DATA FOR LAKE VICTORIA

Lake rainfall (mm)

End of month lake levels (m) above Jinja datum

Changes in level (mm)

Lake outflow (million m^3)

List of gauged tributaries, station codes and catchment area (km^2)

Annual gauged tributary flows (million m^3)

DATA FOR LAKE KYOGA

End of month lake levels (m) above Masindi Port datum

Lake outflows (million m^3)

TOTAL TRIBUTARY INFLOW

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
1956	1020.	719.	579.	977.	1555.	1564.	1733.	2585.	2465.	1796.	1057.	839.	17194.
1957	669.	562.	640.	1035.	2122.	2673.	1941.	2225.	1613.	981.	861.	826.	16147.
1958	648.	660.	688.	711.	1433.	1218.	1647.	1901.	1878.	1414.	781.	765.	13743.
1959	633.	523.	731.	896.	1332.	911.	967.	1237.	1407.	1208.	974.	802.	11670.
1960	663.	574.	863.	1447.	1659.	1554.	1526.	1787.	2204.	1410.	1001.	770.	15455.
1961	608.	531.	572.	703.	1037.	874.	1060.	2276.	2012.	2037.	3954.	3555.	19188.
1962	2419.	1282.	1539.	2079.	4363.	3279.	3283.	3693.	3418.	2331.	1612.	1337.	30634.
1963	1366.	1183.	1384.	2205.	5433.	3242.	2750.	3124.	2192.	1612.	1498.	2591.	23679.
1964	1662.	1309.	1633.	3020.	2234.	2479.	2818.	3591.	2981.	2789.	1485.	1342.	27993.
1965	1179.	912.	945.	1292.	1935.	1368.	1366.	1271.	1046.	1087.	1371.	1162.	14933.
1966	883.	910.	1133.	2222.	2238.	1683.	1710.	1607.	2070.	1329.	1181.	828.	17794.
1967	761.	664.	728.	1065.	2465.	1913.	2535.	2402.	1858.	1585.	1707.	1499.	19182.
1968	1016.	1112.	1775.	2589.	4036.	3201.	2789.	3371.	2104.	1518.	1450.	1936.	26947.
1969	1320.	1431.	1757.	2024.	2745.	1801.	1501.	1551.	1427.	1143.	1021.	1005.	18776.
1970	1209.	1245.	2237.	3630.	3259.	2557.	1918.	2544.	2106.	1756.	1226.	1149.	24835.
1971	878.	665.	677.	1791.	2509.	1816.	1704.	2174.	2129.	1553.	1083.	1035.	18013.
1972	880.	910.	916.	884.	1825.	1854.	1732.	1461.	1158.	1298.	2770.	2292.	17979.
1973	1913.	1342.	1032.	1206.	1793.	1838.	1217.	1552.	1861.	1419.	1735.	1132.	18041.
1974	844.	656.	824.	3570.	2174.	1539.	2631.	1554.	1725.	1356.	986.	854.	19712.
1975	742.	571.	939.	1441.	1493.	1447.	1371.	2140.	2541.	2022.	1111.	1020.	16692.
1976	758.	683.	701.	1006.	1555.	1500.	1479.	1258.	1481.	942.	891.	820.	13073.
1977	998.	949.	931.	3270.	5173.	2162.	2242.	2026.	1533.	1173.	3193.	1847.	25496.
1978	1305.	1371.	5188.	4113.	4033.	2381.	2439.	2580.	2225.	1756.	1639.	2126.	31153.

CATALOGUE OF GAUGED TRIBUTARIES

1	SIO		
2	UPPER NZOIA	/101022	1030
3	NZOIA	1DA2/	3420
4	UPPER YALA	1EE1/102502	11900
5	YALA	1FG1	2390
6	KIBOS	1FG2/103102	2650
7	NYANDO	/	490
8	CHERONGIT	1GD1/104252	2650
9	SONDU	/104272	560
10	AWACH NEAR GENDA	1JG1/105382	3230
11	AWACH KABOUN	1HD1/	503
12	MIGORI	/119242	610
13	GUCHA MIGORI	15C3/	3050
14	MORI	/106142	6840
15	MARA	/108022	590
16	SUGUTI	/107072	10830
17	RWANA GRUMETI	/109012	1020
18	MBALAGETI	/110012	11430
19	SIMYU DIMA	/111012	3730
20	MGOGO	/112022	10790
21	MOAME	/113012	1200
22	ISINGA	/113022	2090
23	KAGERA AT RUSUMO FALLS		4780
24	KAGERA NYAKANYASI		30200
25	NGONO	/115152	55800
26	RUIZI	/115152	2611
27	KATONGA	/116162	5670
28	KAFU	/117062	13020
		/206012	16700

CONTEMPORARY ANNUAL FLOWS AT STATIONS -

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1940	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1941	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1942	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1943	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1944	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1945	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1946	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1947	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1948	0.	0.	0.	0.	0.	0.	-1.	0.	0.	0.	0.	0.	0.	0.
1949	0.	0.	0.	0.	0.	0.	257.	0.	0.	0.	0.	0.	0.	0.
1950	0.	0.	0.	0.	0.	0.	280.	0.	0.	0.	0.	0.	0.	0.
1951	0.	0.	0.	0.	0.	0.	603.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	0.	0.	0.	651.	0.	0.	0.	0.	0.	0.	0.
1953	0.	0.	0.	0.	0.	0.	131.	0.	0.	0.	0.	0.	0.	0.
1954	0.	0.	0.	0.	0.	0.	410.	0.	0.	0.	0.	0.	0.	0.
1955	0.	0.	0.	0.	0.	0.	323.	0.	0.	0.	0.	0.	0.	0.
1956	0.	1390.	0.	597.	0.	0.	475.	0.	1519.	398.	0.	333.	0.	0.
1957	0.	973.	0.	659.	0.	0.	333.	0.	1377.	216.	0.	325.	0.	0.
1958	0.	996.	0.	613.	-1.	0.	299.	0.	825.	168.	0.	116.	0.	0.
1959	0.	755.	0.	475.	466.	0.	196.	0.	833.	134.	0.	96.	0.	0.
1960	0.	909.	0.	771.	719.	0.	-1.	0.	1231.	152.	0.	243.	0.	0.
1961	0.	1818.	0.	1156.	-1.	0.	-1.	0.	1081.	377.	0.	-1.	0.	0.
1962	0.	2397.	0.	1625.	1569.	0.	-1.	0.	2108.	912.	0.	643.	0.	0.
1963	0.	2166.	-1.	1276.	1286.	0.	-1.	0.	1946.	219.	0.	619.	0.	0.
1964	0.	2214.	3694.	1171.	1343.	0.	-1.	0.	1832.	138.	0.	860.	0.	0.
1965	0.	576.	1434.	453.	633.	0.	-1.	0.	737.	71.	0.	200.	0.	0.
1966	0.	952.	2096.	651.	821.	0.	-1.	0.	1181.	141.	0.	412.	0.	0.
1967	0.	1803.	3324.	786.	934.	0.	-1.	0.	1066.	167.	0.	356.	0.	0.
1968	0.	1513.	3251.	1170.	1352.	0.	-1.	0.	2067.	262.	0.	621.	0.	0.
1969	287.	789.	1777.	692.	1114.	68.	247.	23.	1045.	160.	180.	279.	952.	59.
1970	558.	1675.	3175.	937.	1068.	63.	819.	74.	1938.	170.	202.	0.	1899.	324.
1971	345.	0.	2455.	0.	1048.	0.	613.	51.	1269.	0.	157.	0.	1094.	62.
1972	575.	0.	1321.	0.	1118.	0.	439.	46.	1023.	0.	106.	0.	1202.	96.
1973	343.	0.	1689.	0.	1044.	0.	390.	42.	1234.	0.	175.	0.	1546.	122.
1974	268.	0.	1528.	0.	895.	0.	463.	59.	1426.	0.	264.	0.	1798.	189.
1975	284.	0.	3012.	0.	1104.	0.	628.	39.	1419.	0.	203.	0.	1071.	57.
1976	184.	0.	1419.	0.	816.	0.	220.	53.	875.	0.	133.	0.	1205.	63.
1977	364.	0.	3742.	0.	1288.	0.	328.	81.	2186.	0.	280.	0.	2744.	185.
1978	343.	0.	3744.	0.	1599.	0.	789.	125.	-1.	0.	-1.	0.	2481.	202.
1979	283.	0.	1610.	0.	1150.	0.	-1.	-1.	1550.	0.	-1.	0.	-1.	-1.

