A REVIEW AND UPDATE OF THE WATER BALANCE OF LAKE VICTORIA IN EAST AFRICA

Report to the Overseas Development Administration

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Acknowledgements

This study makes extensive use of rainfall, flow and lake level data collected in East Africa. We would like to thank the many individuals and organisations who contributed this information.

Summary

This report describes a review and update of the hydrology of Lake Victoria in East Africa. The aim has been to update previous water balance studies of the lake and to examine the sensitivity of the water balance to possible errors or changes in each of the main components. A preliminary assessment has also been made of the impact of past and projected land use changes on lake levels.

As part of the study, a detailed evaluation has been made of a monthly water balance model developed during a previous study by the Institute of Hydrology. This model covered the period 1925 to 1978. The simulations have been updated to the present and several aspects of the model have been simplified or improved while still retaining a satisfactory water balance. An annual model has also been developed to extend the water balance back to the start of the century and for use in the sensitivity studies of the lake water balance. This model has also been used in conjunction with a stochastic rainfall generation model to estimate the likely future trends in lake levels.

For use in future modelling studies, revised estimates have been obtained for the historical lake outflow, tributary inflow and lake rainfall series. An attempt has also been made to place the variations in lake levels this century in a regional context by comparisons with rainfall, flow and lake level records for other regions in East Africa. These analyses and the water balance models confirm the results from previous studies which have shown a firm link between the lake rainfall and variations in lake levels this century. The influence on levels of land use changes and the Owen Falls dam - constructed at the lake outlet between 1951 and 1954 - is shown to be negligible.

Location map

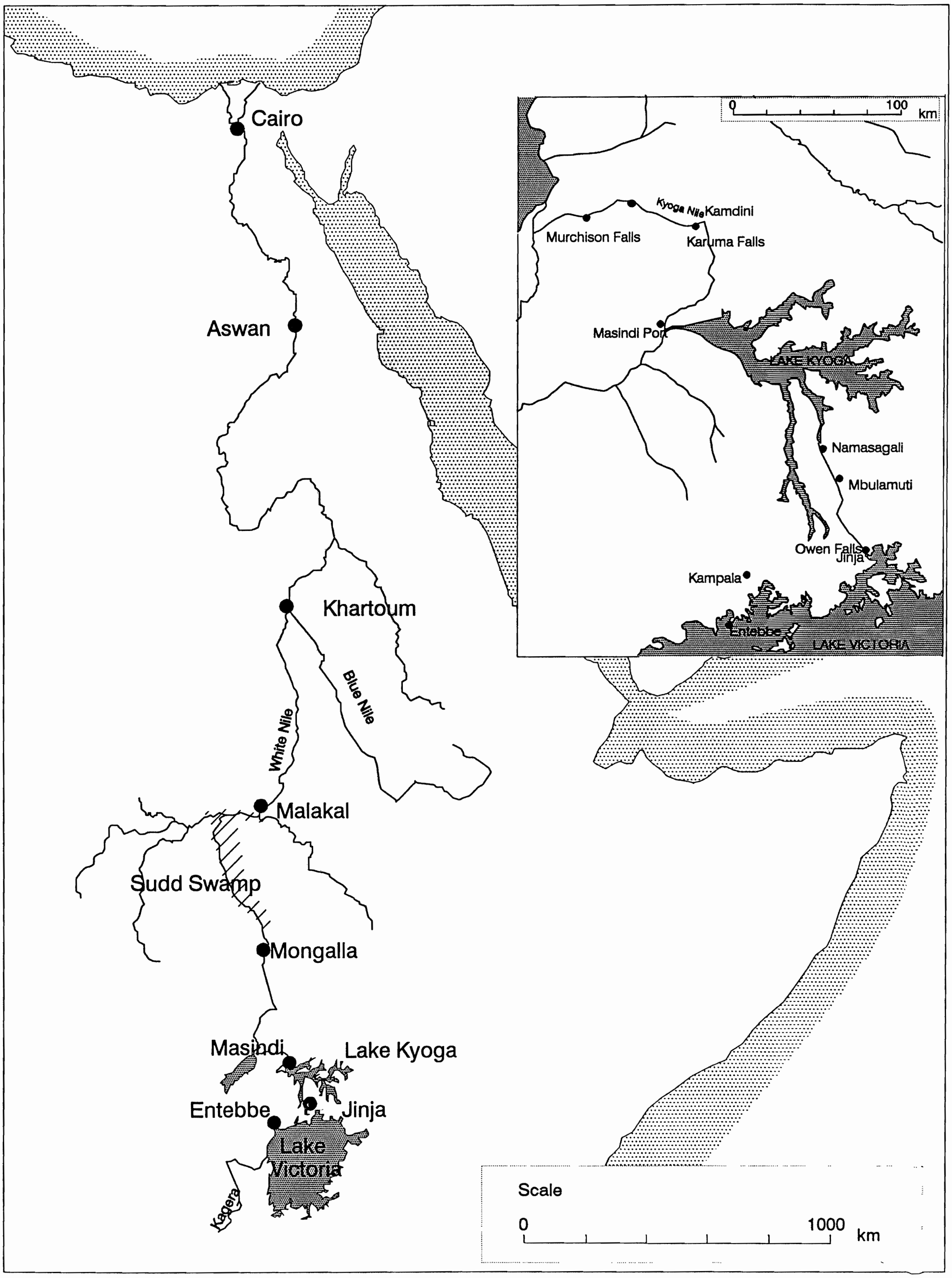


Figure 1.1

1. Introduction

This report describes a review and update of the hydrology of Lake Victoria in East Africa. This work has been performed within the framework of the 'Water Balance of African Lakes' project funded by the Overseas Development Administration. The long term objectives of this project are described in Section 1.1 and the specific objectives of the present study are described in Section 1.2.

1.1 BACKGROUND

The 'Water Balance of African Lakes' study, which started in 1992, aims to develop methods for assessing the possible impacts of land use changes on lake levels in East and Central Africa. Historical records show that many lakes are subject to large fluctuations in level from year to year and it is generally accepted that these fluctuations are due primarily to natural variations in climate. However, changes in land use may also be important. This is particularly likely to be true over long timescales as vegetation and soil cover are important factors in the transformation of rainfall to runoff. Widespread changes in land use may therefore change not only the depth of runoff but also its timing. This would feed through to the overall water balance of the river catchments affected and where these flow into lakes a long term trend in lake levels may be introduced.

The principal change in land use that has taken place in East and Central Africa over the past century has been the progressive replacement of open savannah woodland with agricultural land. More recently there has been a move towards greater use of irrigation in both large and small scale schemes. From theoretical considerations and the results of experiments conducted worldwide it would be expected that a change from forest to agriculture would result in lower evaporation, higher runoff and higher lake levels. A move towards greater areas of irrigated land would tend to have the opposite effect. The impact on lake levels will depend on both the extent and nature of the changes and the importance of direct runoff in the overall water balance of the lake.

To quantify these effects requires the development of process-based models capable of representing the influence of vegetation and soil cover on runoff and the response of lake levels to variations in runoff. Such models could then be used to assess the impact of land use changes in the past on current lake levels and to estimate the impacts of any future planned or hypothetical changes. This information would be useful for assessing the long term yield and hydropower potential of the major African lakes, as well as assisting lakeside communities in planning future developments such as port facilities and irrigation and drinking water supply schemes.

The development of appropriate process-based models is one of the long term objectives of the study. It is envisaged that the results of this work will be presented in a series of reports covering the development of the models and case studies for individual lakes. Initially, two lakes have been selected for detailed study - Lake Victoria and Lake Malawi - and this report presents the preliminary results for Lake Victoria.

1.2 SCOPE OF WORK

The main objective of the present study has been to review and update previous work on the hydrology of Lake Victoria and to examine the sensitivity of the lake water balance to possible errors or future changes in each of the main components. As part of this work, a preliminary assessment has also been made of past and projected changes in land use in the lake catchment and the likely effects of these changes on lake levels. This work should provide a basis for future studies in which process-based models will be used to derive more realistic estimates of the impacts of land use change on lake levels. The results should also be of immediate use in assessments of the water resources and hydropower potential of the Upper Nile.

The starting point for this work has been a major WMO/UNDP funded data collection and analysis exercise for Lake Victoria and the Upper Nile (Hydromet Survey Project; WMO, 1974, 1982). Several subsequent studies have made extensive use of this dataset, including two previous water balance studies by the Institute of Hydrology (1984, 1985; referred to as IH1 and IH2 in this report) and a recent major study by Acres International Ltd. (1990). The WMO and IH studies concluded that the lake water balance this century can be explained satisfactorily solely in terms of natural variations in climate and hence in the inflows and direct rainfall on the lake. By contrast, Acres concluded that the current operating policy at the Owen Falls dam - constructed at the outlet from Lake Victoria between 1951 and 1954 - has led to unnaturally high lake levels in recent years. One of the objectives of the present study has therefore been to resolve this issue by making a detailed examination of the outflow record for the periods before and after construction of Owen Falls dam. It is shown that, from the available evidence, there is little reason to accept the Acres hypothesis and that the modelling strategies used in the previous studies remain valid.

A second objective has been to review and update the data used in the previous IH studies. The original simulations covered the period 1925-78. Following a visit to East Africa, sufficient additional data has been collected to update the models to 1990. Also, using an approximate annual model, it has been possible to extend the water balance back to 1900. The main problem in developing any water balance model for Lake Victoria is the lack of information about the direct rainfall on the lake surface. The estimation methods developed in the IH2 study have therefore been reviewed and an alternative, more easily justified, method has been developed. As part of this work, revised inflow, outflow, lake rainfall and net basin supply series have been derived for use in future modelling studies.

The final objective has been to assess the sensitivity of lake levels to changes in the main components in the water balance and, in particular, to possible changes in inflows due to land use changes. The effect on inflows to date has been estimated from published data for East Africa and the lake catchment and the impact on lake levels estimated using the water balance models. Possible future impacts have also been assessed with the aid of a stochastic rainfall generation model. Based on these studies, suggestions are made for future studies which could improve understanding of the lake water balance and of the likely impacts of land use change on lake levels.

1.3 LAYOUT OF THE REPORT

Previous studies on the water balance of the lake are reviewed in Section 2. Section 3 then describes the validation work on the data and attempts to place the observed variations in lake levels this century in a regional context. The development of the annual and monthly water balance models is described in Sections 4 and 5 together with studies of the sensitivity of the water balance to changes in the individual components. Section 6 then describes how these models were used for a preliminary assessment of the impacts of land use change on lake levels. The main conclusions from this study are given in Section 7 together with suggestions for future work. Finally, Appendix A reviews the hydrological aspects of the Acres study and explains why the conclusions from this study regarding the lake outflow record have been rejected in the present work.

2. Previous water balance studies

2.1 HYDROLOGICAL BACKGROUND

Lake Victoria, with a surface area of about 67,000 km^2, is the largest lake in Africa and one of the largest lakes in the world. It is the main source of water for the White Nile and, since 1954, has provided most of Uganda's electricity through the Owen Falls hydropower scheme constructed at its outlet.

The level of the lake is determined by the balance between direct rainfall, tributary inflows, lake evaporation and lake outflows. By international agreement, releases from the Owen Falls dam are constrained to follow the Agreed Curve, which is a best estimate of the natural outflow which would have occurred if the dam had not been constructed (Figure 2.1). Figure 2.2 summarises levels since measurements first started in 1896. The most striking feature is the sudden and - at the time - unexpected rise of almost 2.5 metres between October 1961 and May 1964, although travellers accounts suggest that levels were also as high or higher in 1878 (Piper, *et al.*, 1986). Clearly, the level of Lake Victoria is highly variable and any process-based model capable of predicting future levels should be able to explain these sudden changes. Key issues include the sensitivity of the lake to natural variations in rainfall, the impact (if any) of the construction of Owen Falls dam on levels, and the extent to which land use changes may have affected levels.

One immediate effect of the 1961-64 rise was to highlight the need for a better understanding of the hydrology of the lake and of its likely behaviour in the future. These concerns resulted in the establishment of the WMO/UNDP Hydromet Survey Project (WMO, 1968, 1974 and 1982) whose main objective was to review and collect hydrometeorological data for the Upper Nile basin and Lake Victoria in particular. During this project, which lasted from 1967 to 1981, the network of raingauges was much improved and the fraction of the catchment which was gauged was increased from about 40% to 80%. Several experimental catchments were also established and research studies initiated on, for example, lake evaporation and the climatology of the lake. The main data collection work came to an end in 1979-80 with the war in Uganda and since then much of the river gauging network has fallen into disrepair, although rainfall data continue to be collected at many sites. WMO involvement in the project ended in 1981 although the riparian nations of the Nile have continued to fund background work on data collection and processing to the present day.

The main dataset produced by the Hydromet Survey project covered the period 1969-78 and several major water balance studies have made use of this data. The project itself included a modelling and interpretation phase (1975-81) and the results of these studies are discussed in Section 2.2. Between 1983 and 1985, this work was extended and new models developed by the Institute of Hydrology in connection with estimates of the hydropower potential of the Upper Nile. This work is discussed in Section 2.3. Finally, in a major review of future hydropower development options, Acres International Ltd. (1990) presented a detailed evaluation of the outflow record from the lake, which is summarised in Section 2.4 and Appendix A. There have also been a number of research studies on specific aspects of the lake water balance and some of these are discussed in Sections 3 to 6. Further background information on the hydrology of Lake Victoria can be found in the previous Institute of Hydrology reports (1984, 1985).

History of the Agreed Curve

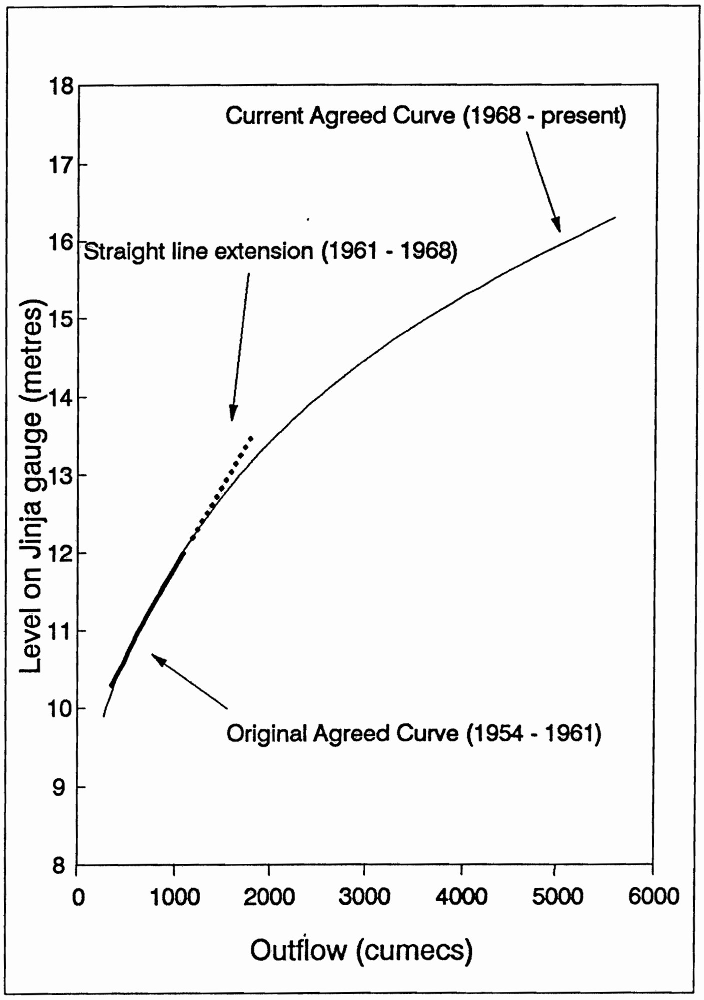


Figure 2.1

Lake Victoria end of month lake levels since 1896

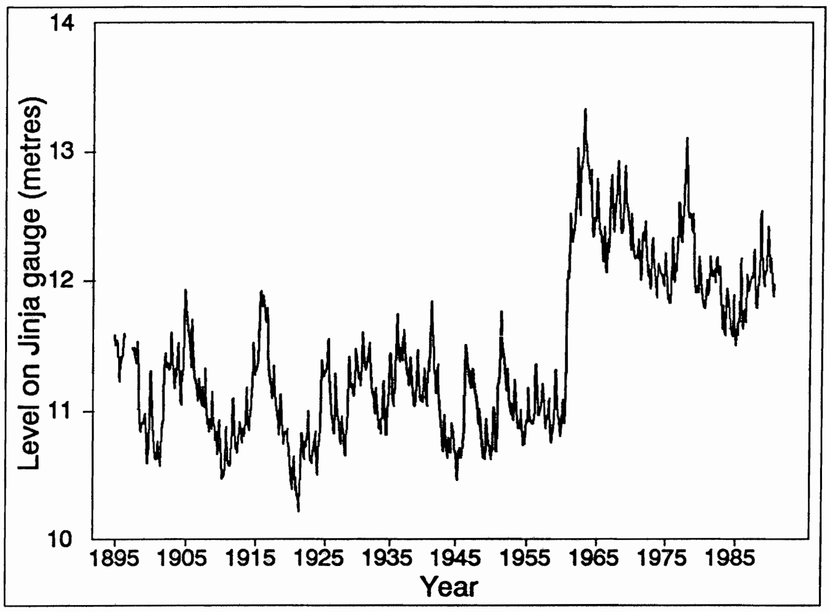


Figure 2.2

2.2 WMO HYDROMET SURVEY PROJECT (1967-81)

The results from the Hydromet Survey project were reported in a series of data yearbooks, consultants' reports and two main reports (WMO, 1974 and 1982). Kite (1981, 1982 and 1984) presents some of the main conclusions from the project regarding the lake water balance, the statistical characteristics of the outflow record and possible alternative lake regulation plans. A mathematical model of the Upper Nile basin was also developed for use in studying alternative lake regulation and hydropower schemes (Brown *et al.*, 1979).