CONTEMPORARY ANNUAL FLOWS AT STATIONS -

	15	16	17	18	19	20	21	22	23	24	25	26	27	29
1940	0.	0.	0.	0.	0.	0.	0.	0.	0.	5403.	0.	0.	0.	0.
1941	0.	0.	0.	0.	0.	0.	0.	0.	0.	4880.	0.	0.	0.	0.
1942	0.	0.	0.	0.	0.	0.	0.	0.	0.	6568.	0.	0.	0.	0.
1943	0.	0.	0.	0.	0.	0.	0.	0.	0.	4474.	0.	0.	0.	0.
1944	0.	0.	0.	0.	0.	0.	0.	0.	0.	4106.	0.	0.	0.	0.
1945	0.	0.	0.	0.	0.	0.	0.	0.	0.	3306.	0.	0.	0.	0.
1946	0.	0.	0.	0.	0.	0.	0.	0.	0.	3825.	0.	0.	0.	0.
1947	0.	0.	0.	0.	0.	0.	0.	0.	0.	5405.	0.	0.	0.	0.
1948	0.	0.	0.	0.	0.	0.	0.	0.	0.	4505.	0.	0.	0.	0.
1949	0.	0.	0.	0.	0.	0.	0.	0.	0.	3650.	0.	0.	0.	0.
1950	0.	0.	0.	0.	0.	0.	0.	0.	0.	3653.	0.	0.	0.	0.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	4978.	0.	0.	0.	0.
1952	0.	0.	0.	0.	0.	0.	0.	0.	0.	6759.	0.	0.	0.	0.
1953	0.	0.	0.	0.	0.	0.	0.	0.	0.	4859.	0.	0.	0.	52.
1954	0.	0.	0.	0.	0.	0.	0.	0.	0.	5136.	0.	0.	0.	190.
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	4352.	0.	0.	0.	229.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	4904.	0.	0.	0.	201.
1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	6285.	0.	0.	0.	310.
1958	0.	0.	0.	0.	0.	0.	0.	0.	0.	5425.	0.	0.	0.	137.
1959	0.	0.	0.	0.	0.	0.	0.	0.	0.	4734.	0.	0.	0.	68.
1960	0.	0.	0.	0.	0.	0.	0.	0.	0.	6211.	0.	0.	0.	507.
1961	0.	0.	0.	0.	0.	0.	0.	0.	0.	5006.	0.	0.	0.	340.
1962	0.	0.	0.	0.	0.	0.	0.	0.	0.	9118.	0.	0.	0.	1422.
1963	0.	0.	0.	0.	0.	0.	0.	0.	0.	11498.	0.	0.	0.	1434.
1964	0.	0.	0.	0.	0.	0.	0.	0.	0.	11073.	0.	0.	0.	1281.
1965	0.	0.	0.	0.	0.	0.	0.	0.	0.	7719.	0.	0.	0.	645.
1966	0.	0.	0.	0.	0.	0.	0.	0.	0.	7538.	0.	0.	0.	1091.
1967	0.	0.	0.	0.	0.	0.	0.	0.	0.	6252.	0.	0.	0.	641.
1968	0.	0.	0.	0.	0.	0.	0.	0.	0.	10375.	0.	0.	0.	321.
1969	978.	72.	310.	71.	476.	37.	71.	100.	0.	8923.	0.	61.	101.	747.
1970	1736.	66.	539.	214.	1000.	89.	76.	170.	0.	8477.	769.	211.	151.	633.
1971	1072.	6.	324.	127.	331.	11.	26.	0.	-1.	7030.	644.	-1.	65.	232.
1972	543.	46.	369.	139.	637.	56.	93.	0.	-1.	7587.	803.	199.	31.	247.
1973	425.	18.	206.	51.	362.	17.	25.	0.	6731.	7713.	877.	186.	94.	512.
1974	1213.	71.	400.	152.	-1.	53.	52.	0.	6712.	7333.	522.	209.	105.	359.
1975	388.	17.	74.	55.	235.	21.	12.	0.	5031.	6083.	712.	322.	110.	457.
1976	200.	31.	94.	54.	101.	6.	9.	0.	5217.	5932.	647.	241.	120.	234.
1977	1528.	107.	516.	243.	1113.	95.	119.	0.	6697.	6931.	767.	345.	144.	0.
1978	3166.	153.	873.	251.	1294.	146.	152.	0.	7899.	-1.	-1.	676.	222.	0.
1979	-1.	103.	441.	223.	1302.	72.	76.	0.	3622.	0.	1032.	0.	-1.	0.

LAKE KYOGA LEVELS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	10.04	9.97	9.94	10.00	10.05	10.14	10.20	10.28	10.36	10.32	10.28	10.18
1913	10.04	9.97	9.94	10.00	10.28	10.44	10.66	10.69	10.53	10.50	10.52	10.35
1914	10.22	10.12	10.14	10.16	10.18	10.21	10.25	10.29	10.33	10.37	10.42	10.47
1915	10.52	10.35	10.34	10.45	10.58	10.62	10.61	10.61	10.62	10.65	10.66	10.60
1916	10.52	10.50	10.57	10.64	10.63	10.99	11.13	11.24	11.49	11.69	11.81	11.70
1917	11.57	11.55	11.47	11.76	12.24	12.69	12.84	12.89	13.11	13.49	13.37	13.07
1918	12.76	12.47	12.19	12.10	12.08	11.92	11.77	11.66	11.42	11.25	11.10	10.96
1919	10.73	10.84	11.00	11.06	11.21	11.21	11.29	11.16	11.06	11.02	11.02	10.89
1920	10.71	10.59	10.58	10.75	10.73	11.01	10.96	10.92	10.86	10.80	10.69	10.56
1921	10.42	10.37	10.32	10.35	10.39	10.45	10.49	10.49	10.41	10.36	10.26	10.12
1922	9.96	9.91	9.90	9.97	10.03	10.09	10.04	10.07	10.10	10.10	10.00	9.96
1923	9.74	9.70	9.69	9.83	10.03	10.14	10.37	10.49	10.60	10.73	10.69	10.53
1924	10.39	10.35	10.23	10.37	10.54	10.53	10.53	10.63	10.70	10.61	10.57	10.42
1925	10.27	10.17	10.13	10.20	10.23	10.24	10.25	10.22	10.18	10.16	10.18	10.20
1926	10.16	10.07	10.04	10.43	10.64	11.05	11.26	11.35	11.49	11.53	11.51	11.43
1927	11.35	11.26	11.24	11.36	11.50	11.53	11.51	11.42	11.36	11.18	11.08	10.92
1928	10.76	10.56	10.48	10.57	10.50	10.94	10.98	11.00	10.99	10.93	10.90	10.73
1929	10.60	10.45	10.40	10.50	10.66	10.63	10.66	10.65	10.61	10.59	10.50	10.47
1930	10.45	10.42	10.50	10.70	10.96	11.16	11.21	11.29	11.34	11.39	11.32	11.20
1931	11.05	10.95	10.95	11.11	11.35	11.43	11.54	11.60	11.66	11.89	11.83	11.50
1932	11.35	11.25	11.40	11.44	11.62	11.69	11.75	11.79	11.92	11.89	11.59	11.80
1933	11.67	11.60	11.58	11.63	11.71	11.69	11.65	11.68	11.66	11.57	11.43	11.35
1934	11.20	11.02	10.93	10.93	11.04	11.06	11.10	11.09	11.01	10.95	10.88	10.80
1935	10.70	10.63	10.58	10.67	10.76	10.89	10.94	10.94	10.95	10.92	10.80	10.71
1936	10.69	10.81	10.85	11.07	11.23	11.40	11.47	11.51	11.51	11.36	11.18	11.06
1937	10.95	10.88	10.92	11.02	11.20	11.36	11.48	11.55	11.46	11.44	11.53	11.45
1938	11.35	11.23	11.18	11.26	11.36	11.38	11.39	11.40	11.40	11.38	11.28	11.11
1939	10.99	10.91	10.66	10.95	11.03	11.04	11.06	11.05	10.97	10.89	10.68	10.72
1940	10.63	10.62	10.67	10.80	10.96	11.02	11.20	11.30	11.19	11.11	11.08	11.01
1941	10.92	10.85	10.69	10.99	11.20	11.34	11.36	11.41	11.42	11.32	11.40	11.41
1942	11.32	11.26	11.35	11.53	11.91	12.12	12.08	12.08	11.98	11.78	11.56	11.38
1943	11.13	10.99	10.84	10.84	10.90	10.86	10.89	10.94	10.84	10.72	10.51	10.31
1944	10.15	10.04	10.01	10.10	10.24	10.25	10.27	10.28	10.28	10.24	10.22	10.21
1945	10.12	10.10	10.01	10.00	10.36	10.51	10.71	10.89	10.98	10.85	10.70	10.57
1946	10.40	10.22	10.12	10.21	10.32	10.46	10.54	10.81	10.97	11.12	11.00	10.89
1947	10.74	10.61	10.55	10.75	11.01	11.28	11.45	11.45	11.61	11.54	11.34	11.22
1948	11.04	10.96	10.93	10.92	10.98	11.06	11.12	11.20	11.23	11.24	11.16	10.98
1949	10.82	10.69	10.56	10.56	10.59	10.59	10.58	10.57	10.69	10.59	10.46	10.36
1950	10.25	10.08	10.19	10.30	10.40	10.48	10.55	10.68	10.84	10.74	10.56	10.43
1951	10.35	10.34	10.33	10.59	10.83	10.83	11.00	11.06	11.07	10.94	10.93	11.15
1952	11.18	11.07	11.03	11.07	11.12	11.07	11.01	11.03	11.07	11.01	10.88	10.68
1953	10.56	10.41	10.35	10.44	10.49	10.49	10.50	10.50	10.48	10.50	10.52	10.36
1954	10.35	10.38	10.42	10.56	10.78	10.96	11.09	11.19	11.19	11.08	10.90	10.78
1955	10.66	10.60	10.59	10.62	10.65	10.61	10.63	10.68	10.71	10.81	10.73	10.64
1956	10.57	10.50	10.47	10.60	10.78	10.88	11.04	11.20	11.18	11.29	11.13	11.01
1957	10.76	10.66	10.63	10.73	10.96	11.21	11.21	11.21	11.11	10.95	10.36	10.75
1958	10.64	10.68	10.63	10.66	10.96	10.37	11.01	11.09	11.10	11.08	10.91	10.86
1959	10.78	10.73	10.73	10.81	10.91	10.95	10.98	11.02	11.19	11.10	11.04	10.94
1960	10.80	10.69	10.73	10.87	11.14	11.21	11.20	11.20	11.19	11.10	11.06	10.82
1961	10.70	10.51	10.47	10.53	10.59	10.65	10.68	10.86	11.01	11.35	12.23	12.73
1962	12.86	12.74	12.67	12.62	12.82	12.87	12.83	12.85	12.91	12.92	12.92	12.97
1963	12.74	12.72	12.71	12.91	13.23	13.21	13.28	13.32	13.38	13.40	12.98	13.09
1964	13.03	12.96	12.92	13.05	13.35	13.36	13.33	13.16	13.27	13.46	13.35	13.19
1965	13.10	13.05	13.07	13.09	13.11	13.07	12.91	12.70	12.57	12.57	12.55	12.50
1966	12.44	12.46	12.49	12.66	12.69	12.89	12.67	12.66	12.66	12.64	12.62	12.38
1967	12.23	12.05	11.95	12.02	12.16	12.20	12.24	12.23	12.23	12.26	12.34	12.42
1968	12.31	12.25	12.30	12.48	12.81	13.02	13.00	12.92	12.76	12.81	12.69	12.57
1969	12.50	12.59	12.63	12.59	12.72	12.85	12.77	12.65	12.64	12.57	12.51	12.51
1970	12.24	12.20	12.26	12.43	12.69	12.82	12.85	12.89	12.90	12.89	12.78	12.63
1971	12.45	12.32	12.10	12.23	12.32	12.29	12.31	12.34	12.38	12.34	12.21	12.02
1972	11.95	11.87	11.33	11.97	11.90	12.02	11.98	12.01	11.93	12.04	12.15	12.18
1973	12.12	12.05	12.01	12.04	12.12	12.20	12.13	12.13	12.10	12.08	12.07	11.93
1974	11.70	11.50	11.59	11.65	11.72	11.81	11.94	12.05	12.14	11.99	11.78	11.58
1975	11.50	11.41	11.25	11.35	11.21	11.15	11.39	11.66	12.14	12.41	12.27	12.05
1976	11.67	11.80	11.65	11.71	11.77	11.78	11.81	11.87	11.84	11.74	11.63	11.52
1977	11.39	11.34	11.32	11.50	11.65	11.73	11.85	11.97	12.00	11.98	12.14	12.14