The main use of the mathematical model was in studies of the likely impact of various lake regulation and irrigation/water supply schemes on future lake levels. Attempts were also made to simulate the sudden rise in lake levels of 1961-64 and a smaller rise of about 1.5 m between 1977 and 1980. These simulations showed that the full rise could not be modelled using the observed data alone but that, if the lake rainfall estimates used in the model were increased arbitrarily by 25-30% in some years, good agreement was obtained between predicted and observed levels. This result suggested that improvements were required in the methods used for estimating lake rainfall from land based rainfall gauges but no further work on this problem was possible within the time available. In these studies, the lake rainfall was estimated from isohyetal maps based on all the available rainfall data at the time and on the results of climatological modelling of the atmospheric circulation over the lake.

In parallel with these simulations, more general water balance studies were carried out to try and understand the cause of the 1961-64 rise in lake levels (Kite, 1981, WMO, 1982). This work, which will be discussed further in Section 3, suggested that the rise must have been due primarily to natural causes (i.e. increased rainfall) and that, over the period for which release records were available (1957-79), releases from Owen Falls dam have closely followed the Agreed Curve. Comparisons with other nearby lakes showed similar jumps in level in the early 1960s and late 1970s, suggesting that a widespread climatological change must have occurred over the region. Again, these results will be discussed further in Section 3.

2.3 INSTITUTE OF HYDROLOGY (1983-85)

Between 1983 and 1985, the Institute of Hydrology carried out two reviews of the hydrology of Lake Victoria. The work was performed in association with Sir Alexander Gibb and Partners and Kennedy and Donkin and was funded by the Overseas Development Administration. The overall aims of these studies were (a) to determine whether water balance models alone could explain the observed variations in lake levels this century and (b) to assess the likely future outflows (and hence hydropower potential) at the Owen Falls dam site. Two methods were used for estimating future levels; stochastic modelling of the net basin supply series derived from lake outflows and changes in storage, and stochastic modelling of the lake and catchment rainfall series, coupled with a water balance model for the lake. The results of this work were presented in two main reports (Institute of Hydrology, 1984, 1985) and a technical paper (Piper *et al.*, 1986).

In the IH1 study, the lake rainfall was estimated using a method established by de Baulny and Baker (1970), based on applying seasonally varying weighting factors to data for 8 raingauges sited around the shore of the lake. These gauges were selected since they were the only lakeshore gauges with records available for most of this century. Where possible, total tributary inflows were estimated by developing simple correlations relating flows in the ungauged catchments to known inflows from gauged catchments. For periods with no gauged inflows, a simple soil moisture accounting model was developed to relate the total inflows to the lake rainfall. Monthly mean values for lake evaporation were taken from WMO (1982) and lake outflows were computed from the Agreed Curve. Using this model, it was found that, over the period 1925-78, reasonable estimates for lake levels could be achieved provided that the lake rainfall estimates were increased by 7.5% throughout the simulation period and that a single increase of 22% was made to the rainfall for 1962. The model was also used to determine equilibrium levels for periods of constant rainfall and the time taken for levels to change between equilibrium levels.

Stochastic modelling studies in the first study were confined to modelling the lake rainfall series alone. Following a detailed examination of the data for the period 1925-78, a model was chosen which incorporated some representation of the observed correlation between October and November rainfall and that between these rainy months and the following March and April rainy season. Probabilities of future levels over a thirty year planning horizon were computed based on 1000 realisations of the lake rainfall record. The simulations suggested that changes in level of the magnitude experienced between 1961 and 1964 are not unique and that, over a thirty year period, there is a serious risk that levels might rise high enough to threaten the safety of the Owen Falls installation.

Following this first study, several sources of uncertainty were identified which could possibly be resolved by more detailed analysis. The main concern was that the stochastic model rarely generated long periods of stable lake levels comparable to those observed between 1900 and 1960. Other concerns were the adjustments needed to the lake rainfall estimates to close the water balance and the use of the lake rainfall in modelling tributary inflows, rather than the catchment rainfalls. It was also considered worthwhile to try stochastic modelling of the net basin supply series, derived from lake levels and the Agreed Curve, for comparison with results from the main studies based on stochastic modelling of rainfall.

The second study was completed in 1985. Several major improvements were made to the lake rainfall and tributary inflow models. In the revised rainfall model, lake rainfalls were still estimated from the same 8 gauges, but using a more sophisticated weighting scheme to combine the individual values (see Section 5.1). Revised estimates for the lake evaporation were also obtained based on Penman estimates for several lakeside stations. Sufficient additional rainfall data was also obtained to derive catchment area average rainfalls for the period 1925-78 and these estimates were used, in conjunction with a conceptual rainfall runoff model, to hindcast the total inflow to the lake back to 1925. Improvements were also made in the methods used to estimate inflows from the ungauged portion of the catchment.

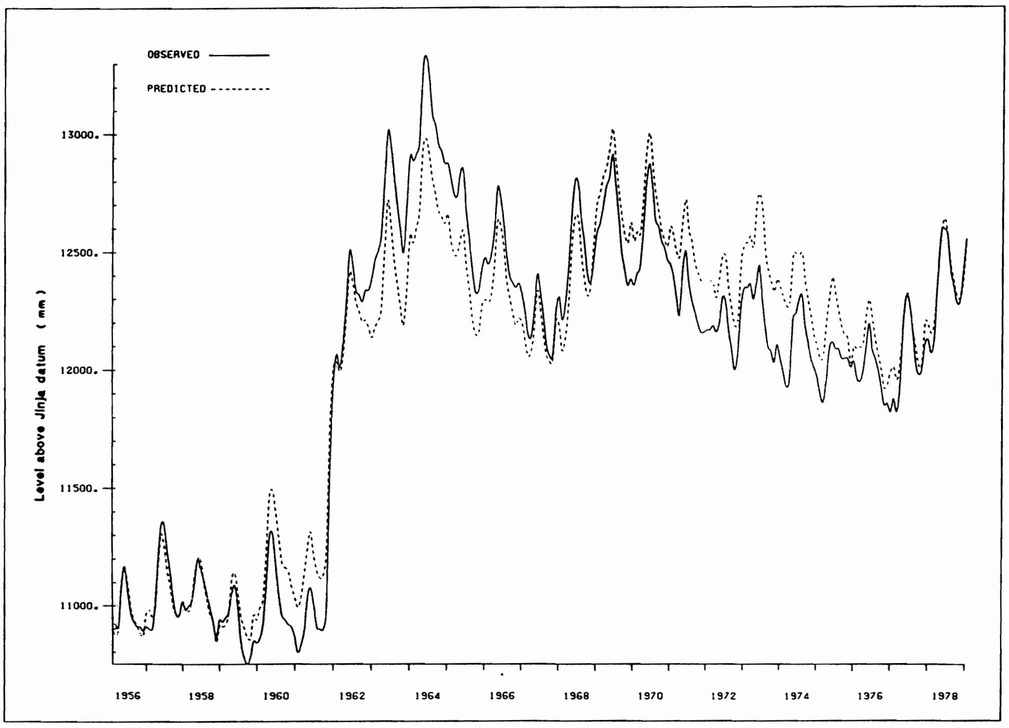
Two lake water balances were derived, covering the periods 1956-78 and 1925-78 (Figure 2.3). Both showed that the lake behaviour could be explained reasonably well by the water balance model, without recourse to any special adjustments to match the sudden rise of 1961-64 or the long periods of nearly stable levels. The stochastic modelling studies were based on this revised model. The techniques from the earlier study were developed to model the joint statistics of the catchment rainfall series and the 8 lakeside rainfall series for use with the water balance model. Some serial correlation was still included but on a shorter time scale than in the first study.

The results from the multivariate stochastic modelling suggested that extreme lake levels are less likely than expected from the first study. However, it still remained difficult to generate sequences of lake levels containing both sudden rises in level and longer periods of relatively

Comparison of observed and predicted end of month levels

(a) 1956 -78 (b) 1925 -78 (Piper et al., 1986)

(a)



(b)

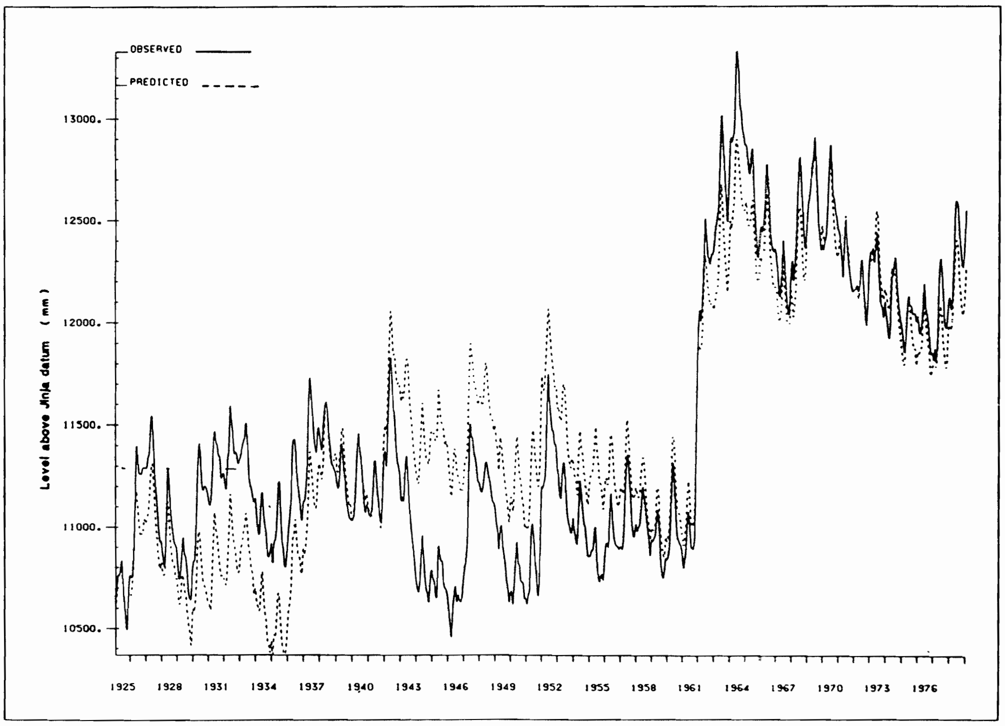


Figure 2.3

stable lake levels like those experienced in the period 1900-60. Similar results were also obtained from a stochastic model of the net basin supply series alone. Some additional simulations were also performed to explore the effects of possible changes in the release policy for Owen Falls dam. The overall conclusion from these studies was that the predicted future lake levels were consistent with historical evidence of past lake levels and - with some reservations - provided a reasonable basis for planning future engineering works on the Victoria Nile.

2.4 ACRES INTERNATIONAL LTD. (1990)

Between 1989 and 1990, the Canadian consulting engineers Acres International Ltd. carried out a study of the feasibility of increasing power generating capacity at the Owen Falls site in order to meet anticipated increases in Uganda's power requirements. The work was performed in collaboration with the Uganda Electricity Board and was funded by the World Bank. The overall conclusion was that the least cost option would be to begin by constructing an additional hydropower plant on the right bank of the Nile, supplied by a canal with an offtake just upstream of the Owen Falls dam. The recommended generating capacity of 102 MW would supplement the installed capacity at Owen Falls dam which is currently being uprated to 180 MW. The Acres report covered many different aspects of the proposed scheme, including load demand forecasts, alternative hydropower options, environmental and socio-economic factors, the required spillway capacity at Owen Falls and the overall engineering design. Only the aspects relating specifically to the water balance of Lake Victoria have been considered in this review.

The stated aim of the hydrological studies was to develop a record of monthly streamflows at the Owen Falls dam (a reference hydrology) to be used as the basis for evaluating the firm energy potential of the site and of points downstream. These studies were based mainly on data extracted from previous reports, although the lake level record was updated from 1978 to mid-May 1990. An outflow record was constructed for the period 1900-90 using lake levels and the Agreed Curve for the periods 1900-56 and 1979-90, and the recorded releases from Owen Falls dam for the period 1957-78. The starting point for the analysis was the observation that both this record, and the inflow available for outflow series (i.e. the net basin supply series) show a marked discontinuity from 1961, shortly after the end of construction work and channel improvements at Owen Falls dam (Figure 2.4).

Several reasons for this discontinuity were considered, including errors in the lake level record, changes in land use, climatological causes, errors in the Agreed Curve and discrepancies arising from departures from the Agreed Curve since the start of operations at Owen Falls dam. Of these possibilities, errors in the Agreed Curve were thought to be the most likely explanation, in the sense that the curve does not fully represent the natural rating of Ripon Falls before construction of Owen Falls dam. The conclusion was that the current Agreed Curve considerably underestimates the natural outflows which occurred before the completion of Owen Falls dam in 1954. In effect, this attributes the increase in mean levels since 1964 (compared to the period up to 1954) to construction of the dam. Regional shifts in rainfall regime were ruled out as a possible cause on the basis that, in previous studies (e.g. Kite, 1981), extensive adjustments to the lake rainfall were required to fully simulate the 1961-64 rise in levels and that stochastic models were not able to fully reproduce the range of levels observed in the historic record (e.g. Institute of Hydrology, 1984).

A full history of the Agreed Curve is given in Section 3.3 but, briefly, the curve was first

Lake Victoria net basin supply 1900 - 90

(Acres, 1990)

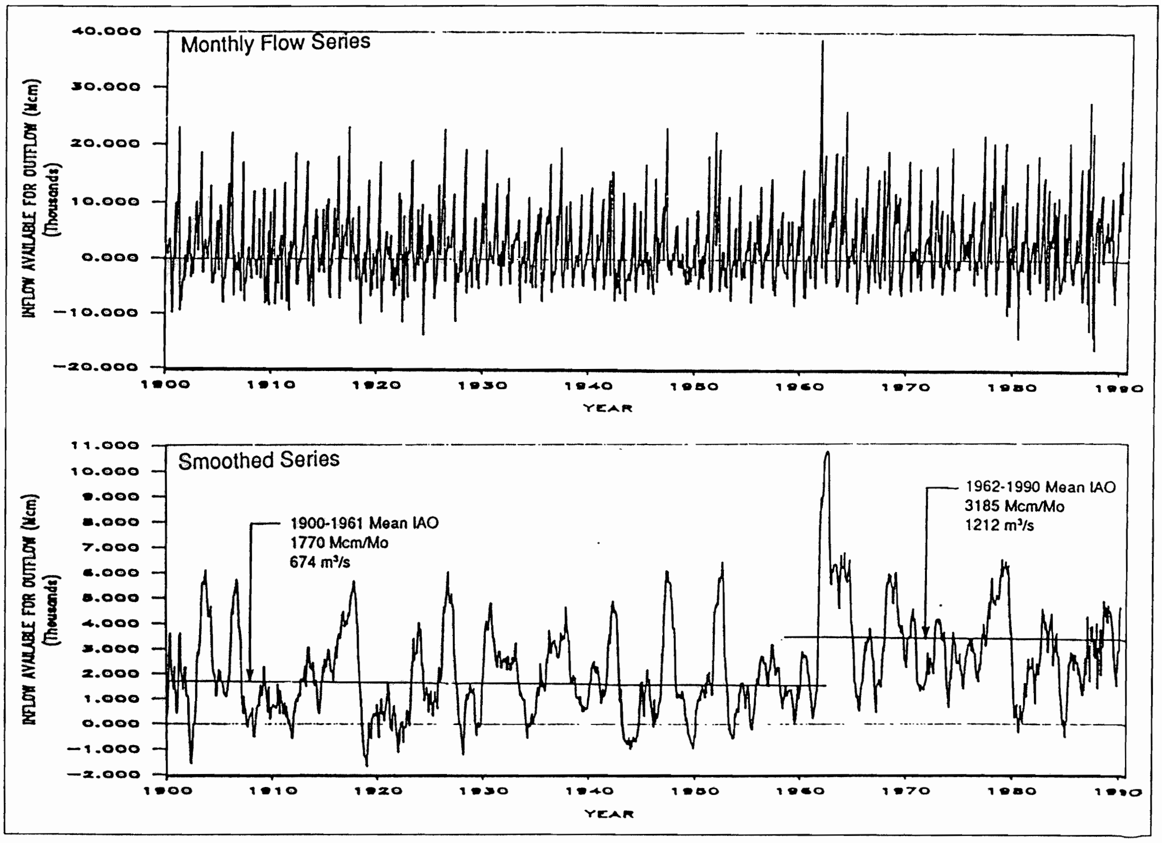


Figure 2.4

established on the basis of simultaneous measurements of lake levels at Jinja and discharges at the Namasagali gauging station which is about 75 km downstream of the original outlet from the lake at Ripon Falls. Acres concluded that the Namasagali discharge measurements could not be relied upon because the river section at the site is prone to changes in size and shape and because the site is subject to backwater effects from Lake Kyoga (indeed, the site was abandoned in 1969 for this reason). Adjustments using data from stations further down the Nile were also ruled out because "their ratings were found to be as variable as that at Namasagali" and "appear to have been adjusted to maintain consistency with the outflow recorded at Owen Falls". Cumulative mass plots and double mass plots were presented which were interpreted as confirming these conclusions. Also, on the basis of analytical hydraulic modelling studies, Acres estimated that the current Agreed Curve underestimates the actual outflows pre-1954 by between 19% and 65%, according to the channel shape assumed for the Ripon Falls before the start of construction work at Owen Falls dam (Figure 2.5). It was concluded that "there is no question of reverting to the hydrologic regime defined by the pre-1954 data set as this data set is not representative of the true hydrology during that period but contains serious data errors".

Having established a reference hydrology, least cost and risk assessment studies were performed using a reservoir simulation model. It was generally assumed that releases will continue to be determined by the Agreed Curve, although some preliminary studies were also performed using alternative regulation plans. The results of these simulations will not be reported here but some mention should be made of the data series used to drive the model as these will be referred to again in Appendix A of this report. Our understanding is that three alternative sequences were used to represent the net basin supply. The first, called the reference hydrology, was based on the measured releases from Owen Falls dam from 1961 to 1989 (possibly extended by using the 1949-60 flows adjusted by some unspecified correction method). The other two series were used to represent the worst case low-flow hydrology and were based on the minimum 40 year period in the corrected and uncorrected 1900-89 flow sequences. The reference and low-flow hydrology were initially assigned recurrence probabilities of 99% and less than 1% respectively. In the final simulations, the full range of probabilities (0-100%) was considered in order to identify the point at which each project would become economically viable. The preferred development option was chosen on the basis of these simulations.

Further studies

Acres' conclusions regarding the outflow record had major implications on existing views of the water resources and hydropower potential of the Upper Nile. An independent review of the hydrological aspects of the study was therefore commissioned in 1990. This review (Cassidy, 1991) focussed on the accuracy of the discharge measurements at Namasagali, the synthetic Agreed Curves which Acres derived by hydraulic modelling, Acres' preliminary assessments of the need for a spillway at Owen Falls dam and, finally, the methods used by Acres to assess the risk associated with a return of the low flows observed in the period 1900-1960. Again, the flood and risk assessment aspects will not be discussed here.

Cassidy began by reviewing the independent modelling checks on the Agreed Curve which Acres performed using a one dimensional hydraulic model called HEC-2. Cassidy concluded that this model has some technical limitations when applied to a complex non-uniform flow such as existed at Ripon Falls before construction of Owen Falls dam. Independent calculations by Sir Alexander Gibb and Partners (Gibb) were also cited which showed that by adopting an alternative, and equally plausible, compound weir model the opposite conclusion could be reached i.e. that the Agreed Curve is substantially correct. Cassidy

Estimates of the Agreed Curve derived from a hydraulic model

(Acres, 1990)

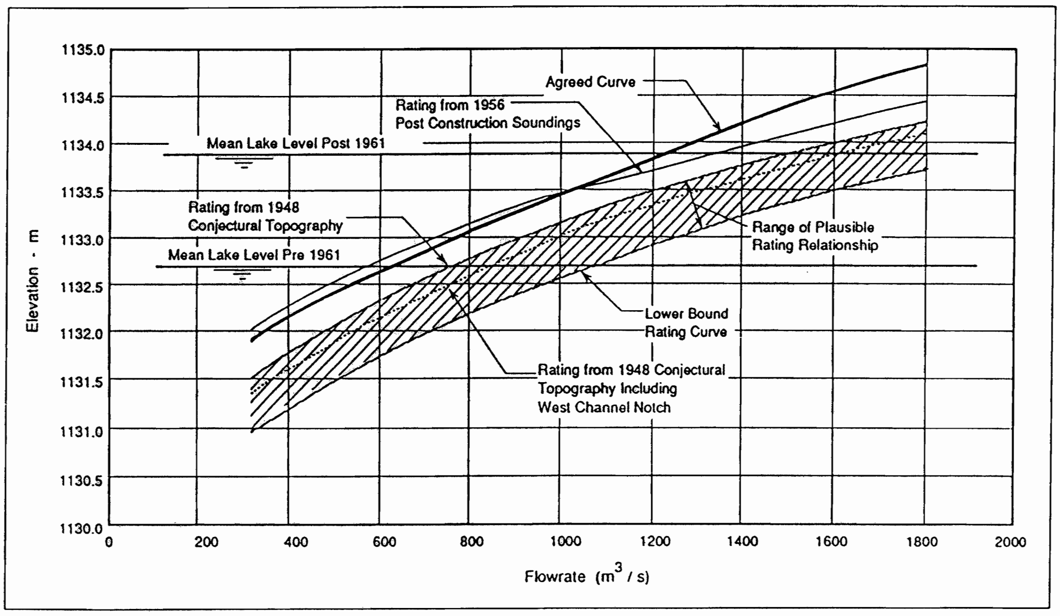


Figure 2.5

therefore placed a low weighting on the evidence from these modelling studies. Instead, his main conclusions were based on a set of simultaneous measurements of releases from Owen Falls dam and discharges at Namasagali made during the commissioning of Owen Falls dam (1955-56). These seemed to show beyond reasonable doubt that the flows measured at Namasagali at that time were to within a few percent of flows computed at the dam from the turbine and sluice ratings. Cassidy therefore concluded that errors in the Agreed Curve are small and that the pre-1954 lake outflows computed from this curve must also be regarded as correct to within a few percent.

A second review of the Acres report (Gibb, 1990) dealt mainly with the conclusions reached by Acres on the accuracy of the Agreed Curve and the hydrology of the Upper Nile and Lake Victoria before 1954. Again, the main conclusion was that the suggested errors in the Agreed Curve are not consistent with the evidence available and that the full outflow record based on this curve is correct and should be used in any future hydropower assessments. Climatological studies were cited (Farmer, 1981) which suggest that lake levels have remained high since 1961 due to an increase in rainfall during the October/November rainfall season resulting from a shift in the regional atmospheric circulation. The increased lake levels since 1961-64 could therefore result from an observed climatological phenomenon. Also, work by Nicholson (1980) suggests a link between the high lake levels in the late 1800s and above normal rainfall in the period 1875-95. Acres also noted that this change appears in the net basin supply series although they attributed the apparent shift to data errors rather than climatological causes.

A detailed study was also made of the Namasagali discharge measurements on which the Agreed Curve is based. From the descriptions in the "Nile Year Books" (Hurst, various years) - the authoritative source of data on the Nile - it was concluded that the methods used to measure flows at Namasagali were valid and, by implication, were in accordance with current hydrometric practice. Also, the original measurements were abstracted from the yearbooks and plotted against simultaneous measurements of lake levels at Jinja obtained from the same source. This analysis (Figure 2.6), which was restricted to a period (1923-1950) before the start of construction at Owen Falls, seems to confirm that the Agreed Curve is valid, provided of course that the Namasagali discharge measurements are correct.

To check the Namasagali measurements, a monthly comparison was made between flows at Namasagali and flows at Mongalla further down the Nile during the period 1905-79. Both records were computed from river level observations and the rating equations valid at the time of the observations. The two records agree well during low flow periods with, as expected, higher flows at Mongalla during peak flow periods. In particular, the 1961-64 rise in flows is mirrored at both stations. A similar comparison between lake outflows and flows at Mongalla is shown on a cumulative basis in Figure 2.7. While this does not prove conclusively that either record is correct, it does improve confidence in the rating equations and hence the discharge measurements on which they are based. Similar good agreement is also obtained by comparing monthly mean lake outflows and flows at Murchison Falls for the period 1912-71 (Figure 2.8). It was noted that the rating curve for Kamdini, on which the 1940-50 portion of the Murchison Falls record is based, is excellent, unlike the rather less stable curve for Namasagali.

Gibb then consider the main implications of the Acres conclusions regarding the Agreed Curve. According to this hypothesis, releases must have been artificially low from the start of operations at Owen Falls dam in 1954 in order to match the supposedly incorrect Agreed Curve. Only after the rains of 1961-64 did lake levels rise high enough for releases, again

Comparison of the Agreed Curve with Namasagali discharge measurements 1923 - 50

(Gibb, 1990)

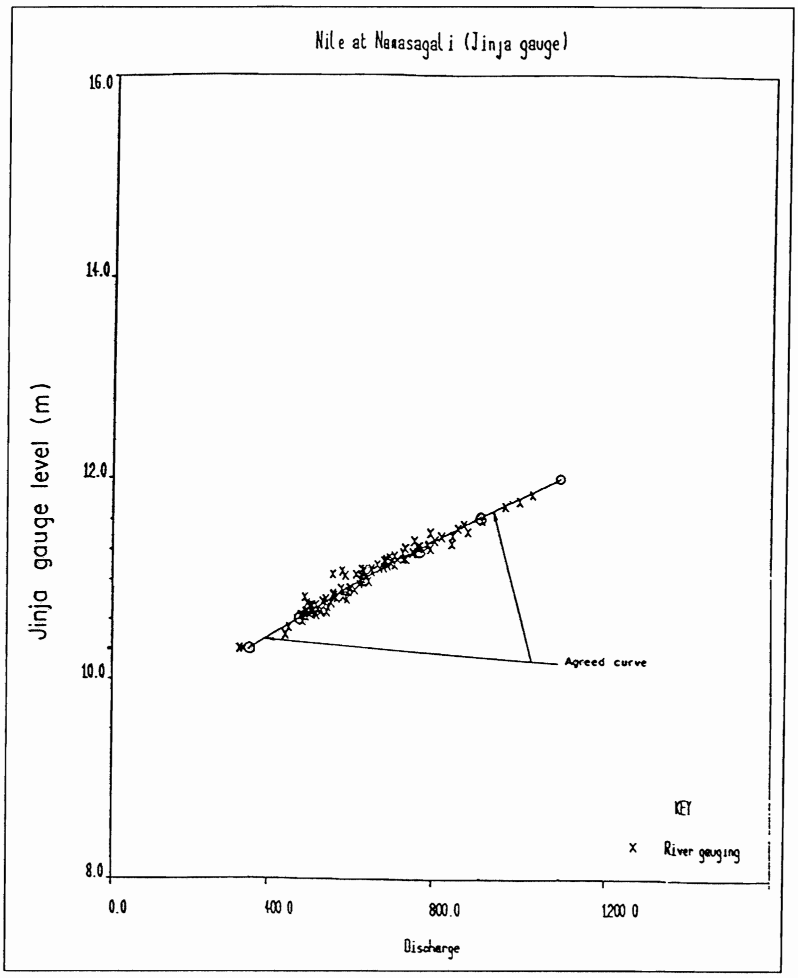


Figure 2.6

Comparison of cumulative flows at Jinja and Mongalla 1905 - 77

(Sutcliffe and Lazenby, 1990)

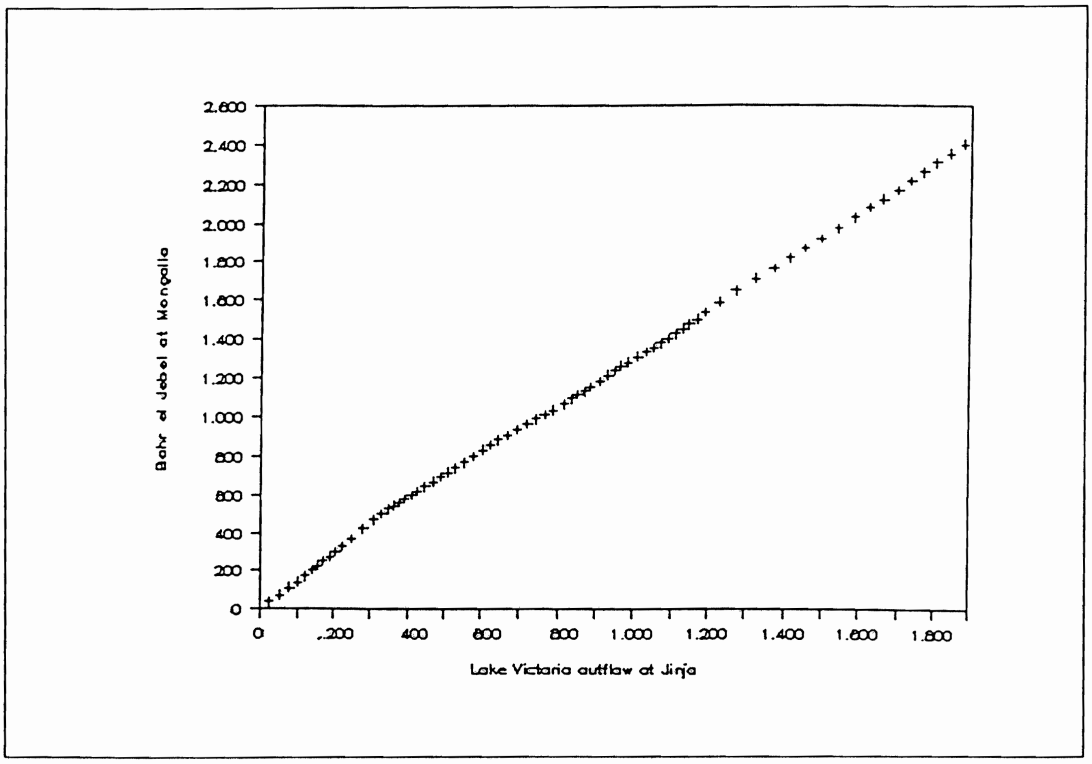


Figure 2.7

Comparison of monthly total flows at Jinja and Murchison Falls 1912 - 72

(Gibb, 1990)

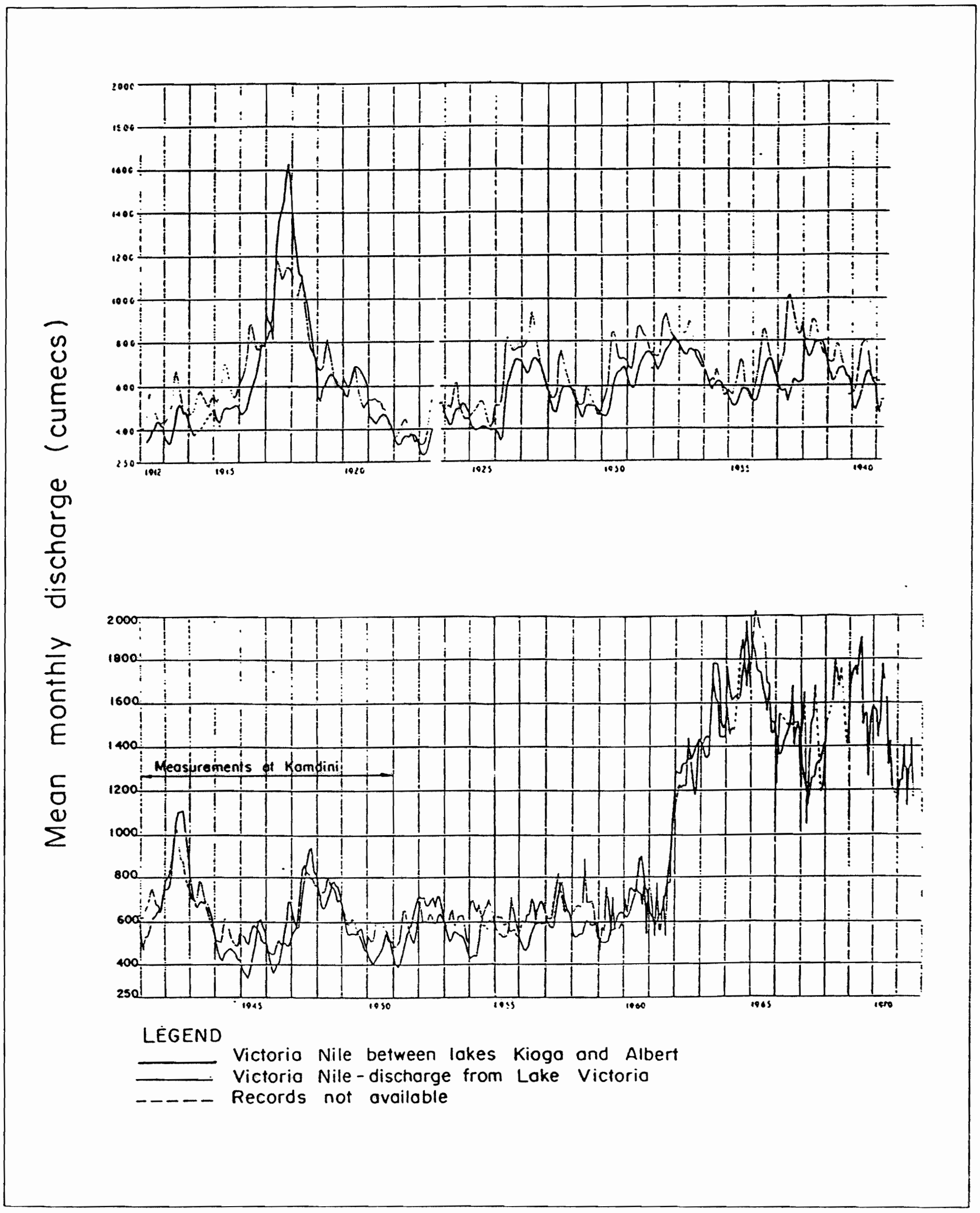


Figure 2.8

made according to the Agreed Curve, to reach pre-1954 values. If this view of events is correct, then flow records for Namasagali and other gauging stations on the Upper Nile should show a sharp decrease in the 1954-60 period compared to flows pre-1954, and the pre-1954 flows should be of a similar magnitude to flows after the end of the 1961-64 wet period. Also, downstream lake and river levels should show similar trends.