FLOWS AT MASINDI PORT

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
1912	891.	891.	891.	890.	960.	971.	1070.	1110.	1129.	1160.	1100.	1121.	12203.
1913	1011.	960.	909.	901.	1051.	1129.	1319.	1410.	1321.	1271.	1269.	1220.	13671.
1914	1140.	950.	1000.	1012.	1027.	1041.	1121.	1150.	1191.	1231.	1269.	1311.	13443.
1915	1351.	1100.	1169.	1160.	1300.	1300.	1351.	1330.	1300.	1359.	1349.	1370.	15439.
1916	1311.	1139.	1300.	1290.	1429.	1489.	1641.	1710.	1769.	1931.	2059.	2101.	19269.
1917	2511.	2191.	2361.	2381.	2259.	3270.	3660.	3751.	4221.	4220.	4229.	4121.	40274.
1918	3810.	3139.	3191.	2899.	2930.	2759.	2720.	2599.	2321.	2200.	1961.	1389.	31969.
1919	1501.	1291.	1571.	1569.	1689.	1681.	1769.	1750.	1621.	1619.	1569.	1579.	19210.
1920	1461.	1299.	1319.	1331.	1490.	1541.	1579.	1571.	1479.	1491.	1391.	1351.	17292.
1921	1560.	1090.	1169.	1100.	1130.	1191.	1260.	1271.	1209.	1201.	1121.	1070.	14423.
1922	960.	809.	880.	870.	971.	960.	990.	979.	989.	1000.	960.	909.	11278.
1923	821.	691.	751.	761.	891.	971.	1110.	1239.	1240.	1381.	1380.	1351.	12586.
1924	1239.	1111.	1121.	1100.	1249.	1279.	1319.	1330.	1360.	1369.	1290.	1279.	15065.
1925	1161.	969.	1051.	1030.	1081.	1069.	1110.	1099.	1041.	1059.	1030.	1070.	12772.
1926	1070.	930.	920.	940.	1370.	1541.	1699.	1809.	1800.	1951.	1670.	1930.	17831.
1927	1871.	1639.	1750.	1720.	1900.	1891.	1941.	1900.	1800.	1780.	1629.	1590.	21411.
1928	1509.	1289.	1290.	1220.	1399.	1479.	1579.	1600.	1541.	1579.	1499.	1480.	17464.
1929	1389.	1179.	1220.	1170.	1359.	1331.	1359.	1370.	1321.	1351.	1269.	1260.	15579.
1930	1249.	1109.	1239.	1279.	1501.	1601.	1729.	1769.	1730.	1831.	1779.	1780.	18596.
1931	1670.	1441.	1560.	1559.	1750.	1800.	1919.	1981.	1950.	2029.	1961.	1959.	21580.
1932	1690.	1680.	1631.	1821.	1941.	1971.	2069.	2101.	2090.	2211.	2090.	2131.	23826.
1933	2080.	1330.	1989.	1909.	2050.	2000.	2029.	1930.	2969.	1999.	1831.	1849.	24466.
1934	1769.	1511.	1590.	1499.	1619.	1590.	1670.	1659.	1590.	1579.	1510.	1491.	19077.
1935	1440.	1240.	1351.	1310.	1410.	1440.	1560.	1560.	1510.	1560.	1461.	1429.	17271.
1936	1410.	1319.	1430.	1520.	1699.	1751.	1890.	1930.	1870.	1890.	1720.	1670.	20149.
1937	1600.	1400.	1539.	1531.	1670.	1720.	1879.	1959.	1870.	1930.	1849.	1930.	20847.
1938	1740.	1680.	1631.	1671.	1860.	1590.	1641.	1699.	1650.	1699.	1531.	1699.	20141.
1939	1560.	1339.	1440.	1409.	1509.	1489.	1539.	1560.	1471.	1469.	1401.	1410.	17596.
1940	1341.	1199.	1359.	1380.	1509.	1559.	1689.	1769.	1730.	1699.	1590.	1611.	18436.
1941	1381.	1131.	1421.	1370.	1491.	1541.	1641.	1659.	1681.	1729.	1691.	1941.	18675.
1942	1999.	1801.	2061.	2150.	2530.	2759.	2961.	2950.	2671.	2731.	2430.	2329.	29572.
1943	2109.	1770.	1820.	1699.	1320.	1300.	1820.	1860.	1769.	1761.	1611.	1520.	21359.
1944	1359.	1149.	1140.	1080.	1209.	1209.	1271.	1260.	1209.	1209.	1111.	1140.	14346.
1945	1051.	869.	949.	870.	990.	1100.	1260.	1429.	1559.	1651.	1510.	1469.	14728.
1946	1311.	1051.	1030.	929.	1019.	1051.	1121.	1271.	1440.	1590.	1811.	1849.	15473.
1947	1721.	1460.	1509.	1479.	1750.	1930.	2190.	2380.	2430.	2530.	2160.	2200.	23739.
1948	2029.	1790.	1791.	1691.	1309.	1839.	1981.	2101.	2041.	2061.	1979.	1911.	23023.
1949	1780.	1469.	1520.	1391.	1461.	1419.	1450.	1450.	1471.	1531.	1360.	1300.	17622.
1950	1209.	1029.	1081.	1069.	1161.	1160.	1249.	1319.	1409.	1480.	1331.	1231.	14728.
1951	1099.	959.	1051.	1069.	1231.	1331.	1461.	1560.	1520.	1600.	1569.	1831.	16233.
1952	2050.	1890.	1930.	1980.	2200.	1950.	1959.	1930.	1847.	1849.	1699.	1710.	22896.
1953	1531.	1291.	1599.	1370.	1450.	1349.	1429.	1429.	1360.	1381.	1339.	1311.	16638.
1954	1161.	1051.	1209.	1909.	1370.	1429.	1579.	1670.	1720.	1879.	1800.	1769.	18547.
1955	1651.	1409.	1509.	1499.	1630.	1549.	1560.	1579.	1580.	1721.	1601.	1560.	18843.
1956	1399.	1229.	1260.	1199.	1290.	1401.	1520.	1590.	1720.	1849.	1811.	1761.	18028.
1957	1641.	1419.	1531.	1479.	1670.	1800.	2061.	2109.	1821.	1780.	1671.	1630.	20610.
1958	1480.	1291.	1440.	1419.	1461.	1499.	1641.	1611.	1520.	1571.	1510.	1421.	17863.
1959	1410.	1230.	1351.	1310.	1389.	1461.	1509.	1531.	1559.	1699.	1671.	1710.	17830.
1960	1689.	1550.	1599.	1709.	1871.	1901.	2179.	2390.	2339.	2090.	1940.	1900.	23259.
1961	1710.	1469.	1560.	1531.	1659.	1650.	1791.	1930.	2049.	2361.	2850.	3960.	24539.
1962	3861.	3241.	3540.	2910.	3151.	3140.	3309.	3411.	3500.	3770.	3689.	4091.	41813.
1963	3679.	3241.	3510.	4011.	4319.	4421.	4611.	4659.	4460.	4231.	3689.	4150.	49450.
1964	4249.	3890.	4190.	4169.	4541.	4379.	4549.	4999.	5159.	5240.	4771.	4651.	54759.
1965	4571.	4000.	4249.	4169.	4619.	4421.	4410.	4121.	3801.	3839.	3819.	4059.	50079.
1966	3689.	3241.	3571.	3700.	4051.	3950.	4260.	4070.	3910.	4040.	3910.	3689.	46212.