Gibb concluded that the Namasagali discharge estimates alone seem to disprove this sequence of events and that the pre-1954 and 1954-60 measurements were very similar. This conclusion would apply even if there was a gross systematic error in the Namasagali rating curve as Acres imply. Other evidence includes (a) the comparisons shown in Figures 2.7 and 2.8 (b) the unique floods of the early 1960s in the Sudd swamps together with a trebling of the area covered between 1952 and 1980 (Sutcliffe and Parks, 1982) (c) the drastic increase in water levels at Murchison Falls from 1961, as evidenced by survey work, tourist photos and movie clips from the early 1950s and the 1960s and (d) greatly increased levels at Lake Albert and Karuma falls after the 1961-64 rise in levels in Lake Victoria. Further evidence is cited from the construction phase of Owen Falls dam. During this time, flows were monitored on a small scale hydraulic model and, at times, were routed through openings of known dimensions in the dam, allowing accurate flow estimates to be made. Gibb conclude that any discrepancies between the actual flows, the Agreed Curve and the results from the hydraulic model would have been immediately apparent to engineers working on the site. It is also pointed out that flows of the magnitude Acres imply (an average of about 1300 m^3s^{-1}) could not have been coped with during the construction phase.

Concluding remarks

The Acres report, together with the Cassidy (1991) and Gibb (1990) reviews, raise a number of interesting questions about the hydrology of the Upper Nile basin and the accuracy of the Lake Victoria outflow record. This has led us to perform an unusually detailed investigation of the lake outflow data. Also, the Acres hypothesis has been investigated further with the aid of a monthly water balance model. Like Cassidy and Gibb, our overall conclusion is that, from all the data available, the Agreed Curve appears to be correct to within a few percent and the pre-1954 outflows based on this curve are a reasonable estimate of the actual flows which occurred. The analyses leading to this conclusion are distributed throughout this report so, for convenience, our findings relating to the Acres report are summarised in Appendix A.

3. Regional analysis of data

This section reviews the data available for Lake Victoria and attempts to place the observed variations in lake levels this century in a regional context. Comparisons are made with levels observed at other lakes in the region and with area average rainfall estimates for East Africa. Also, the outflow record from Lake Victoria is examined in detail and compared with flows observed at stations further down the Nile. On the basis of these studies, new outflow and observed net basin supply series are derived for use in assessing the performance of the water balance models presented later in this report.

3.1 LAKE LEVELS

Regular measurements of lake levels first began in 1896 at Entebbe and were later extended to Jinja (1912) and many other stations. For most of this century, these readings have been published in the Nile Basin Yearbooks (Hurst, various years) as 10 day means and monthly means. Monthly mean levels for Jinja for the period 1957-79 were also published by the Hydromet Survey Project (WMO, 1982). Several independent checks have been made on the consistency of these records. For example, Kite (1981) found reasonable agreement between the levels for four gauges - Entebbe, Jinja, Kisumu and Mwanza - for the period 1950-80. In particular, the 1961-64 rise was recorded at all four gauges. Acres (1990) also confirmed that the values for 1900-78 from these sources agreed with values obtained independently from the Ugandan Water Development Department in Entebbe.

For computing the end of month levels required to estimate storage changes, the method described by de Baulny and Baker (1970) is normally used which is to average the final 10 day mean for the previous month and the first 10 day mean of the current month (e.g. WMO, 1982, Institute of Hydrology, 1984). In this report, all lake levels shown are actual or estimated end of month values for the Jinja gauge. For the period 1900-78 these values were taken from the IH2 report and, for the period 1896-99, values were estimated by correlation with levels at Entebbe. Acres (1990) extended these records up to 1990 and an almost complete set of measurements was also obtained independently for use in the present study. In both of these records, missing values at Jinja were infilled where possible by correlation with levels at Entebbe. A time series comparison (Figure 3.1) shows that there is reasonable agreement between these two records.

In discussions of the sensitivity of the lake water balance, it is helpful to have an idea of the usual range of variation of lake levels, both from month to month and over a whole year. Figure 3.2 shows the distributions of level changes for the period 1896-1992. The median month to month variation is typically about 0.07 m with a maximum of about 0.3 m. The corresponding results for the annual variations are 0.4 m and 1.1 m. Taking a longer term view, several studies have shown that the level of Lake Victoria has fluctuated significantly in the past. From travellers' accounts, in August 1878 the lake is estimated to have risen to a similar level to the 1964 peak of 13.3 metres (Lamb, 1966, Piper *et al.*, 1986). A compilation of observations from the 1800s for Lake Victoria (Nicholson, 1989; see Figure 3.3) suggests that levels rose from a minimum around 1860 to the peak in 1878, declined gradually to about 1925 (though with several short lived rises) and were then fairly constant until the 1961-64 rise. Flohn and Burkhardt (1985) reach similar conclusions by estimating the approximate lake outflows and hence levels from observed flows at Aswan in the late

Comparison of end of month lake levels 1979 - 90

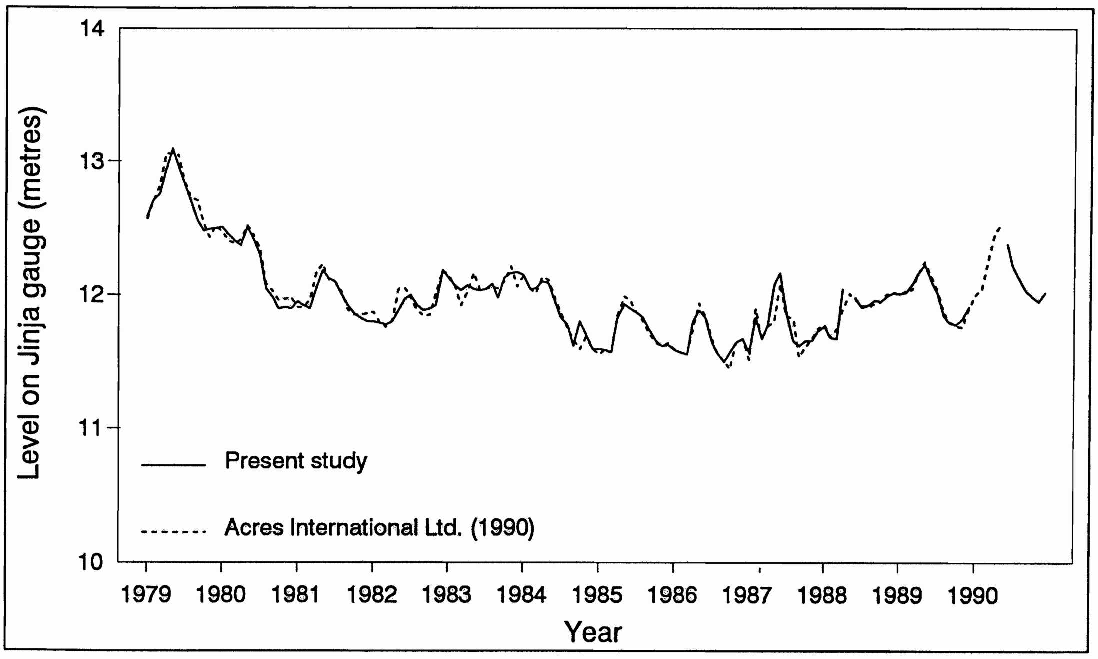


Figure 3.1

Frequency plots of month to month and within year variations of lake levels, for the period 1896 - 1992

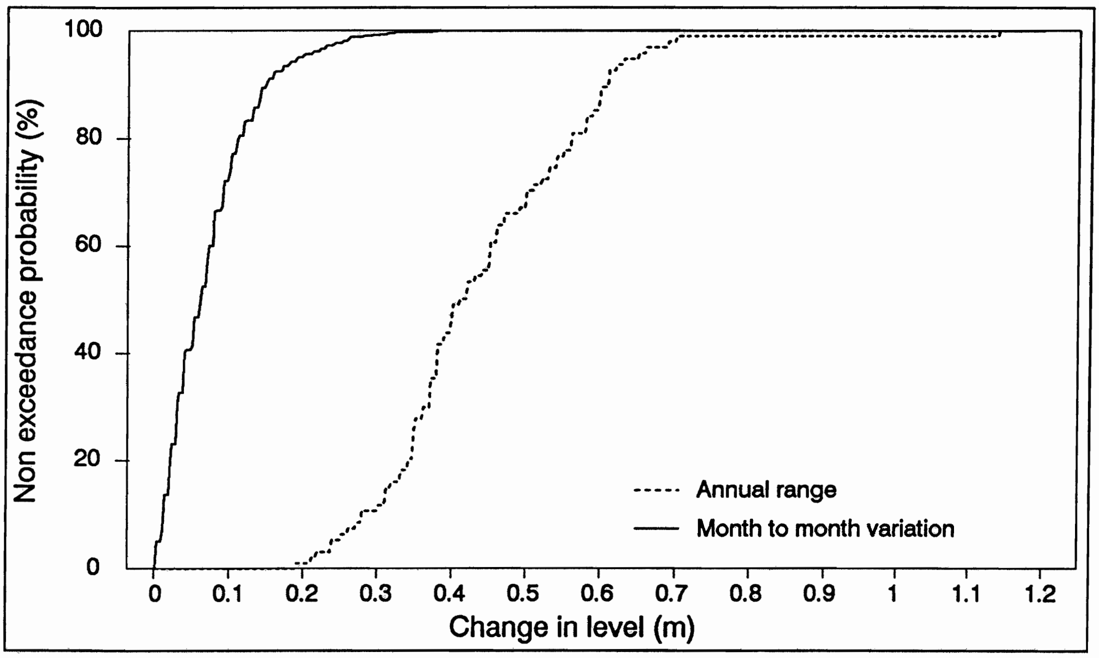


Figure 3.2

1800s and early 1900s.

Figure 3.3 also shows some comparisons with other African lakes. It can be seen that several lakes in the region have similar long term trends in levels to Lake Victoria. For example, Kite (1981) showed that three other lakes - Lakes Malawi, Mobutu Sese Seko and Tanganyika - experienced similar rises in the early 1960s and late 1970s and even matched the smaller rises and falls in the period 1950-80. This is not surprising for Lake Mobutu Sese Seko since this lake is part of the Upper Nile system, but the variations in level for the other two lakes indicate the influence of widespread climatological features. From Lema (1980), Lakes Rudolf (Turkana) and Naivasha also experienced peaks in the late 1800s, followed by a gradual decline, a stable period then a sudden rise in the early 1960s. These comparisons all suggest that the 1961-64 rise in levels at Lake Victoria was caused by a regional increase in rainfall, following a long period of stability in the preceding years. A similar rise appears to have resulted from a rainy period in the late 1800s. This result is considered further in the following section.

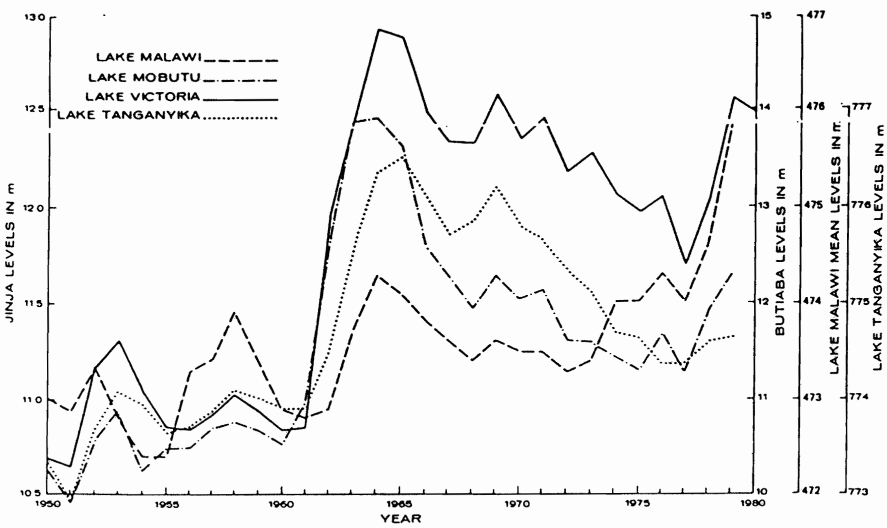
3.2 RAINFALL DATA

Rainfall in East Africa is linked primarily to the seasonal migrations of the Intertropical Convergence Zone (ITCZ) whose maximum range of movement is between about 15°S and 20°N, or from Malawi to northern Kenya. At the latitude of Lake Victoria, this results in two rainy seasons which typically lie between April and May and October and December. The large scale atmospheric circulation over Lake Victoria is approximately from east to west but is strongly influenced by the on-shore and off-shore breezes generated by the lake itself. This local circulation frequently results in the formation of cumulonimbus clouds over the southwestern portion of the lake leading to a significant increase in rainfall over the lake and in a narrow strip of land some 30 km wide around the lake shore (Channon, 1968). The impact of the lake on rainfall can be seen from the only measurements of rainfall ever made near the centre of the lake. These measurements, which were made during a 6 month period by the Hydromet Survey project (WMO, 1982), indicated a total rainfall roughly 30% higher than that observed at any other lakeside or island station during the same period.

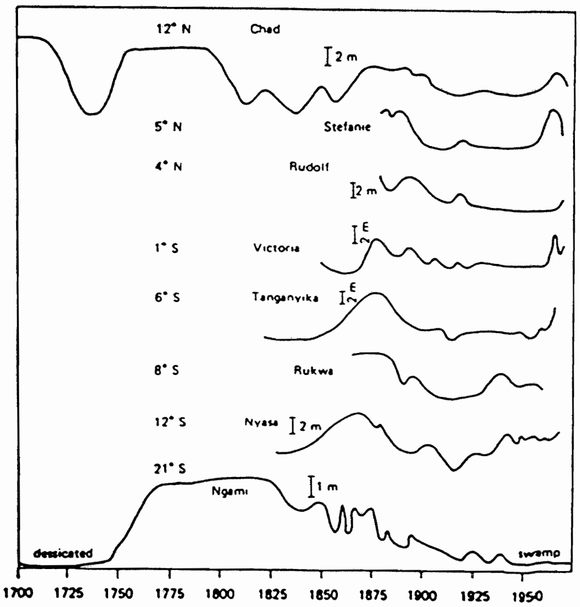
These observations suggest that rainfall variations over the lake basin should be linked to variations over the whole of East Africa. Nicholson (1989) gives an interesting account of rainfall trends over the East African plateau. Historical accounts and observations point to a period of frequent, but short, dry episodes in the mid 1800s, a relatively wet period between the 1870s and 1890s and an abrupt continent-wide decrease starting in 1895 and lasting until the 1910s, but with a wet spell around 1905 in East Africa. Since then, dry periods have been experienced around 1920, in the 1940s and 1950s and the early 1970s, and wet periods have occurred in the 1960s and late 1970s. The Lake Victoria region seems to have largely escaped the effects of the Sahelian drought in recent years. Many reasons have been suggested for these changing patterns of rainfall, including the influence of sea surface temperatures in the Pacific (i.e. the El Nino Southern Oscillation), greenhouse effects and atmospheric feedback from land use changes, but no consensus has yet been reached.

These trends in rainfall are largely confirmed by Figure 3.4, which shows a compilation of regional rainfall estimates taken from several sources. The values for the Kagera catchment and the northeastern lake tributaries have been taken from the IH2 study and updated from 1979 to 1990 in the present study. The values for the lake rainfall are approximate values implied from the lake water balance and are derived in Section 4 of this report. This

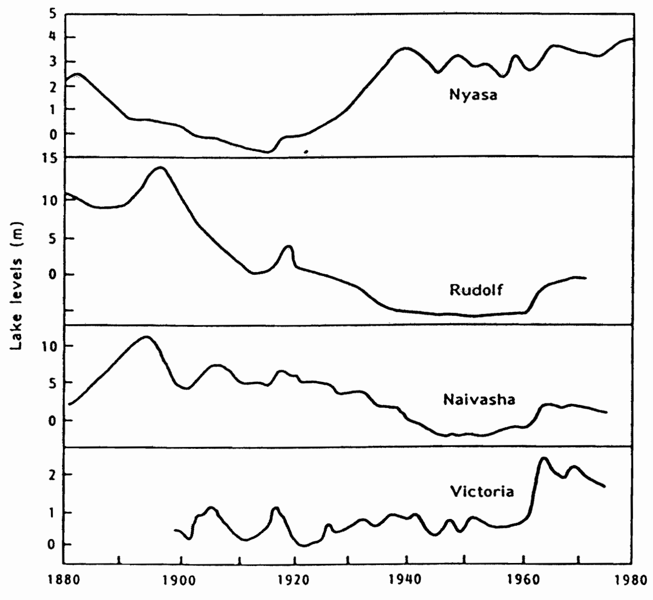
Compilation of lake level comparisons from various sources



(Kite, 1981)



(Nicholson 1989)



(Lema 1980)

Figure 3.3

Compliation of regional rainfall trends from various sources

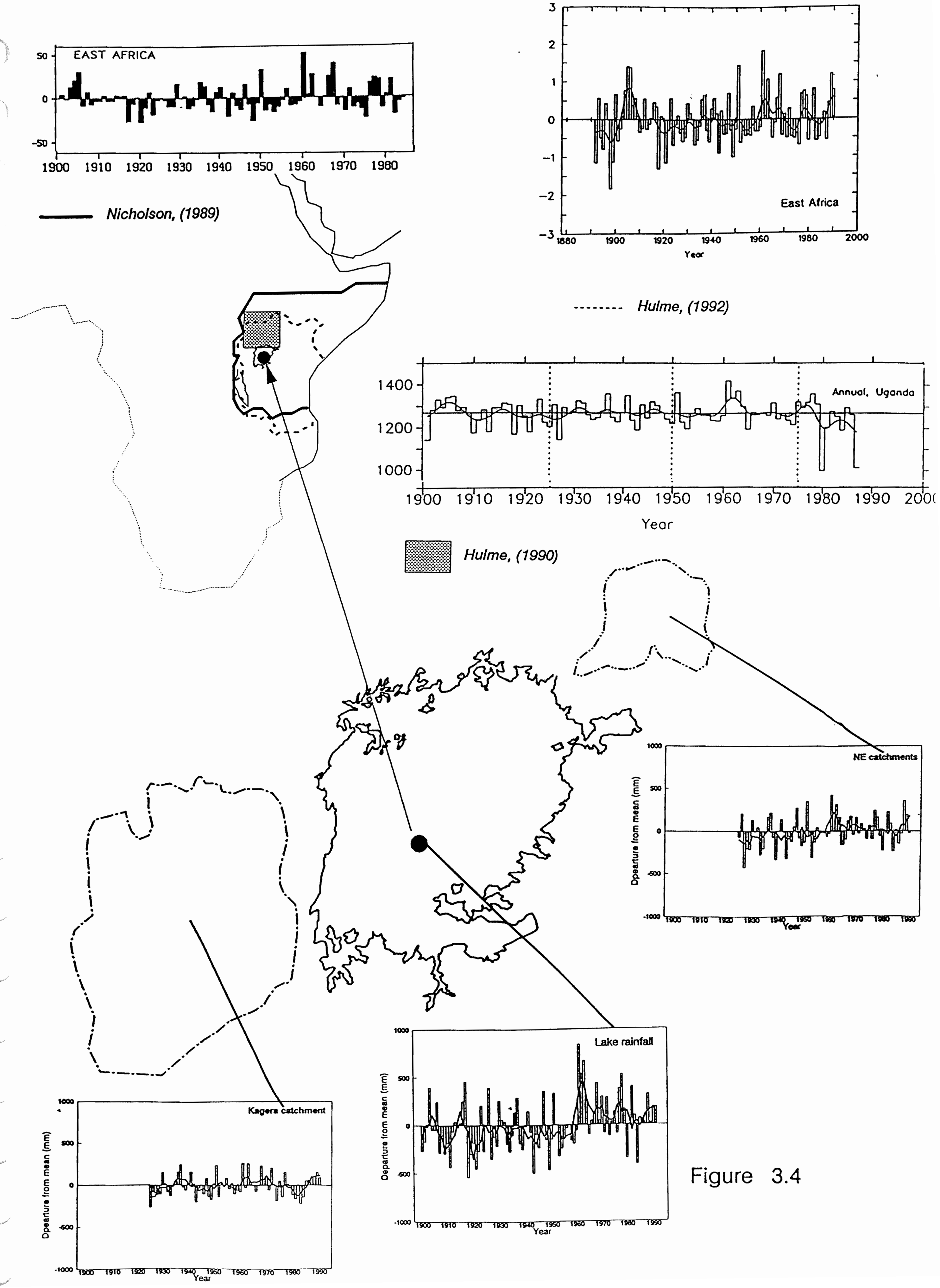


Figure 3.4

compilation confirms the regional nature of the rainfall pattern and, in particular, shows that the increased rainfall in the early 1960s and late 1970s appears in all records, irrespective of the region selected, the number of raingauges used and the area averaging procedure.

These trends also have many similarities to the variations in the level of Lake Victoria this century; for example, the short lived rise in levels around 1905 and the long period of low, roughly constant levels in the 1940s and 1950s. The region-wide increases between 1961 and 1964 are of particular interest because of the sudden rise in the lake levels in this period. Previous studies have shown that, during this period, rainfall increased in both rainy seasons, but particularly in the October-December season (Lamb 1966, Farmer, 1981). Flohn (1987) refers to the 'catastrophic' rains of late 1961 and early 1962 and estimates that, in the Lake Victoria region, rainfall was 1.8 times the normal for the period Aug 1961 to Jan 1962, and almost 4 times normal for November alone. Grundy (1963) describes the widespread flood damage caused throughout Kenya by these rains. Farmer (1981) suggests that 1961 marked a shift in the climate of East Africa and that the mean rainfall since then has been significantly above the mean for the preceding 30 year period, possibly due primarily to an increase in rainfall in the October-November rainy season. The review by Nicholson (1989) suggests that such shifts are not unusual and have often occurred on a timescale of several decades. A comparison of the records for the 8 long term rainfall stations around the shore of Lake Victoria (Figure 3.5) suggests that the heaviest rainfall was to the south and east of the lake. Also, most gauges show a succession of relatively dry years preceding the 1961-64 increase in rainfall.

It is now interesting to ask whether the observed changes in lake level from 1961-64 are consistent with the observed increases in rainfall. The additional rainfall between 1961 and 1964 can be estimated by examining the data for raingauges around the lake shore but first it is necessary to derive an estimate for the relationship between the rainfall observed at these gauges and the total rainfall over the lake. The mean rainfall for these 8 gauges was about 1560 mm for the period 1956-78. For the same period, the IH2 water balance studies suggest that the total lake rainfall was about 1850 mm which in turn suggests that the lake rainfall is on average a factor 1850/1560 = 1.19 higher than the average rainfall recorded at the 8 lakeshore stations. The additional rainfall between 1961 and 1964, compared to the previous 4 year period, was about 1.35 m at the 8 lakeside stations, equivalent to an increase of about 1.6 m over the lake surface. For the same period, the observed additional inflow compared to the previous 4 years was equivalent to roughly a 0.9 m increase in levels and the additional outflow was equivalent to roughly a 1.1 m drop in levels. Again, all values are based on data tabulated in the IH2 report.

These estimates suggest the net increase in levels between Jan 1961 and Dec 1964 was about 1.4 m compared to the observed change of 2.0 metres in the same period. This agreement seems reasonable given the approximate nature of these calculations, and several possible reasons could explain the difference. For example, the total lake evaporation was quite possibly lower in the period 1961-64 as a result of the increased cloudiness and humidity associated with the increased rainfall. A reduction of only 150 mm per year, or about 9%, would explain most of the difference. Another possible explanation is that the seasonal distribution of rainfall changed during the wetter period, resulting in a change in the relationship between total lake rainfall and rainfall at the lakeside stations. These issues will be discussed further in the water balance studies in Sections 4 and 5 of this report. However, as in the previous IH studies, the preliminary conclusion is that the observed rise in levels is consistent with the observed increase in rainfall and - more generally - that there seems to have been a consistent link between lake levels and regional variations in rainfall since lake

Annual departures from mean for 8 lakeshore rainfall stations (1900 - 90)

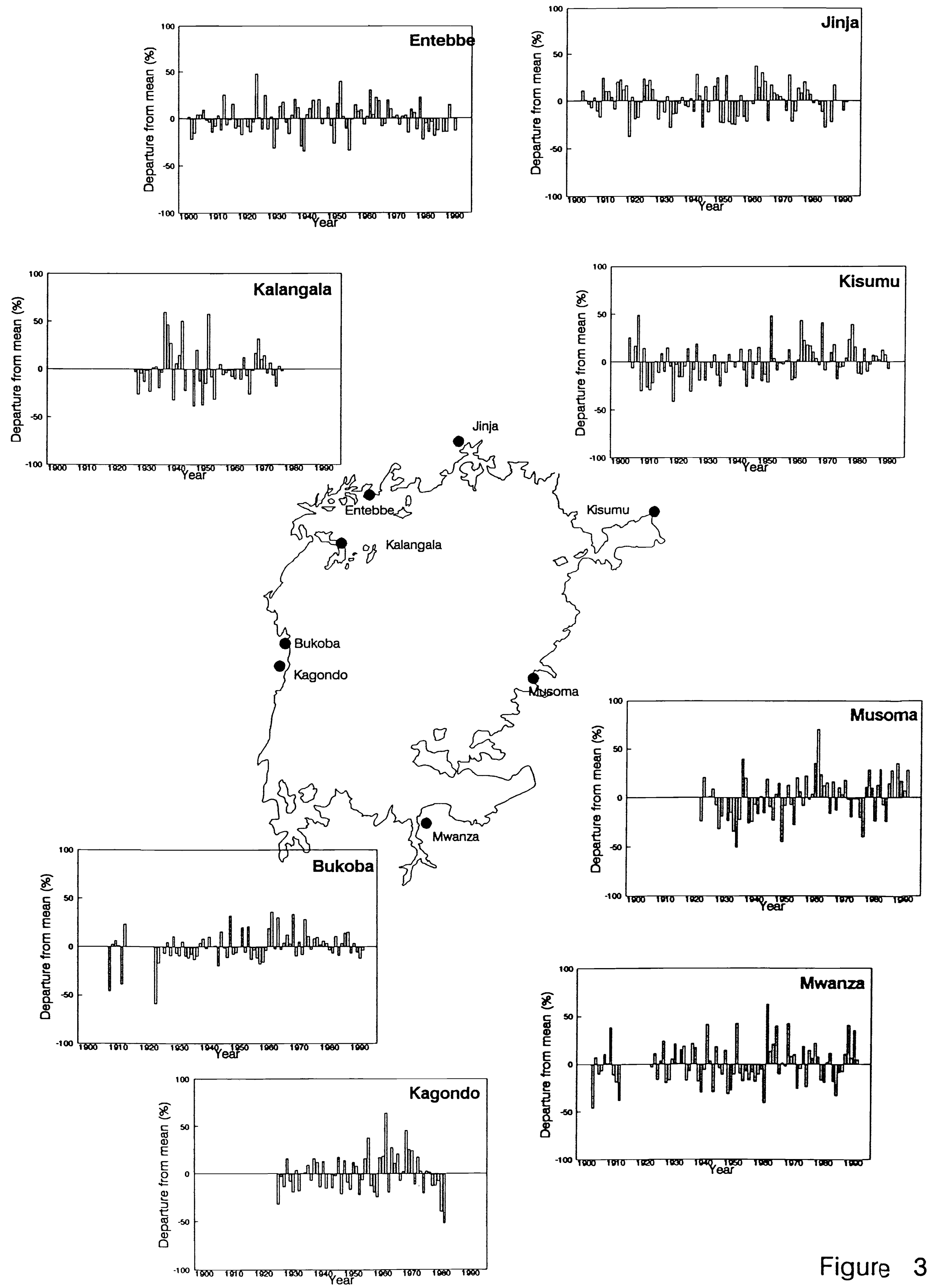


Figure 3.5

level observations first began in the late 1800s.

3.3 OUTFLOWS AND THE AGREED CURVE

The Agreed Curve

Until 1950, the outflow from Lake Victoria was regulated naturally at Ripon Falls. In 1951, temporary river regulation works began at Ripon Falls in preparation for construction of the dam at the Owen Falls site some 3 km further downstream. Maximum flows were limited to about 750-800 m^3s^{-1} (nominally) during this period and, by agreement with Egypt, flows were not to be reduced below 600 m^3s^{-1} in periods when the lake level was high enough to maintain such a flow (Westlake *et al.*, 1954). The dam was closed in 1953 and the water level in the forebay was gradually increased to match the lake level, in the process drowning out the original Ripon Falls. A full account of the design and construction of the dam up to this time is given by Westlake *et al.* (1954) and Bertlin and Olivier (1954).

Since 1954, releases have, by international agreement, been constrained to match the natural outflows from the lake which would have occurred if the dam had not been built. The operating rule which is followed to achieve this is the Agreed Curve. In practice, the dam operators compute releases on a 10 day average basis and adjust flows in subsequent periods if there have been any departures from the Agreed Curve (Cassidy, 1991). This presumably gives the operators the flexibility to vary releases to suit maintenance schedules and load demands. Between 1957 and 1960, further channel improvements were carried out to ensure that flows could still be controlled from the dam during low flow periods.

Starting in late 1961, lake levels began to rise rapidly and, by early 1962, had risen above the upper limit (12.0 metres) of the original Agreed Curve. For the next few years, releases were determined by a straight line extension to the curve, fitted by matching the gradient of the original curve at the point 12.2 metres on the Jinja gauge. In 1968, a new Agreed Curve was adopted based on the results of hydraulic model tests (Hydraulics Research Station, 1966). This new curve is assumed to give a reasonable estimate of the flows which would have occurred naturally for lake levels over the wider range of 9.9-16.3 metres on the Jinja Gauge and has been used to determine the dam releases up to the present day.

These variations of the Agreed Curve are summarised in Figure 2.1. The original curve was established before construction of Owen Falls dam from a comparison of lake levels at Jinja and simultaneous discharge measurements at Namasagali, some 75 km downstream of the dam site. The implicit assumption made was that, at any given time, flows at Ripon Falls are similar to flows at Namasagali. This assumption is reasonable since there are no major inflows or outflows in the reach down to Namasagali, the runoff from the surrounding catchment is negligible compared to the flow in the main channel and major variations in flow normally occur over timescales of several weeks. Direct flow measurements at Ripon Falls were not possible due to the absence of a suitable gauging site. The calculations underlying this curve have been checked many times (e.g. Acres, 1990, Gibb 1990; see Figure 2.6) and the curve is generally accepted to be a good fit to the available data for lake levels up to about 12 m. Of course, much depends on the accuracy of the discharge measurements at Namasagali but the review by Gibb (1990) and our own review (see below) suggests that these measurements are valid.

For the period of artificial regulation since 1954, the accuracy of the Agreed Curve is of less interest from the narrow viewpoint of modelling the water balance of the lake. Provided the dam operators follow the curve exactly, then the lake outflows are defined completely. Any departures from the Agreed Curve can be identified from the recorded releases from the dam computed from the turbine and sluice ratings. Acres (1990) have recently reviewed these ratings by deducing the turbine flows from the recorded monthly energy production over the period 1968-90, and the sluice discharges from the sluice ratings established from model tests. They conclude that the recorded turbine/sluice releases were, on average, about 2.4% too high over this period, primarily because no allowance had been made for the variations in discharge with the operating head over the turbines. Cassidy (1991) also describes tests between 1955 and 1956 in which the turbine/sluice estimates of discharge were found to be some 4-5% lower than measured flows at Namasagali for averaging periods of 1, 2 and 3 days. The preliminary conclusion must be that, to within a few percent, the recorded dam releases since 1954 give a reasonable estimate of the actual outflow from the lake.