1967	3499.	3020.	3131.	2990.	3221.	3241.	3430.	3529.	3469.	3620.	3630.	3759.	40589.
1968	3671.	3231.	3609.	3550.	4081.	4340.	4560.	4549.	4281.	4300.	4159.	4381.	48711.
1969	4231.	3809.	4260.	4081.	4450.	4361.	4509.	4391.	4169.	4070.	3840.	3941.	50113.
1970	3751.	3221.	3521.	3550.	4011.	4029.	4279.	4129.	4151.	4249.	4460.	4260.	47610.
1971	3850.	3241.	3229.	3221.	3620.	3319.	3459.	3590.	3560.	3660.	3371.	3049.	41169.
1972	3100.	2649.	3119.	2329.	3079.	3021.	3100.	3079.	2941.	3090.	3350.	3481.	37028.
1973	3430.	2729.	3210.	3161.	3290.	3139.	3199.	3309.	3311.	3451.	3319.	3240.	36833.
1974	3049.	2510.	2599.	2689.	2630.	2860.	3140.	3170.	3609.	3730.	3029.	2811.	36027.
1975	2811.	2471.	2514.	2420.	2530.	2269.	2479.	2771.	3091.	3660.	3581.	3510.	34111.
1976	3280.	2890.	3280.	2850.	3020.	2969.	3111.	3111.	3070.	3079.	2671.	2840.	36371.
1977	2690.	2350.	2570.	2580.	2830.	2831.	3071.	3191.	3231.	3250.	3249.	3459.	35353.
1978	3459.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3459.

RAINFALL ON LAKE VICTORIA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
1925	143.	144.	199.	143.	144.	84.	64.	72.	66.	127.	251.	111.	1548.
1926	131.	168.	222.	338.	194.	94.	83.	53.	129.	110.	174.	108.	1804.
1927	132.	87.	191.	202.	144.	75.	54.	64.	84.	79.	108.	158.	1378.
1928	133.	153.	201.	301.	262.	86.	60.	63.	39.	124.	103.	143.	1718.
1929	104.	96.	199.	207.	145.	87.	95.	56.	75.	95.	113.	234.	1511.
1930	107.	207.	210.	245.	152.	77.	52.	51.	81.	91.	129.	122.	1554.
1931	151.	90.	220.	232.	272.	64.	129.	47.	48.	79.	169.	88.	1619.
1932	139.	100.	231.	245.	300.	72.	54.	85.	62.	54.	117.	142.	1601.
1933	288.	177.	191.	150.	208.	62.	83.	98.	58.	125.	80.	165.	1685.
1934	109.	105.	133.	242.	213.	60.	59.	99.	41.	104.	99.	193.	1456.
1935	69.	267.	131.	206.	224.	112.	34.	31.	67.	124.	195.	263.	1723.
1936	182.	129.	206.	313.	127.	209.	60.	55.	96.	79.	122.	222.	1800.
1937	92.	160.	229.	240.	257.	84.	70.	39.	101.	193.	242.	234.	1941.
1938	124.	68.	218.	265.	193.	105.	27.	45.	77.	145.	214.	155.	1636.
1939	66.	151.	192.	164.	173.	93.	58.	69.	85.	89.	131.	78.	1349.
1940	131.	232.	224.	281.	218.	58.	102.	72.	102.	86.	146.	90.	1742.
1941	107.	88.	152.	240.	139.	148.	52.	94.	52.	111.	247.	307.	1787.
1942	258.	76.	310.	276.	279.	49.	40.	132.	40.	84.	182.	70.	1796.
1943	64.	213.	134.	241.	202.	131.	27.	52.	68.	46.	126.	94.	1398.
1944	132.	141.	227.	275.	252.	55.	70.	60.	111.	128.	225.	194.	1870.
1945	159.	148.	132.	148.	347.	79.	91.	103.	99.	56.	173.	80.	1615.
1946	48.	63.	105.	279.	239.	130.	89.	114.	96.	86.	136.	145.	1530.
1947	202.	164.	177.	319.	336.	83.	86.	43.	109.	104.	121.	162.	1911.
1948	152.	68.	158.	259.	132.	68.	76.	76.	109.	129.	101.	146.	1530.
1949	51.	81.	55.	269.	99.	68.	102.	80.	84.	97.	82.	213.	1281.
1950	126.	47.	254.	266.	265.	75.	89.	114.	68.	81.	77.	178.	1640.
1951	108.	186.	206.	264.	260.	113.	66.	81.	67.	134.	269.	445.	2199.
1952	69.	96.	239.	236.	195.	65.	88.	77.	90.	74.	183.	45.	1457.
1953	220.	72.	164.	274.	134.	79.	39.	46.	98.	124.	156.	117.	1523.
1954	65.	143.	102.	268.	234.	61.	76.	57.	74.	100.	153.	181.	1514.
1955	263.	132.	191.	242.	229.	45.	85.	60.	130.	85.	104.	227.	1793.
1956	172.	92.	131.	274.	163.	78.	36.	79.	98.	79.	134.	214.	1550.
1957	128.	51.	180.	263.	199.	66.	72.	59.	30.	105.	147.	183.	1483.
1958	91.	107.	158.	214.	239.	155.	52.	47.	70.	69.	114.	153.	1469.
1959	144.	168.	150.	264.	136.	79.	75.	81.	99.	115.	195.	140.	1646.
1960	175.	139.	304.	352.	119.	66.	62.	30.	127.	143.	106.	108.	1781.
1961	139.	209.	224.	198.	174.	67.	79.	102.	139.	289.	386.	195.	2201.
1962	87.	92.	246.	317.	349.	93.	89.	137.	90.	196.	115.	137.	1948.
1963	160.	131.	192.	364.	275.	56.	33.	44.	66.	82.	250.	316.	2019.
1964	148.	217.	224.	354.	173.	95.	83.	71.	71.	114.	148.	173.	1871.
1965	47.	123.	152.	185.	215.	40.	88.	36.	124.	172.	282.	151.	1615.
1966	165.	149.	265.	253.	75.	99.	49.	77.	99.	111.	183.	195.	1720.
1967	122.	65.	171.	179.	302.	109.	67.	68.	125.	152.	274.	92.	1726.
1968	36.	200.	241.	316.	216.	137.	44.	44.	71.	158.	267.	259.	1989.
1969	165.	234.	189.	216.	222.	64.	75.	51.	88.	129.	213.	99.	1745.
1970	99.	142.	259.	292.	210.	64.	50.	60.	44.	128.	134.	241.	1723.
1971	117.	65.	144.	229.	258.	39.	96.	62.	93.	100.	138.	136.	1477.
1972	248.	165.	64.	201.	238.	162.	48.	75.	81.	200.	277.	184.	1943.
1973	147.	169.	145.	298.	224.	86.	16.	77.	81.	121.	158.	127.	1649.
1974	144.	114.	151.	261.	128.	155.	177.	35.	71.	80.	95.	100.	1511.
1975	124.	228.	232.	192.	228.	120.	89.	78.	93.	119.	86.	234.	1823.
1976	153.	192.	173.	237.	221.	96.	62.	103.	95.	55.	157.	176.	1725.
1977	150.	67.	230.	212.	210.	79.	52.	78.	70.	179.	236.	123.	1686.
1978	121.	170.	298.	278.	193.	97.	64.	64.	59.	168.	144.	282.	1933.