Taking a wider view, the accuracy of the Agreed Curve is important in assessing the impact, if any, of Owen Falls dam on lake levels especially in view of the Acres hypothesis (see Section 2.4) that the high levels since 1961-64 are largely a consequence of construction of the dam. Two effects need to be considered, namely (a) the impact on levels if the operators do not follow the Agreed Curve and (b) the impact on levels if the Agreed Curve itself is not a good representation of the natural flows which would have occurred in the absence of the dam. An assessment of both these effects is given in the following sections.

The outflow record

Using the Agreed Curve, it is possible to estimate the outflows from Lake Victoria for the whole period over which lake levels are available. In addition, actual monthly total releases from Owen Falls dam were compiled for the period 1957-79 inclusive by the Hydromet Survey project and values for the period 1980-87 are given in the Nile Year Books. Values for the period 1989-91 were kindly provided by the Uganda Water Development Department (WDD) in Entebbe. Also, discharge measurements were made at Namasagali at frequencies of up to 10/year from 1940-50, 1/week from 1951-57 and up to 1/month from 1958 to 1970. From 1970, measurements were also made at the Mbulamuti gauging station some 20 km upstream and were continued up to about 1978. As will be shown, for the slowly varying flows on the Victoria Nile, the Namasagali and Mbulamuti constitute a valuable cross-check on the outflow estimates from other sources.

From these data, we have computed three estimates for the outflows from the lake. The first estimate (Record A) is based on the observed lake levels and Agreed Curve throughout. Monthly outflows have been estimated by applying the Agreed Curve to daily values of lake levels estimated by linear interpolation between the end of month lake levels. The second record (Record B) consists of the turbine/sluice releases from 1957 to 1991. A third, novel, record (Record C) has been computed directly from the Namasagali and Mbulamuti discharge measurements. The method used is to interpolate linearly between individual measurements and then sum the resulting daily flows to obtain monthly total flows (Figure 3.6). This method should provide excellent flow estimates provided that the interval between measurements is much less than the time over which significant variations in flow occur. This is certainly true in the period 1951-57 when discharges were measured every week and also seems to give reasonable results for the earlier period when the interval between measurements was longer. In the calculations, the maximum interval allowed between consecutive measurements was 2 months; for longer periods, values in the resulting gaps were set missing.

Figure 3.7 compares Records A, B and C. The comparison between the Agreed Curve

Interpolation method for estimating monthly total flows from individual discharge measurements

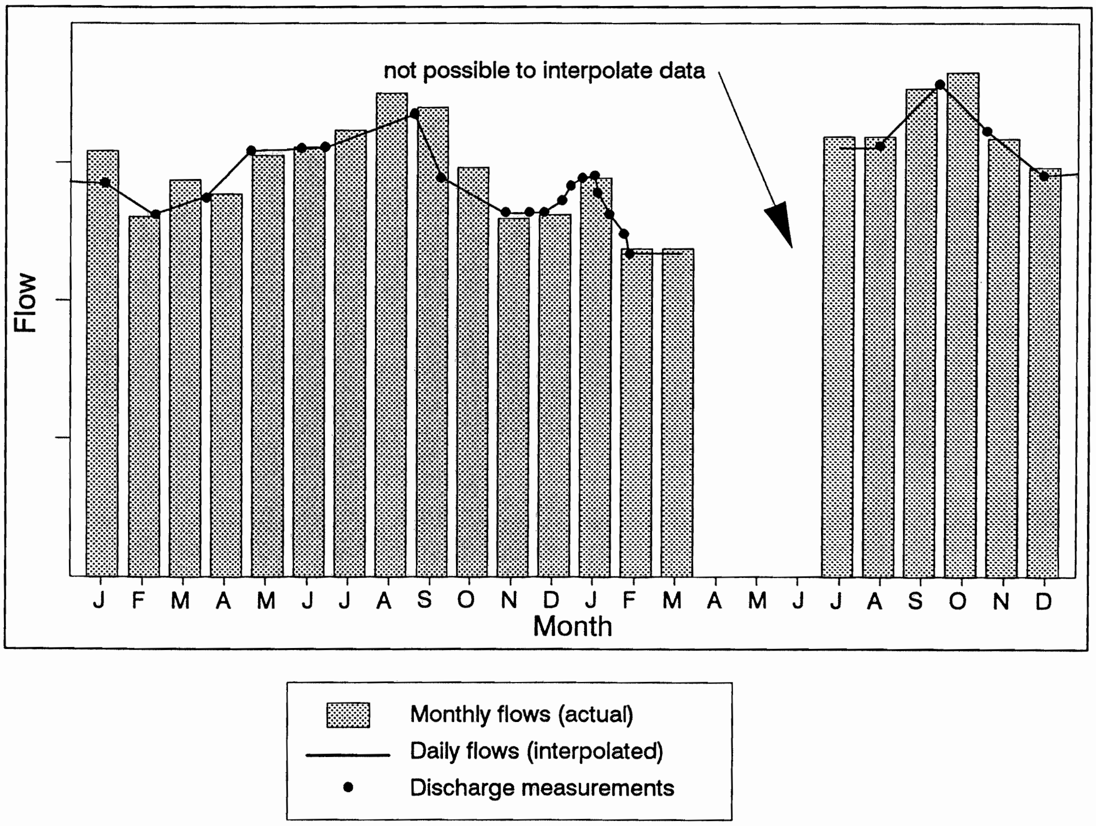
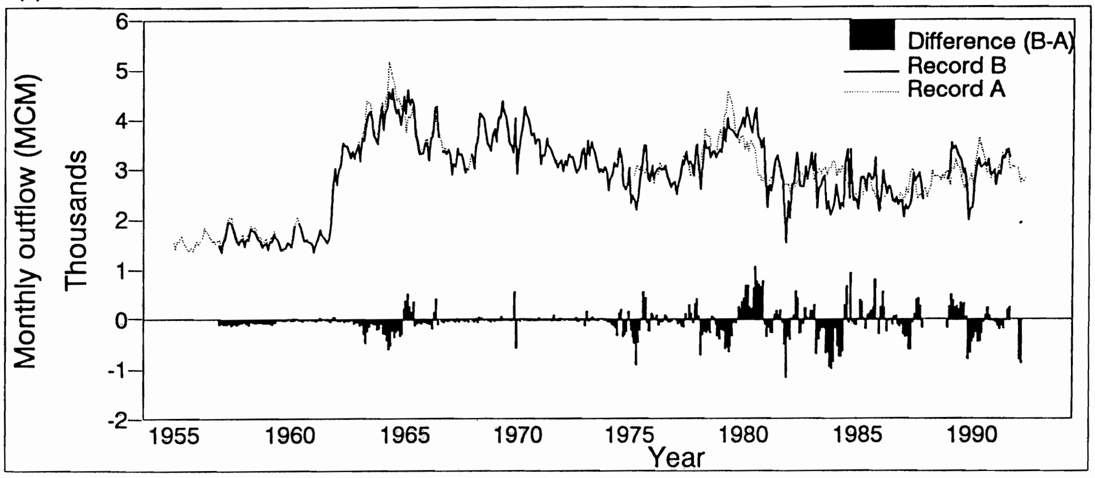


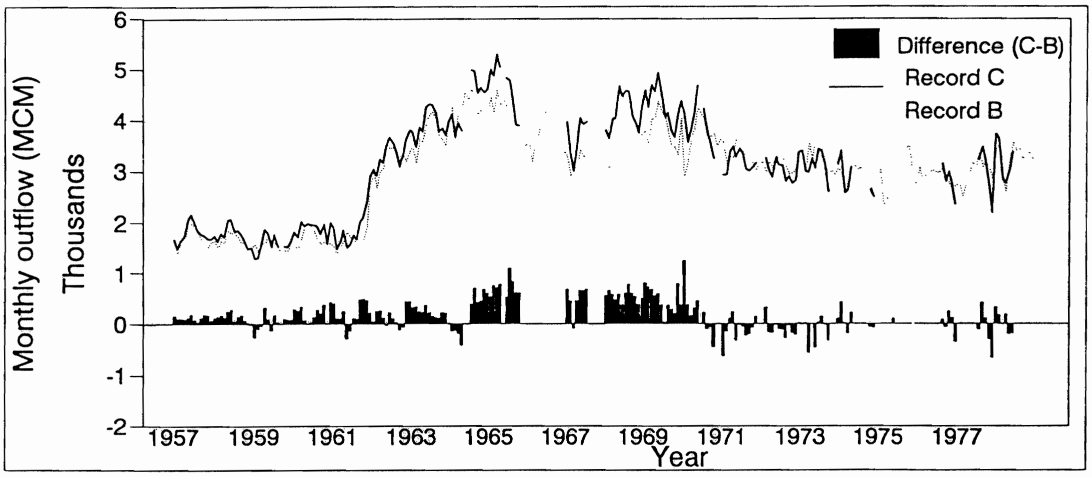
Figure 3.6

Comparison of monthly total outflow records A, B and C

(a) A vs B



(b) B vs C



(c) A vs C

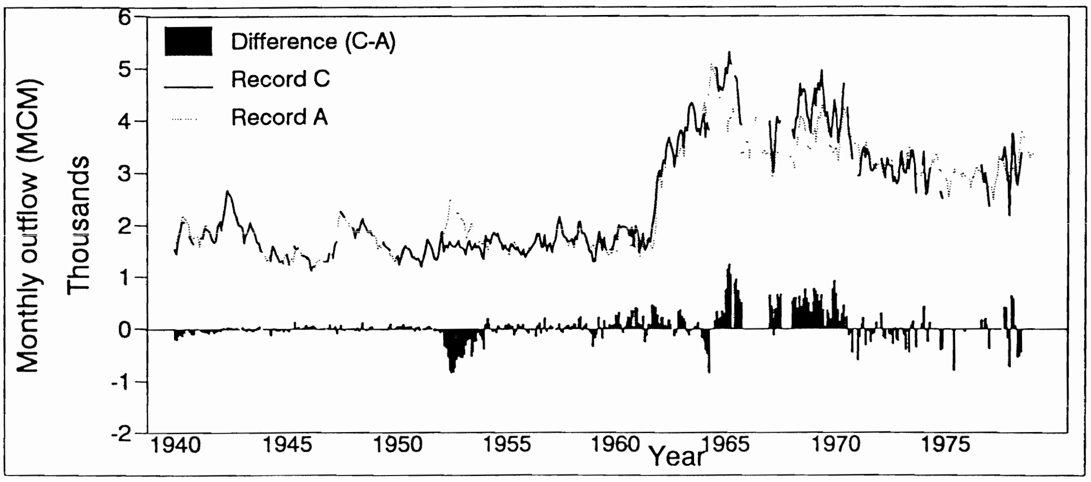


Figure 3.7

estimates and the turbine/sluice releases (A vs B) suggests that there have been significant departures from the Agreed Curve on several occasions but that usually compensatory releases have been made at a later date. The differences in the period 1961-67 are expected as releases were determined by a straight line extension to the Agreed Curve at this time. Other significant differences also occurred in the late 1970s and early 1980s. Following Kite (1981), these differences can be converted to equivalent changes in lake level, for convenience assuming a constant lake area of 67,000 km^2. These calculations, shown in Figure 3.8, confirm Kite's conclusion that the cumulative effect on levels was negligible in the period 1957-80. The calculations also show that the effect continued to be small in the period up to 1991.

The comparison of the turbine/sluice releases and the Namasagali record (B vs C) seems to confirm the conclusion (Cassidy, 1991) that the Namasagali discharge measurements were consistently about 5% higher than the releases recorded at the dam during the 1950s. The small random scatter in the differences between the two stations can be attributed to random measurement errors in either record and minor losses/inflows in the reach down to Namasagali. Again, the cumulative effect of these differences on lake levels is very small. After the 1961 rise in levels, the difference between the two records is larger, with the Record C estimates some 10% higher than the estimates based on the recorded releases. From 1970, when the discharge measurements were switched to Mbulamuti, the errors are smaller and vary randomly about zero. These results suggest a possible problem with the Namasagali discharge measurements in the period 1961-70 as a result of the increased water levels/flows at that time. This point is discussed further below.

The final comparison, between the Agreed Curve estimates and the discharge measurement record (A vs C), seems to confirm that, from 1940 to 1951, the Agreed Curve gives a good estimate of the actual flows. This, of course, is not surprising since the Agreed Curve was based on the Namasagali discharge measurements in that period. However, it does increase confidence in the validity of estimating outflows from the Namasagali discharge measurements for the period when only 10 measurements were made per year. A more interesting feature of this comparison is that, for the period 1952-53, the actual outflows were well below the estimates given by the Agreed Curve, presumably due to the temporary reductions in flow associated with construction of the Owen Falls dam. The cumulative effect on levels in this period was about 0.15 m, which agrees reasonably well with an estimate of 0.11 m made at the time (Bertlin and Olivier, 1954). From the start of dam operations in 1954, it is more difficult to interpret the results of this comparison since the discharge measurements only give an indication of the dam releases on the day the measurement was made. On a daily basis, it is unlikely that the dam operators can always follow the Agreed Curve exactly, although the objective is to achieve this agreement over longer timescales (Cassidy, 1991). However, it again seems clear that the over-estimates in the Namasagali discharge measurements increased after 1961, since Record C is consistently above Record B from this time.

Our overall conclusions from these comparisons are:

(a) Since the start of operations in 1954, releases from the dam have on average matched the Agreed Curve but departures lasting several weeks have often occurred followed by compensatory releases, particularly in the mid 1960s and late 1970s/early 1980s. However, the cumulative effect of these departures on lake levels is small.

(b) Flows at Ripon Falls were significantly restricted in the period 1952-53 to allow construction work to proceed.

Implied cumulative error in lake levels from Figure 3.7

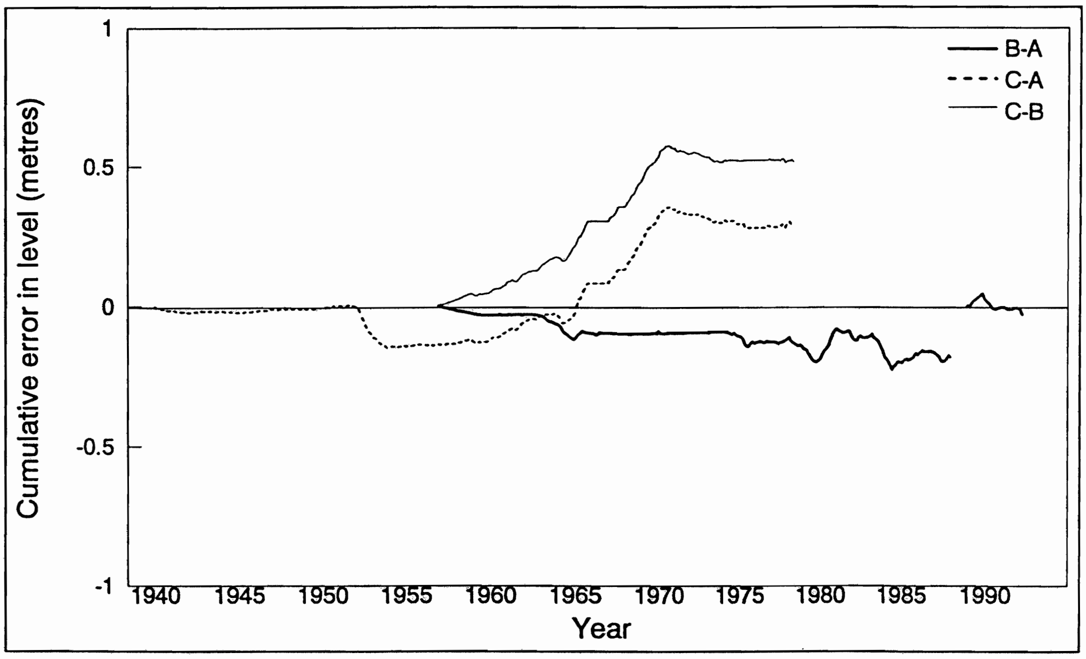


Figure 3.8

(c) Until the rise in levels in 1961, the Namasagali discharge measurements agreed to within about 5% with the turbine/sluice estimates of releases from the Owen Falls dam. After 1961, it seems that the Namasagali measurements were about 10% higher than the recorded releases.

These results suggest that with the data available the best estimate which can be obtained for the outflow record is as follows:

1896-1939 Agreed Curve+lake levels	(Record A)
1940-1956 Namasagali discharge measurements	(Record C)
1957-1991 Turbine/sluice releases	(Record B)

Using this approach, revised 'observed' outflow and net basin supply series have been calculated for use in evaluating the water balance models described later in this report. Any missing values in the final record have been infilled using the Agreed Curve. The general principle has been to use measured values at Owen Falls in preference to values measured at Namasagali, and to use measured values at Namasagali in preference to values estimated from the Agreed Curve. It could perhaps be argued that, for the period 1940-50, the Agreed Curve would provide slightly better estimates; however, the comparison of Records A and C shows that there is little difference between these records in this period and the use of Record C does have the advantage of using direct observations of flows rather than estimates of flows from levels and a rating curve.