LAKE VICTORIA LEVELS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
1900	10.59	10.90	10.91	10.90	10.92	10.95	10.97	10.91	10.74	10.59	10.59	10.72	0.
1901	10.70	10.76	10.94	11.26	11.30	11.13	11.02	10.88	10.80	10.72	10.71	10.64	0.
1902	10.62	10.65	10.62	10.71	10.76	10.69	10.68	10.64	10.58	10.57	10.69	10.82	0.
1903	10.90	10.90	10.94	11.07	11.32	11.43	11.41	11.34	11.33	11.35	11.36	11.34	0.
1904	11.31	11.32	11.37	11.53	11.59	11.49	11.39	11.30	11.24	11.17	11.24	11.31	0.
1905	11.32	11.26	11.37	11.46	11.51	11.33	11.23	11.15	11.07	11.04	11.13	11.30	0.
1906	11.27	11.34	11.62	11.91	11.92	11.91	11.77	11.74	11.69	11.62	11.57	11.55	0.
1907	11.48	11.45	11.33	11.55	11.69	11.60	11.45	11.35	11.26	11.23	11.23	11.23	0.
1908	11.18	11.15	11.07	11.09	11.24	11.21	11.16	11.13	11.06	11.03	11.11	11.18	0.
1909	11.10	11.03	11.02	11.18	11.32	11.17	11.03	10.89	10.93	10.98	10.83	10.93	0.
1910	10.91	10.87	10.85	11.01	11.14	10.99	10.90	10.89	10.86	10.77	10.79	10.83	0.
1911	10.79	10.66	10.71	10.89	10.92	10.85	10.71	10.63	10.63	10.47	10.50	10.48	0.
1912	10.49	10.51	10.56	10.82	10.87	10.78	10.69	10.62	10.60	10.57	10.57	10.57	0.
1913	10.59	10.66	10.74	10.85	11.08	11.09	10.99	10.85	10.74	10.70	10.71	10.75	0.
1914	10.60	10.63	10.79	10.82	10.91	10.90	10.84	10.80	10.79	10.75	10.86	10.86	0.
1915	10.90	10.82	10.94	11.04	11.17	11.14	11.02	10.89	10.88	10.84	10.89	11.00	0.
1916	11.00	11.09	11.11	11.35	11.51	11.45	11.31	11.27	11.33	11.30	11.30	11.34	0.
1917	11.37	11.45	11.45	11.76	11.89	11.91	11.81	11.79	11.86	11.88	11.87	11.82	0.
1918	11.79	11.70	11.67	11.77	11.73	11.67	11.46	11.32	11.29	11.22	11.21	11.18	0.
1919	11.09	11.12	11.30	11.32	11.34	11.21	11.15	11.04	11.03	10.96	10.94	10.91	0.
1920	10.91	10.81	10.89	11.12	11.12	11.09	10.92	10.84	10.76	10.74	10.77	10.82	0.
1921	10.83	10.82	10.83	10.81	10.85	10.77	10.73	10.71	10.59	10.55	10.45	10.45	0.
1922	10.39	10.55	10.46	10.60	10.64	10.57	10.38	10.48	10.35	10.33	10.35	10.34	0.
1923	10.22	10.34	10.34	10.58	10.82	10.82	10.80	10.73	10.65	10.62	10.65	10.76	0.
1924	10.72	10.79	10.77	10.87	10.99	10.94	10.71	10.69	10.61	10.63	10.60	10.59	0.
1925	10.69	10.68	10.76	10.76	10.80	10.83	10.70	10.61	10.53	10.50	10.68	10.76	0.
1926	10.75	10.76	10.88	11.07	11.38	11.36	11.27	11.26	11.26	11.29	11.29	11.29	0.
1927	11.29	11.34	11.37	11.51	11.54	11.41	11.21	11.17	11.09	11.00	10.93	10.93	0.
1928	10.87	10.82	10.82	11.02	11.23	11.24	11.12	11.04	10.98	10.93	10.91	10.89	0.
1929	10.79	10.74	10.78	10.87	10.95	10.87	10.85	10.78	10.68	10.65	10.65	10.78	0.
1930	10.83	10.85	11.03	11.29	11.41	11.31	11.23	11.18	11.20	11.20	11.18	11.15	0.
1931	11.11	11.12	11.22	11.39	11.47	11.42	11.40	11.35	11.34	11.24	11.26	11.26	0.
1932	11.21	11.19	11.33	11.41	11.59	11.52	11.46	11.36	11.37	11.35	11.31	11.33	0.
1933	11.35	11.39	11.42	11.44	11.51	11.43	11.28	11.21	11.19	11.15	11.12	11.14	0.
1934	11.05	10.98	10.97	11.11	11.17	11.08	11.01	10.97	10.87	10.85	10.87	10.92	0.
1935	10.82	10.92	10.94	11.02	11.18	11.22	11.08	10.94	10.89	10.81	10.81	10.90	0.
1936	10.99	11.06	11.17	11.39	11.43	11.41	11.29	11.21	11.15	11.08	11.03	11.12	0.
1937	11.13	11.19	11.31	11.57	11.73	11.65	11.56	11.45	11.39	11.37	11.48	11.47	0.
1938	11.41	11.38	11.50	11.58	11.61	11.57	11.46	11.40	11.32	11.30	11.28	11.26	0.
1939	11.21	11.19	11.26	11.40	11.39	11.29	11.23	11.13	11.09	11.05	11.04	11.03	0.
1940	11.04	11.08	11.22	11.38	11.46	11.38	11.33	11.24	11.13	11.07	11.11	11.09	0.
1941	11.06	11.06	11.09	11.19	11.32	11.30	11.19	11.12	11.05	11.03	11.16	11.34	0.
1942	11.37	11.30	11.50	11.69	11.83	11.75	11.60	11.54	11.43	11.33	11.30	11.25	0.
1943	11.13	11.15	11.13	11.28	11.35	11.26	11.12	11.04	10.96	10.90	10.83	10.75	0.
1944	10.70	10.68	10.74	10.87	10.96	10.85	10.75	10.69	10.67	10.63	10.74	10.79	0.
1945	10.75	10.73	10.67	10.67	10.90	10.87	10.83	10.83	10.73	10.70	10.69	10.66	0.
1946	10.59	10.51	10.40	10.60	10.67	10.71	10.63	10.67	10.64	10.63	10.66	10.74	0.
1947	10.86	10.84	10.95	11.27	11.50	11.45	11.43	11.37	11.34	11.30	11.23	11.22	0.
1948	11.19	11.17	11.20	11.26	11.32	11.31	11.26	11.23	11.18	11.13	11.12	11.10	0.
1949	11.03	10.98	10.89	10.98	11.01	10.92	10.86	10.82	10.74	10.70	10.66	10.68	0.
1950	10.68	10.62	10.73	10.84	10.93	10.83	10.81	10.74	10.73	10.72	10.65	10.65	0.
1951	10.62	10.67	10.70	10.95	11.02	10.95	10.84	10.78	10.68	10.68	10.87	11.18	0.
1952	11.19	11.22	11.27	11.50	11.75	11.63	11.55	11.48	11.47	11.41	11.40	11.30	0.
1953	11.25	11.15	11.15	11.29	11.32	11.25	11.11	11.04	11.01	10.97	10.99	11.05	0.
1954	10.98	10.94	10.92	11.06	11.23	11.18	11.10	11.03	11.00	10.93	10.86	10.86	0.
1955	10.86	10.89	10.89	10.97	11.00	10.86	10.77	10.73	10.76	10.77	10.74	10.84	0.
1956	10.92	10.92	10.91	11.08	11.17	11.07	10.97	10.93	10.91	10.91	10.89	10.91	0.
1957	10.90	10.90	11.00	11.19	11.34	11.35	11.24	11.15	11.03	10.96	10.96	11.02	0.
1958	10.98	11.00	11.02	11.10	11.20	11.16	11.11	11.05	10.99	10.93	10.86	10.94	0.
1959	10.93	10.95	10.97	11.05	11.09	11.00	10.85	10.78	10.75	10.73	10.85	10.84	0.
1960	10.86	10.92	11.08	11.29	11.31	11.18	11.05	10.96	10.94	10.92	10.91	10.87	0.
1961	10.80	10.83	10.89	11.03	11.08	11.01	10.91	10.90	10.90	11.01	11.56	11.94	0.
1962	12.07	12.01	12.11	12.29	12.51	12.45	12.34	12.32	12.29	12.34	12.34	12.39	0.
1963	12.47	12.51	12.53	12.80	13.02	12.95	12.82	12.70	12.59	12.50	12.70	12.91	0.
1964	12.89	12.92	12.98	13.30	13.33	13.24	13.09	13.04	12.96	12.91	12.88	12.88	0.
1965	12.92	12.75	12.74	12.64	12.85	12.67	12.55	12.42	12.33	12.34	12.43	12.48	0.
1966	12.45	12.49	12.59	12.78	12.73	12.63	12.49	12.40	12.37	12.35	12.37	12.32	0.
1967	12.25	12.15	12.14	12.25	12.41	12.33	12.23	12.11	12.06	12.06	12.25	12.31	0.
1968	12.21	12.28	12.44	12.67	12.81	12.79	12.64	12.54	12.41	12.37	12.46	12.58	0.
1969	12.62	12.69	12.73	12.82	12.92	12.80	12.66	12.51	12.43	12.36	12.39	12.36	0.
1970	12.41	12.44	12.59	12.79	12.88	12.78	12.64	12.61	12.55	12.52	12.47	12.45	0.
1971	12.40	12.31	12.23	12.42	12.51	12.39	12.30	12.25	12.20	12.16	12.16	12.17	0.
1972	12.17	12.19	12.16	12.20	12.31	12.29	12.17	12.09	12.00	12.07	12.27	12.35	0.
1973	12.35	12.37	12.30	12.37	12.45	12.31	12.19	12.10	12.08	12.03	12.11	12.05	0.
1974	11.97	11.93	11.96	12.21	12.24	12.30	12.32	12.19	12.12	12.05	12.01	11.97	0.
1975	11.90	11.86	11.95	12.09	12.12	12.09	12.09	12.05	12.05	12.05	12.01	12.04	0.
1976	11.97	11.95	11.99	12.09	12.20	12.09	12.05	12.00	11.93	11.85	11.86	11.82	0.
1977	11.88	11.82	11.93	12.21	12.32	12.28	12.17	12.03	11.98	12.00	12.11	12.13	0.
1978	12.07	12.14	12.40	12.59	12.60	12.57	12.43	12.36	12.29	12.29	12.41	12.56	0.