Further conclusions about the accuracy of these records cannot be reached without an absolute check on the Namasagali discharge measurements since these underpin both the Agreed Curve and the Record C estimates. The main interest is in the accuracy of the measurements before 1957 since the turbine/sluice releases are available from this time as a more reliable alternative. These checks are especially important in the light of the Acres (1990) suggestion of a 19-65% under-estimate before 1954 in the conventional outflow record based on the Agreed Curve (Record A).

The Namasagali discharge measurements
Discharge measurements were first made at Namasagali in 1923 and then were made regularly from 1940 until about 1970, when the site was closed down in favour of the Mbulamuti gauging station about 20 km upstream. The reason for this change was the increasing difficulty of establishing a stable rating curve at Namasagali, due mainly to backwater effects from Lake Kyoga at the higher river and lake levels since 1961. However, this should not have greatly affected the accuracy of the discharge measurements themselves, provided the measurements were made carefully using suitable equipment.

The Nile Year Books (Hurst, various years) show that discharges at Namasagali have always been estimated using the 'half depth' method, in which the total discharge estimated from the 'half depth' velocities is multiplied by a correction factor of 0.96 to account for the variations in velocity with depth. Berg (1953) gives an interesting account of a discharge measurement at this site in which the full velocity profile was measured using a new Ott current meter calibrated in Germany. This study, made on 19/11/52, suggested that the correction factor for this site should be 0.91 rather than 0.96, which in turn suggests that the discharge measurements reported in the Nile Year Books up to that time were some 5-6% too high.

During this discharge measurement, the measured discharge was 564 m^3s^{-1} compared with a value 594 m^3s^{-1} obtained using the usual half depth method and the 0.96 factor. For comparison, the lake level at that time was about 11.4 metres, which would have corresponded to about 814 m^3s^{-1} on the original Agreed Curve. Outflows at this time were, of course, reduced to aid construction work at Owen Falls dam. An interesting comment in Berg's account states that the current meter calibration was also checked against a Gurley meter owned by the Egyptian Physical Department, who had been responsible for most of the Namasagali discharge measurements up to that time. These two instruments and a third Swiss Amsler instrument all agreed to within 0.6%. It is believed that the 0.96 factor continued to be used throughout the 1950s, so this result seems to confirm the result from comparisons with the turbine/sluice estimates (see above) that discharges at Namasagali were some 5% too high during the 1950s. The 5% difference noted in Figure 3.7 can therefore be attributed almost entirely to the Namasagali records rather than the turbine/sluice release record. This conclusion does not necessarily apply to the measurements made after 1961, however, due to the sudden increase in river levels and flows at that time. Indeed, the comparisons shown in Figure 3.7 suggest that the error increased to about 10% from 1961, most probably due to a change in the velocity profile at the site and backwater effects from Lake Kyoga. However, further data (e.g. full velocity profiles) would be needed to prove conclusively that this increase in errors did occur.

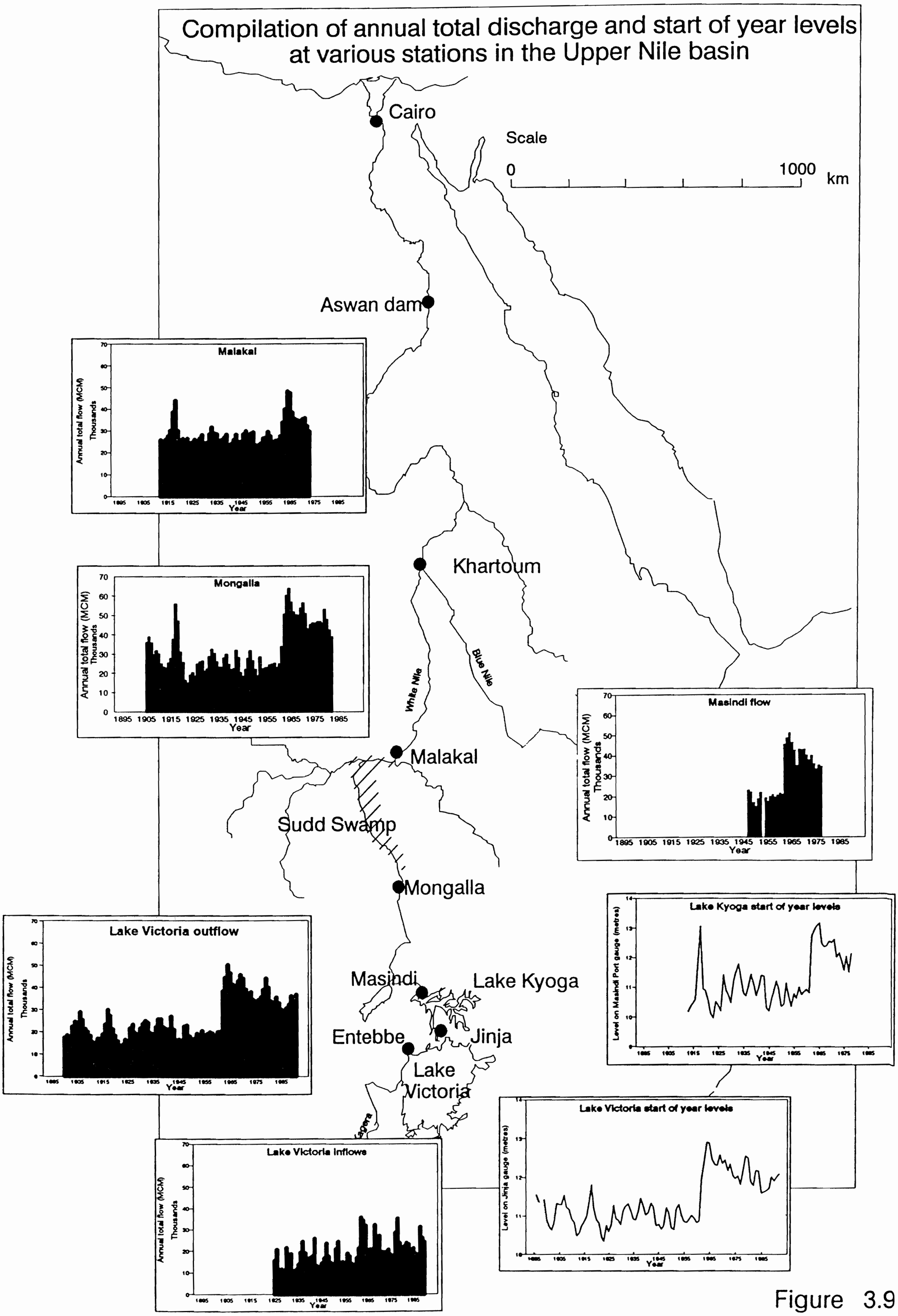
As a final check on the Namasagali measurements and the lake outflows based on these measurements, comparisons have been made of the revised lake outflow record (Record D) with stations further downstream. Monthly comparisons for 3 stations - Jinja, Murchison Falls and Mongalla - have already been shown in Figures 2.7 and 2.8 and seem to confirm the Namasagali record. Many other such comparisons have been made before in research studies on the hydrology of the Nile. However, this interesting subject falls outside the scope of the present study and, for the limited objective of checking the Namasagali record, the compilation of results shown in Figure 3.9 is probably sufficient. The map shows annual total discharges at a number of sites and has been deliberately compiled from a number of different sources to avoid the possibility of bias due to systematic transcription, unit conversion or other errors in any one source. The sources used are:

Lake Victoria outflows	- Record D from this report
Masindi Port	- UNDP/World Bank (1987)
Mongalla	- Nile Year Books (Hurst, various years)
Malakal	- Cairo Univ./MIT from Shahin (1985)

These four records are also plotted together in Figure 3.10. It is worth noting that the Masindi Port record was completely revised during the UNDP/World Bank study and is based on the levels (2/day) taken from the original record sheets and converted using new rating curves developed during the study. Figure 3.9 also shows levels for Lake Kyoga and Lake Victoria and the total annual inflows to the lake estimated in Section 5.2 of this report.

The most notable feature of these records is that all stations downstream of the lake registered the sudden rise in flows around 1915 and in the period 1961-64. As expected, the rise at Malakal is delayed due to the influence of the Sudd swamps. The general pattern of flows is similar over the whole century and there is no evidence of a sudden change in flows in 1954 at the start of operations at Owen Falls dam as Acres (1990) imply. The overall conclusion from this comparison, the other comparisons presented in this section, and Figures 2.7 and 2.8, must be that the Agreed Curve provides a good estimate for the lake outflows over the whole period of record.

The main uncertainty which remains is the interesting question of whether the extended



Compilation of annual total discharge and start of year levels at various stations in the Upper Nile basin
Cairo
Scale
0
1000
km
Aswan dam
Khartoum
Blue Nile
White Nile
Malakal
Sudd Swamp
Mongalla
Masindi
Lake Kyoga
Jinja
Entebbe
Lake Victoria
Malakal
Mongalla
Masindi flow
Lake Victoria outflow
Lake Kyoga start of year levels
Lake Victoria start of year levels
Lake Victoria inflows
Annual total flow (MCM)
Thousands
Year
Level on Masindi Port gauge (metres)
Level on Jinja gauge (metres)

Figure 3.9

Comparison of annual total flows at 4 gauging stations in the Upper Nile basin

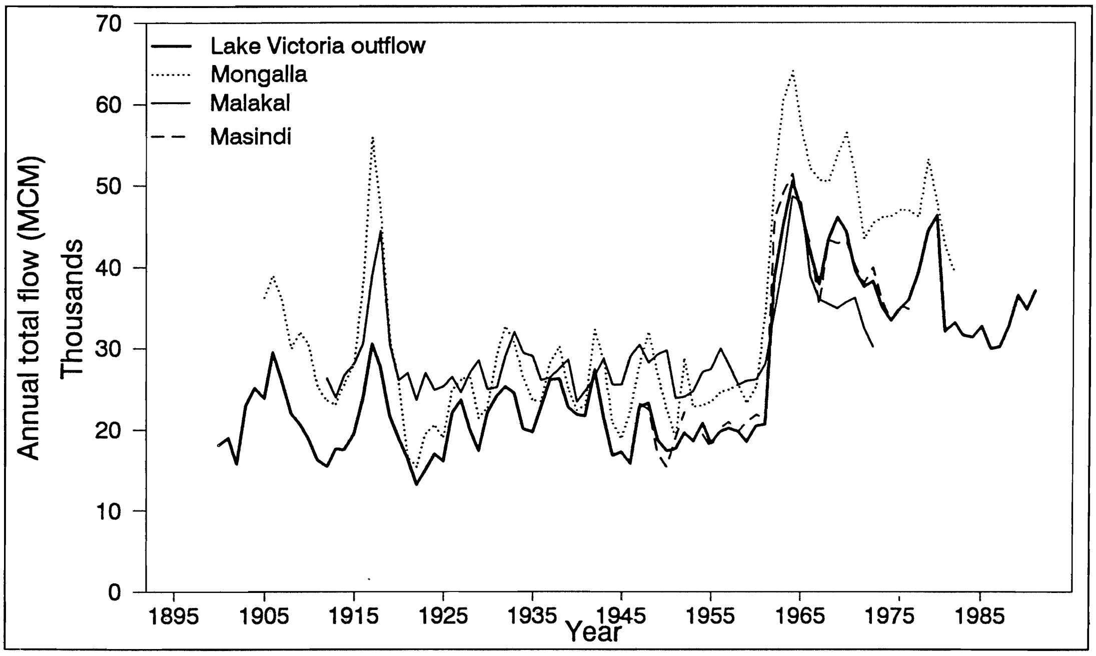


Figure 3.10

Agreed Curve for levels above 12.0 m gives a reasonable estimate of the natural outflows which would have occurred if the Owen Falls dam had not been built. This question is only of interest from the narrow viewpoint of determining whether lake levels since 1961 have been significantly altered by construction of Owen Falls dam (and, by implication, whether more or less flow should be released in order to reproduce the behaviour of the natural lake).

From Figure 2.1, the form of the extrapolation above 12.0 m seems physically reasonable, and the model tests on which the extrapolation is based seem to have been made carefully using accurate survey data for the higher water levels since 1961 (Hydraulic Research Station, 1966). However, as Acres (1990) point out, there is only limited data available on the shape of the natural channel before construction work started, so the form of the extrapolation will always be open to doubt. Indeed, hydraulic calculations by Acres suggest a significant error in the Agreed Curve both above and below levels of 12.0 m although, for reasons discussed in Appendix A, these calculations are also open to doubt.

It seems unlikely that this issue can ever be completely resolved. The natural lake is only known to have reached levels above 12.0 m in the 1870s long before outflow measurements were started. Perhaps the main argument in favour of the extended Agreed Curve is that the original curve is known to be accurate for levels up to 12.0 m (see above), the extrapolation looks reasonable and only a small portion of the extrapolated part of the curve has ever been used. The highest level reached since 1961 is only about 13.3 m and, in the 32 years up to 1992, the annual mean level exceeded 12.5 m in only 7 years. Errors in the extrapolation over this limited range are therefore unlikely to be large. Also, the water balance models presented in the next two sections suggest that the behaviour of the lake can be explained satisfactorily mainly in terms of natural variations in rainfall, without hypothesising any significant influence from Owen Falls dam.

4. Annual water balance model

Quantitative estimates of past and future lake levels are best obtained using a water balance model. In this study, two models have been evaluated; an annual model and a monthly model. The advantage of an annual timestep is that seasonal variations in rainfall, inflow and evaporation need not be considered and the lag between catchment rainfall and inflow to the lake can reasonably be neglected. The development of the model is described in Section 4.1 and the results are presented in Section 4.2. The main aim has been to map out the broad features of the lake response and to identify trends in lake level over the period for which data are available. The second model is described in Section 5 and has arguably the best performance of any of the many water balance models for Lake Victoria so far developed. This model works on a monthly time step and was developed during the second (IH2) Institute of Hydrology study (1985).

4.1 DEVELOPMENT OF THE MODEL

The main factors which determine the level of the lake are direct rainfall on the lake surface, lake evaporation, tributary inflows and the natural (pre 1952-53) or regulated (1954-) outflows. On an annual basis, the lake evaporation can reasonably be assumed to be constant, tributary inflows are related to the lake rainfall and lake outflows can be estimated from the Agreed Curve. Hence it should be possible to develop a water balance model for the lake in which the lake rainfall is the only input variable. Several models of this type have been developed previously and have generally given reasonable results (e.g. Kite, 1981, Institute of Hydrology, 1984). The aim in this study has been to develop a new model using as few calibration factors as possible in order to illustrate the main features of the lake response. The main interest is in the sensitivity of lake levels to changes in individual components in the water balance and, in particular, to possible changes in inflows which might, for example, be caused by land use changes.

The annual water balance for the lake is given by:

$$\Delta h = P - E + \left[\frac{Q_i - Q_o}{A} \right] \tag{4.1}$$

where Δh is the change in water level over the year, P is the annual rainfall on the lake, E is the annual evaporation, Q_i is the annual total tributary inflow, Q_o is the annual total outflow and A is the surface area of the lake. As usual, unknown terms such as seepage from the lake or minor abstractions have been neglected, although in practice these may account for part of the inevitable differences between the predicted and observed levels and outflows.

To estimate the lake rainfall, it is necessary to derive a relationship between the total rainfall over the lake and the rainfall measured at the lakeshore stations. Over this century, the number of lakeshore stations has been gradually increased, particularly during the Hydromet Survey project. However, for long term estimates, it is best to use a constant number of stations to avoid possible bias in the results and de Baulny and Baker (1970) correctly identified that only the following 8 stations have reliable long term records:

Jinja	1902-91
Entebbe	1900-91 (and some data from 1896)
Kalangala	1926-77
Bukoba	1906-12, 1922-92
Kagondo	1925-83
Mwanza	1902-11, 1922-92
Musoma	1922-92
Kisumu	1903-90

The years indicate the periods for which mainly complete records were obtained in the present study. For this simple model, no attempt has been made to apply weighting factors to the data for these stations. Instead, the average lakeshore rainfall has been estimated as simply the average of all 8 stations in years in which all stations have data, and by the following relationship:

$$P = \frac{\bar{P}}{N} \sum_{i=1}^{N} \frac{P_i}{\bar{P}_i} \tag{4.2}$$

in years in which one or more stations has missing data. Here P_i is the annual rainfall for station i, and $\bar{P}_i$ and $\bar{P}$ are the mean rainfalls for station i and for the average record respectively calculated for the years in which all stations had data. This method minimises the bias introduced in years when there are missing values for one or more stations. Obviously, it is desirable to use as many stations as possible in computing the lakeshore average rainfall, so the accuracy of these estimates will not be so good before 1925. However, the accuracy should still be sufficient to give an indication of the lake response in this period. Annual lakeshore rainfalls have been computed for the period 1900-91 for use in the water balance simulations.