CHANGE IN LAKE LEVEL

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP.	OCT	NOV	DEC	SUM
1900	30.	10.	10.	-10.	20.	30.	20.	-60.	-170.	-150.	0.	130.	-140.
1901	-20.	60.	180.	320.	40.	-170.	-110.	-140.	-80.	-90.	-10.	-70.	-80.
1902	-20.	30.	-30.	90.	50.	-70.	-10.	-40.	-60.	-10.	120.	130.	180.
1903	30.	0.	40.	130.	250.	110.	-20.	-70.	-10.	20.	10.	-20.	520.
1904	-30.	10.	50.	160.	60.	-100.	-100.	-90.	-60.	-70.	70.	70.	-30.
1905	10.	-60.	110.	90.	50.	-130.	-150.	-80.	-80.	-30.	90.	170.	-10.
1906	-30.	70.	230.	290.	10.	-10.	-140.	-30.	-50.	-70.	-50.	-20.	250.
1907	-70.	-30.	-120.	220.	140.	-90.	-150.	-100.	-90.	-30.	0.	0.	-320.
1908	-50.	-30.	-80.	20.	150.	-30.	-50.	-30.	-70.	-30.	80.	70.	-50.
1909	-50.	-70.	-10.	160.	140.	-150.	-140.	-140.	40.	50.	-150.	100.	-250.
1910	-20.	-40.	-20.	160.	130.	-150.	-90.	-10.	-30.	-90.	20.	40.	-100.
1911	-40.	-130.	50.	180.	30.	-70.	-140.	-80.	0.	-160.	30.	-20.	-350.
1912	10.	20.	50.	260.	50.	-90.	-90.	-70.	-20.	-30.	0.	0.	90.
1913	20.	70.	80.	110.	230.	10.	-100.	-140.	-110.	-40.	10.	40.	180.
1914	-150.	90.	110.	30.	90.	-10.	-60.	-40.	-10.	-40.	110.	0.	110.
1915	-60.	20.	120.	100.	130.	-30.	-120.	-130.	-10.	-40.	50.	110.	140.
1916	0.	30.	30.	240.	160.	-60.	-140.	-40.	60.	-30.	0.	40.	340.
1917	30.	80.	0.	310.	130.	20.	-100.	-20.	70.	20.	-10.	-50.	480.
1918	-30.	-90.	-30.	100.	10.	-110.	-210.	-140.	-30.	-70.	-10.	-30.	-640.
1919	-90.	30.	180.	20.	20.	-130.	-60.	-110.	-10.	-70.	-20.	-30.	-270.
1920	0.	-100.	80.	230.	0.	-30.	-170.	-80.	-80.	-20.	30.	50.	-90.
1921	10.	-10.	10.	-20.	40.	-80.	-40.	-20.	-120.	-40.	-100.	0.	-370.
1922	-60.	160.	-90.	140.	40.	-70.	-190.	100.	-130.	-20.	20.	-10.	-110.
1923	-120.	120.	0.	240.	240.	0.	-20.	-70.	-80.	-30.	30.	110.	420.
1924	-40.	70.	-20.	100.	120.	-50.	-230.	-20.	-80.	20.	-30.	-10.	-170.
1925	100.	-10.	80.	0.	40.	30.	-130.	-90.	-80.	-30.	180.	80.	170.
1926	-10.	10.	120.	190.	310.	-20.	-90.	-10.	0.	30.	0.	0.	530.
1927	0.	50.	30.	140.	30.	-130.	-200.	-40.	-80.	-90.	-70.	0.	-360.
1928	-60.	-50.	0.	200.	260.	-40.	-120.	-90.	-60.	-50.	-20.	-20.	-40.
1929	-100.	-50.	40.	90.	30.	-80.	-20.	-70.	-100.	-30.	0.	130.	-110.
1930	50.	20.	180.	260.	120.	-100.	-80.	-50.	20.	0.	-20.	-30.	370.
1931	-40.	10.	100.	170.	80.	-50.	-20.	-50.	-10.	-100.	20.	0.	110.
1932	-50.	-20.	140.	80.	130.	-70.	-60.	-100.	10.	-20.	-40.	20.	70.
1933	20.	40.	30.	20.	70.	-50.	-150.	-70.	-20.	-40.	-30.	20.	-190.
1934	-90.	-70.	-10.	140.	60.	-90.	-70.	-40.	-100.	-20.	20.	50.	-220.
1935	-100.	100.	20.	80.	160.	40.	-140.	-140.	-50.	-80.	0.	90.	-20.
1936	90.	70.	110.	220.	40.	-20.	-120.	-80.	-60.	-70.	-50.	90.	220.
1937	10.	60.	120.	260.	160.	-80.	-90.	-110.	-60.	-20.	110.	-10.	350.
1938	-60.	-30.	120.	80.	30.	-40.	-110.	-60.	-80.	-20.	-20.	-20.	-210.
1939	-50.	-20.	70.	140.	-10.	-100.	-60.	-100.	-40.	-40.	-10.	-10.	-230.
1940	10.	40.	140.	160.	80.	-80.	-50.	-90.	-110.	-60.	40.	-20.	60.
1941	-30.	0.	30.	100.	130.	-20.	-110.	-70.	-70.	-20.	130.	180.	250.
1942	30.	-70.	200.	190.	140.	-80.	-150.	-60.	-110.	-100.	-30.	-50.	-90.
1943	-120.	20.	-20.	150.	70.	-90.	-140.	-80.	-80.	-60.	-70.	-80.	-500.
1944	-50.	-20.	60.	130.	90.	-110.	-100.	-60.	-20.	-40.	110.	50.	40.
1945	-40.	-20.	-60.	0.	230.	-30.	-40.	0.	-100.	-30.	-10.	-30.	-130.
1946	-70.	-80.	-110.	200.	70.	40.	-80.	40.	-30.	-10.	30.	80.	80.
1947	120.	-20.	110.	320.	230.	-50.	-20.	-60.	-30.	-40.	-70.	-10.	480.
1948	-30.	-20.	30.	60.	60.	-10.	-50.	-30.	-50.	-50.	-10.	-20.	-120.
1949	-70.	-50.	-90.	90.	30.	-90.	-60.	-40.	-80.	-40.	-40.	20.	-420.
1950	0.	-60.	110.	110.	90.	-100.	-20.	-70.	-10.	-10.	-70.	0.	-30.
1951	-30.	50.	30.	250.	70.	-70.	-110.	-60.	-100.	0.	190.	310.	530.
1952	10.	30.	50.	230.	250.	-120.	-80.	-70.	-10.	-60.	-10.	-100.	120.
1953	-50.	-100.	0.	140.	30.	-70.	-140.	-70.	-30.	-40.	20.	60.	-250.
1954	-70.	-40.	-20.	140.	170.	-50.	-80.	-70.	-30.	-70.	-70.	0.	-190.
1955	0.	30.	0.	80.	30.	-140.	-90.	-40.	30.	10.	-30.	100.	-20.
1956	80.	0.	-10.	170.	90.	-100.	-100.	-40.	-20.	0.	-20.	20.	70.
1957	-10.	0.	100.	190.	150.	10.	-110.	-90.	-120.	-70.	0.	60.	110.
1958	-40.	20.	20.	80.	100.	-40.	-50.	-60.	-60.	-60.	-70.	80.	-80.
1959	-10.	20.	20.	80.	40.	-90.	-150.	-70.	-30.	30.	70.	-10.	-100.
1960	20.	60.	160.	210.	20.	-130.	-130.	-90.	-20.	-20.	-10.	-40.	30.
1961	-70.	30.	60.	140.	50.	-70.	-100.	-10.	0.	110.	550.	380.	1070.
1962	130.	-60.	100.	180.	220.	-60.	-110.	-20.	-30.	50.	0.	50.	450.
1963	80.	40.	70.	220.	220.	-70.	-130.	-120.	-110.	-90.	200.	210.	520.
1964	-20.	30.	60.	320.	30.	-90.	-150.	-50.	-80.	-50.	-30.	0.	-30.
1965	-60.	-70.	-10.	100.	10.	-180.	-120.	-130.	-90.	10.	90.	50.	-400.
1966	-30.	40.	100.	190.	-50.	-100.	-140.	-90.	-30.	-20.	20.	-50.	-160.
1967	-70.	-100.	-10.	110.	150.	-80.	-100.	-120.	-50.	0.	190.	60.	-10.
1968	-100.	70.	160.	230.	140.	-20.	-150.	-100.	-130.	-40.	90.	120.	270.
1969	40.	70.	90.	40.	100.	-120.	-140.	-150.	-80.	-70.	30.	-30.	-220.
1970	50.	30.	150.	200.	90.	-100.	-140.	-30.	-60.	-30.	-50.	-20.	90.
1971	-50.	-90.	-80.	190.	90.	-130.	-80.	-50.	-50.	-40.	0.	10.	-280.
1972	0.	20.	-30.	40.	110.	-20.	-120.	-80.	-90.	70.	200.	80.	190.
1973	0.	20.	-70.	70.	80.	-140.	-120.	-90.	-20.	-50.	30.	-60.	-500.
1974	-60.	-60.	30.	250.	30.	60.	20.	-130.	-70.	-70.	-40.	-40.	-30.
1975	-70.	-40.	90.	140.	30.	-30.	0.	-40.	0.	0.	-40.	30.	70.
1976	-70.	-20.	40.	190.	110.	-110.	-40.	-50.	-70.	-60.	10.	-40.	-220.
1977	60.	-60.	110.	280.	110.	-40.	-110.	-140.	-50.	20.	110.	20.	310.
1978	-60.	70.	260.	190.	10.	-30.	-140.	-70.	-70.	0.	120.	150.	430.

LAKE VICTORIA OUTFLOWS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
1900	1560.	1429.	1600.	1531.	1600.	1580.	1659.	1641.	1471.	1311.	1181.	1359.	17922.
1901	1359.	1259.	1560.	1699.	2040.	1901.	1791.	1659.	1419.	1461.	1331.	1341.	18820.
1902	1311.	1150.	1300.	1269.	1450.	1360.	1351.	1319.	1261.	1220.	1230.	1480.	15702.
1903	1520.	1431.	1619.	1629.	1951.	2101.	2211.	2149.	2020.	2101.	2080.	2139.	22952.
1904	2080.	1941.	2090.	2199.	2330.	2311.	2281.	2101.	1979.	1919.	1880.	2021.	25182.
1905	2050.	1359.	2040.	2160.	2310.	2181.	2050.	1919.	1761.	1740.	1699.	1919.	23689.
1906	2061.	1820.	2240.	2580.	2851.	2731.	2749.	2621.	2490.	2500.	2370.	2380.	29394.
1907	2219.	2050.	2179.	2140.	2479.	2399.	2350.	2190.	2010.	1981.	1901.	1989.	25886.
1908	1919.	1750.	1931.	1720.	1900.	1891.	1919.	1860.	1751.	1729.	1730.	1871.	21871.
1909	1860.	1600.	1721.	1741.	2040.	1950.	1309.	1651.	1531.	1611.	1489.	1579.	20582.
1910	1619.	1409.	1539.	1520.	1831.	1730.	1619.	1571.	1510.	1491.	1419.	1491.	18749.
1911	1501.	1259.	1341.	1419.	1611.	1520.	1480.	1311.	1269.	1220.	1080.	1161.	16172.
1912	1161.	1061.	1191.	1300.	1560.	1450.	1410.	1341.	1251.	1239.	1170.	1220.	15373.
1913	1220.	1179.	1370.	1409.	1670.	1761.	1750.	1619.	1429.	1381.	1339.	1440.	17567.
1914	1341.	1230.	1410.	1440.	1571.	1559.	1549.	1520.	1419.	1421.	1440.	1571.	17471.
1915	1520.	1339.	1539.	1621.	1879.	1821.	1791.	1641.	1510.	1531.	1499.	1670.	19360.
1916	1689.	1630.	1320.	1891.	2259.	2220.	2171.	2021.	1950.	2090.	1979.	2101.	23822.
1917	2090.	1930.	2240.	2339.	2771.	2741.	2760.	2669.	2619.	2771.	2700.	2760.	30441.
1918	2701.	2370.	2519.	2500.	2680.	2490.	2369.	2230.	1971.	1989.	1880.	1951.	27650.
1919	1831.	1639.	1339.	1919.	2139.	1950.	1919.	1780.	1681.	1721.	1580.	1619.	21617.
1920	1619.	1439.	1520.	1600.	1320.	1779.	1710.	1560.	1429.	1421.	1380.	1491.	18830.
1921	1509.	1351.	1520.	1450.	1491.	1450.	1421.	1421.	1290.	1220.	1170.	1081.	16374.
1922	1030.	991.	1150.	1181.	1279.	1251.	1161.	1089.	1051.	979.	971.	1030.	13162.
1923	931.	850.	971.	1080.	1359.	1461.	1509.	1421.	1321.	1300.	1261.	1399.	14863.
1924	1399.	1349.	1410.	1471.	1670.	1639.	1469.	1381.	1269.	1279.	1261.	1260.	16858.
1925	1330.	1230.	1331.	1391.	1480.	1440.	1450.	1341.	1181.	1169.	1181.	1421.	15993.
1926	1440.	1291.	1480.	1601.	2061.	2080.	2050.	2010.	1940.	2010.	1971.	2040.	21973.
1927	2040.	1859.	2109.	2140.	2401.	2220.	2090.	1959.	1800.	1750.	1621.	1600.	23591.
1928	1579.	1409.	1509.	1510.	1919.	1950.	1890.	1801.	1650.	1641.	1559.	1600.	20018.
1929	1520.	1300.	1450.	1409.	1651.	1559.	1539.	1491.	1370.	1341.	1279.	1410.	17319.
1930	1480.	1390.	1630.	1821.	2179.	2140.	2050.	1919.	1849.	1919.	1849.	1900.	22126.
1931	1839.	1620.	1900.	2000.	2230.	2181.	2190.	2149.	2070.	2010.	1909.	1999.	24097.
1932	1951.	1810.	1981.	2059.	2321.	2311.	2299.	2211.	2070.	2131.	2010.	2061.	25215.
1933	2090.	1970.	2179.	2140.	2310.	2210.	2101.	1959.	1860.	1879.	1769.	1871.	24338.
1934	1809.	1530.	1670.	1671.	1919.	1769.	1750.	1681.	1559.	1531.	1499.	1600.	19989.
1935	1560.	1380.	1641.	1639.	1820.	1960.	1890.	1689.	1541.	1531.	1429.	1531.	19510.
1936	1651.	1600.	1831.	1971.	2211.	2160.	2131.	1999.	1839.	1820.	1699.	1761.	22674.
1937	1839.	1709.	1959.	2181.	2519.	2461.	2431.	2329.	2140.	2149.	2119.	2299.	26135.
1938	2219.	1990.	2230.	2300.	2449.	2360.	2321.	2211.	2059.	2050.	1971.	1999.	26161.
1939	1959.	1750.	1951.	2049.	2179.	2059.	1999.	1900.	1761.	1780.	1681.	1740.	22809.
1940	1729.	1640.	1871.	1961.	2259.	2140.	2149.	2040.	1849.	1809.	1720.	1820.	22987.
1941	1801.	1581.	1609.	1800.	2010.	2000.	1989.	1871.	1741.	1729.	1730.	1999.	22060.
1942	2149.	1891.	2171.	2370.	2650.	2601.	2519.	2401.	2251.	2131.	2010.	2050.	27195.
1943	1900.	1670.	1839.	1860.	2131.	1971.	1919.	1769.	1639.	1611.	1510.	1469.	21289.
1944	1399.	1279.	1359.	1429.	1651.	1541.	1480.	1389.	1310.	1319.	1290.	1480.	16927.
1945	1450.	1291.	1359.	1290.	1469.	1520.	1539.	1520.	1429.	1381.	1310.	1381.	16939.
1946	1300.	1080.	1161.	1121.	1319.	1360.	1330.	1330.	1300.	1300.	1261.	1421.	15283.
1947	1450.	1351.	1571.	1741.	2230.	2251.	2211.	2179.	2049.	2101.	2041.	1989.	23164.
1948	1919.	1780.	1919.	1860.	2080.	2020.	2010.	1989.	1880.	1860.	1611.	1820.	22948.
1949	1761.	1549.	1611.	1559.	1681.	1611.	1571.	1531.	1429.	1410.	1300.	1319.	18333.
1950	1359.	1201.	1330.	1419.	1579.	1499.	1509.	1440.	1370.	1361.	1321.	1330.	16738.
1951	1319.	1191.	1319.	1471.	1689.	1650.	1590.	1480.	1339.	1351.	1401.	1710.	17510.
1952	1959.	1810.	1931.	2070.	2519.	2500.	2409.	2321.	2210.	2230.	2119.	2109.	26237.
1953	2050.	1741.	1879.	1860.	2120.	1961.	1919.	1791.	1671.	1670.	1611.	1750.	22022.
1954	1721.	1470.	1619.	1639.	1890.	1909.	1839.	1780.	1660.	1659.	1520.	1560.	20266.
1955	1531.	1441.	1560.	1580.	1729.	1559.	1501.	1421.	1360.	1480.	1391.	1461.	18012.
1956	1560.	1520.	1560.	1629.	1860.	1779.	1710.	1630.	1559.	1600.	1531.	1579.	19518.
1957	1579.	1441.	1630.	1751.	2021.	2070.	2040.	1919.	1741.	1670.	1611.	1689.	21160.
1958	1689.	1540.	1710.	1660.	1911.	1860.	1860.	1791.	1671.	1659.	1520.	1579.	20449.
1959	1161.	1141.	1590.	1569.	1721.	1639.	1611.	1501.	1401.	1440.	1440.	1549.	17763.
1960	1539.	1460.	1689.	1880.	2061.	1940.	1839.	1670.	1580.	1611.	1569.	1579.	20417.
1961	1520.	1361.	1520.	1621.	1801.	1709.	1651.	1590.	1549.	1611.	1950.	2690.	20574.
1962	3009.	2689.	2990.	3060.	3521.	3451.	3459.	3349.	3221.	3360.	3200.	3379.	38688.
1963	3481.	3161.	3631.	3560.	3890.	4099.	4150.	4011.	3669.	3631.	3529.	3989.	44801.
1964	4249.	3790.	4139.	4229.	4549.	4400.	4611.	4279.	4120.	4201.	3879.	4011.	50457.
1965	4469.	4121.	4000.	4281.	4399.	4309.	3700.	3550.	3291.	3309.	3311.	3521.	46862.
1966	3521.	3170.	3620.	3661.	4231.	4250.	3649.	3459.	3329.	3371.	3301.	3379.	42941.
1967	3301.	2890.	3100.	3039.	3419.	3280.	3301.	3159.	2920.	3009.	2990.	3349.	37758.
1968	3269.	3010.	3459.	3570.	4110.	4071.	4000.	3799.	3490.	3459.	3361.	3711.	43310.
1969	3791.	3540.	4030.	4011.	4351.	4141.	4030.	3791.	3511.	3470.	3319.	3371.	45356.
1970	2899.	3199.	3649.	3840.	4249.	4081.	4011.	3839.	3669.	3719.	3511.	3601.	44269.
1971	3580.	3100.	3280.	3259.	3609.	3459.	3390.	3280.	3119.	3159.	3029.	3140.	39404.
1972	3181.	2960.	3170.	3060.	3301.	3231.	3250.	3199.	2941.	2961.	3039.	3360.	37653.
1973	3411.	2979.	3561.	3259.	3529.	3399.	3199.	3111.	2930.	3009.	2930.	3041.	38360.
1974	2969.	2570.	2819.	2860.	3111.	3039.	3041.	3411.	3241.	2701.	2580.	2690.	35034.
1975	2929.	2280.	2490.	2409.	2171.	2259.	2870.	3031.	3490.	3521.	3179.	2800.	33428.
1976	3031.	2790.	2831.	2910.	3020.	3070.	2980.	3090.	2860.	2859.	2601.	2840.	34931.
1977	2969.	2660.	2790.	2860.	3240.	3049.	3331.	3100.	3200.	3079.	3169.	3440.	36886.
1978	3494.	2858.	2370.	3228.	3569.	3407.	3440.	3213.	3340.	3368.	3218.	3349.	39355.