To calibrate the relationship between lake rainfall and the rainfall measured at the shore, the main data collection period of the Hydromet Survey project (1969-78; see Section 2.3) has been chosen. In this period, approximately 80% of the lake catchment was gauged and good estimates for the remaining ungauged portion were obtained in the IH2 study. Releases from Owen Falls dam were also computed directly from the turbine/sluice ratings in this period and several methods for estimating or measuring the lake evaporation were evaluated. Following a review of these evaporation studies, Piper *et al.* (1986) suggested a best estimate of 1600 mm for the average annual evaporation. Thus, for this period, the implied lake rainfall can be estimated to reasonable accuracy using measured values for the other main components in the water balance and the computed changes in lake storage. The resulting annual water balance is:

Lakeshore rainfall	1537 mm
Implied lake rainfall	1811 mm
Tributary inflows	336 mm
Outflows	567 mm
Assumed lake evaporation	1600 mm

Figure 4.1 shows a comparison of the annual lakeshore values and the implied lake rainfall. A best fit straight line suggests that the lake rainfall is on average about 1.18 ($=k_1$, say) times the lakeshore value. This value has been assumed in the water balance simulations presented below and is close to the estimate of 1.19 presented in Section 3.2 based on the estimated

Relationship between annual implied lake rainfall and rainfall measured at the lakeshore stations (1969 -78)

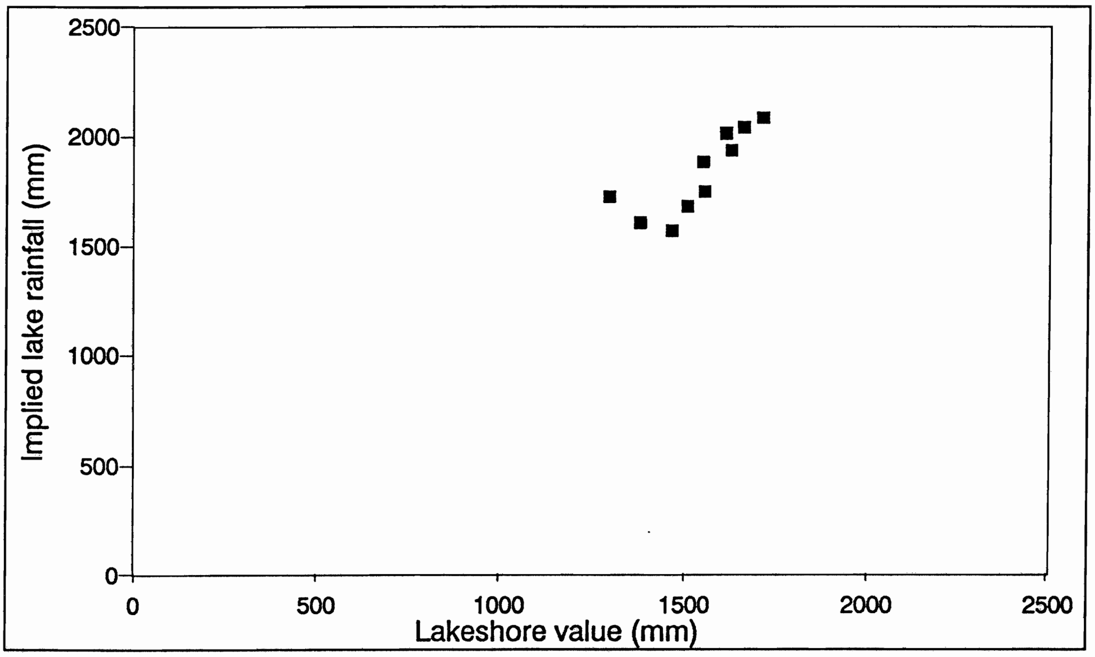


Figure 4.1

water balance for the period 1956-78.

To estimate the total tributary inflows, it is convenient to develop a relationship between the annual total inflow and the lake rainfall. For this comparison, a best estimate of the inflow record for the period 1925-90 has been used. The derivation of this record is described in Section 5.2 of this report but, briefly, the record is based as far as possible on measured inflows with missing values infilled using a conceptual rainfall runoff model. Figure 4.2 shows that there is a reasonably consistent relationship between annual inflows and the lake rainfall, and that the runoff coefficient appears to increase with increasing lake rainfall. For the sensitivity studies, two representations have been used for the inflows and both are plotted in Figure 4.2. The first assumes a constant runoff coefficient, k say, of 0.16 and the second a runoff coefficient which varies with the lake rainfall, with the inflow given by:

$$Q_i = \frac{kAP^4}{P_k^3} \tag{4.3}$$

where P_k is a constant. A best fit was obtained for $P_k = 1.8$ m.

The lakeshore rainfall series, the three constants k, k_1 and P_k and the assumed evaporation are sufficient to define the lake water balance completely provided that the remaining component in the balance - the lake outflow - can be estimated from the Agreed Curve. The results presented in Section 3.3 indicate that, although there have been some minor departures from the Agreed Curve since the start of operations at Owen Falls dam in 1954, the curve seems to have been followed fairly closely in terms of annual total releases. No attempt has been made to represent these minor departures in the simulations. To represent the Agreed Curve, a cubic spline approximation from the IH2 study has been used. The accuracy of this curve is excellent; for example, on a plot with the same scales as Figure 2.1, the curve could not be distinguished from the actual Agreed Curve. The remaining unknown in Equation (4.1) - the lake surface area - has been estimated from the elevation/area relationship established by land surveys during the Hydromet Survey project.

As a first check on the model, Figure 4.3 compares the estimated net basin supply (N_i) for the two inflow models and the 'observed' net basin supply (N_o) calculated from the observed lake levels and the best estimate of the outflow record (Record D) derived in Section 3.3. These two quantities are defined by:

$$N_i = P - E + \frac{Q_i}{A} \qquad and \qquad N_o = \Delta h + \frac{Q_o}{A} \tag{4.4}$$

The agreement is reasonable for both inflow models, although the polynomial model (Equation 4.3) gives a better representation of the increase in net basin supply during the 1961-64 period. Both models seem able to represent the large year to year variations in the observed record. The errors in net basin supply vary randomly in many periods, and are typically in the range 10,000-20,000 MCM/year, equating to about 0.15-0.30 m per year in terms of depth over the lake surface. Larger cumulative errors can build up in periods when several consecutive years of positive or negative error occur. From Figure 4.3, there are several such periods, notably around 1910, 1920, the early 1940s and 1950s and around 1980. The largest errors in predicted lake levels can therefore be expected in these periods. Expressed in terms of depth over the lake, the estimated records have a mean of about 0.43 m (0.44 m) and a standard deviation of 0.27 m (0.40 m), where the values are for the linear and (polynomial) inflow models respectively. For comparison, the observed record has a mean

Relationship between annual total inflow to the lake
and the annual implied lake rainfall (1925-90)

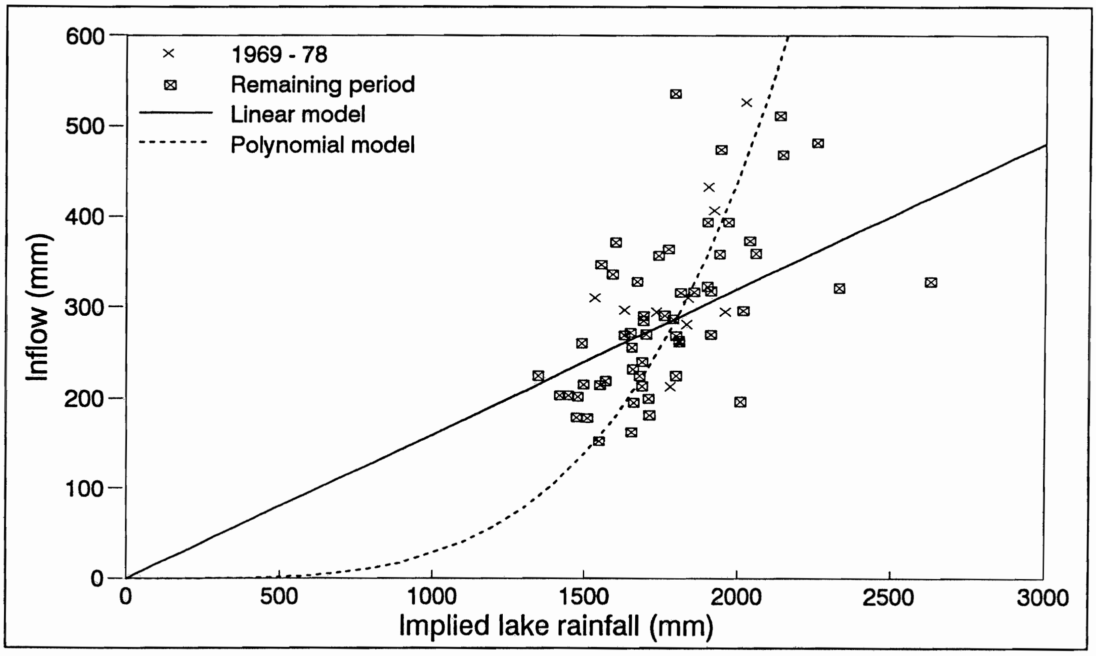


Figure 4.2

Comparison of observed and predicted net basin supply for the period 1900 - 91

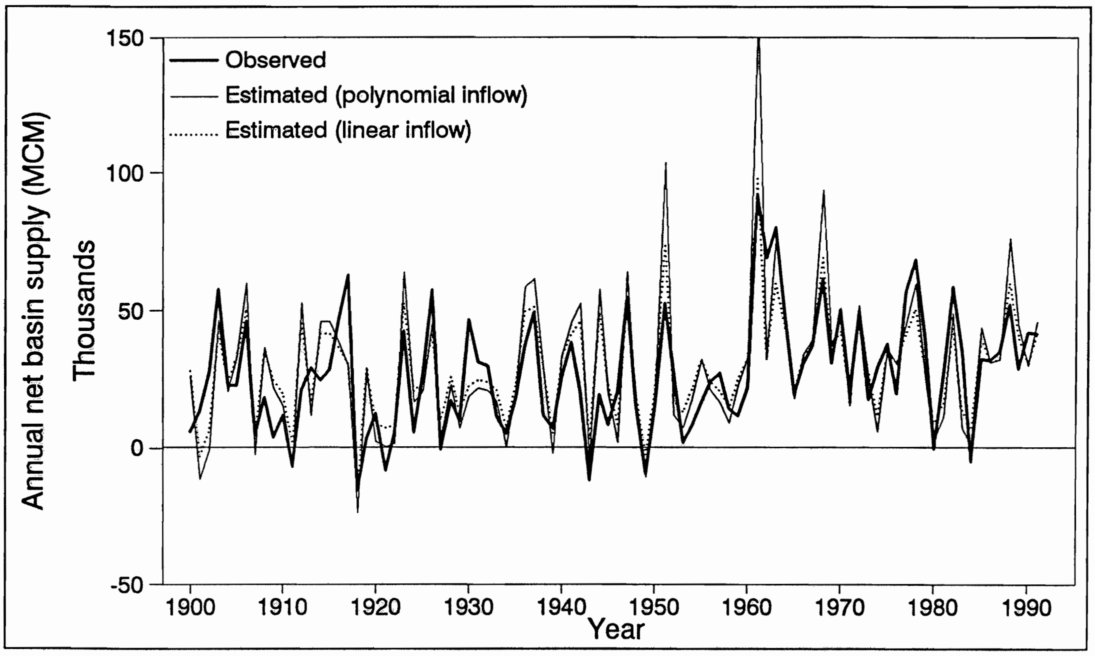


Figure 4.3

of 0.40 m and standard deviation of 0.31 m over the same period.

These results are largely confirmed by the lake level simulations. To estimate lake levels, it is necessary to use an iterative method to solve Equation (4.1). An approximate scheme has been used here in which lake outflows are computed using the mean of the start and end of year water levels. Figures 4.4 and 4.5 compare predicted and observed start of year levels for the period 1900-91 for the linear and polynomial inflow models respectively. The agreement is reasonable, and the observed and predicted levels at the end of the simulation are very close, showing that the overall water balance is approximately correct. The predicted rise between 1961 and 1964 is about 1.5 m for the linear model and about 1.9 m for the polynomial model, compared to the observed change of about 2.0 m in start of year levels. The largest errors are about 0.5 m and, as expected, occur mainly in the periods when the net basin supply estimates were worst. To put these errors in context, it should be remembered that the average annual lake rainfall is about 1.8 m, so a cumulative error in lake level of 0.5 m, built up over several years, represents only a small fraction of the input rainfall which drives the model. The two models therefore seem to give a reasonable indication of lake levels and, in some periods, such as the last 20 years, give an excellent representation of observed levels. The differences between the linear and polynomial inflow models are small except during periods of high rainfall such as the period 1961-64.

4.2 Sensitivity studies

The main motivation for developing the annual water balance model was to assess the sensitivity of lake levels to variations in the individual components in the water balance. To assist with interpretation of the results, these studies have been performed using various idealised forms for the rainfall series which drives the model. Except in a few cases (noted below), the form used for the inflow model is not important so, for convenience, the linear inflow model has been used in most of the simulations.

(a) Equilibrium response

The first set of simulations concerns the response of the lake during long periods of more or less constant rainfall or net basin supply. Since the lake rainfall is the only input variable to the model, it might be expected that, in such periods, the lake will reach a stable level dependent on the magnitude of the rainfall or net basin supply. This behaviour has been illustrated previously using a rather more complicated annual water balance model developed during the IH1 study. Figure 4.6 shows the variation in lake levels for a range of values of net basin supply and starting level. The assumed values of net basin supply (0.0 m, 0.5 m, 1.0 m) correspond to annual lake rainfalls of 1380 mm, 1810 mm and 2240 mm respectively for the linear inflow model and 1470 mm, 1810 mm and 2080 mm for the polynomial inflow model.

The simulations show that typically, after a period of 10-20 years, a stable level is reached irrespective of the starting level, but dependent on the value specified for the rainfall/net basin supply. Previous, more complicated, water balance studies have also obtained similar results. For example, the IH1 study indicated a response time of 8-10 years for a start level of 12.0 m. Using a stochastic model, Salas *et al.* (1982) again obtained a value of about 10 years and Evans (1990), using a simple monthly water balance model, suggests a value of 6-12 years.

Comparison of observed and predicted start of year levels
for the period 1900 - 91

(Linear inflow model)

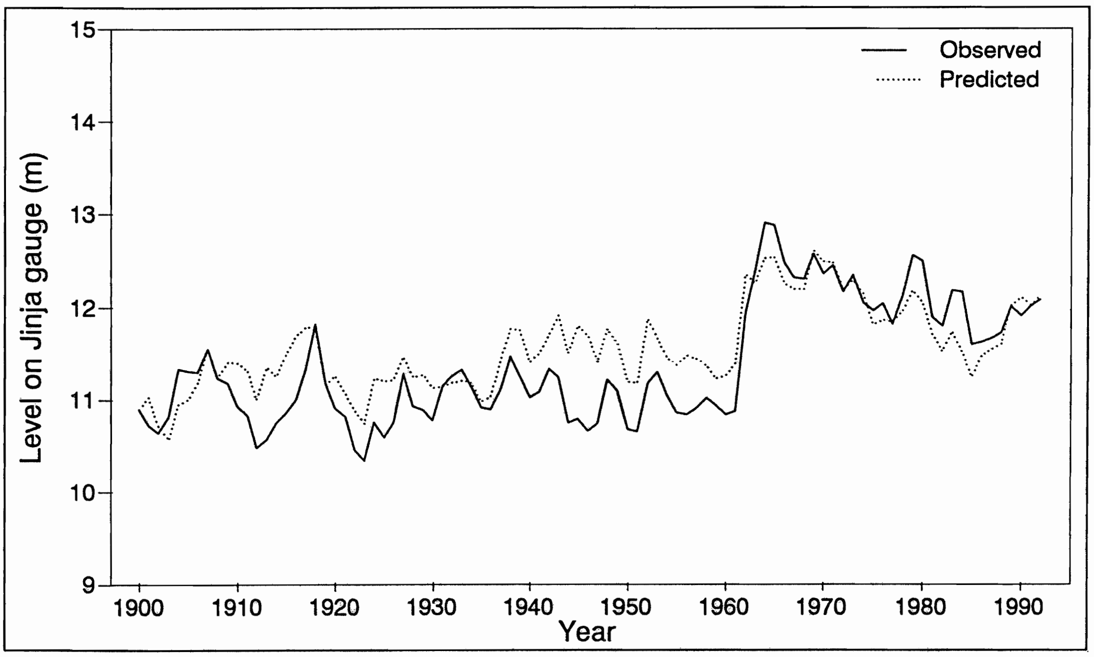


Figure 4.4

Comparison of observed and predicted start of year levels
for the period 1900 - 91

(Polynomial inflow model)

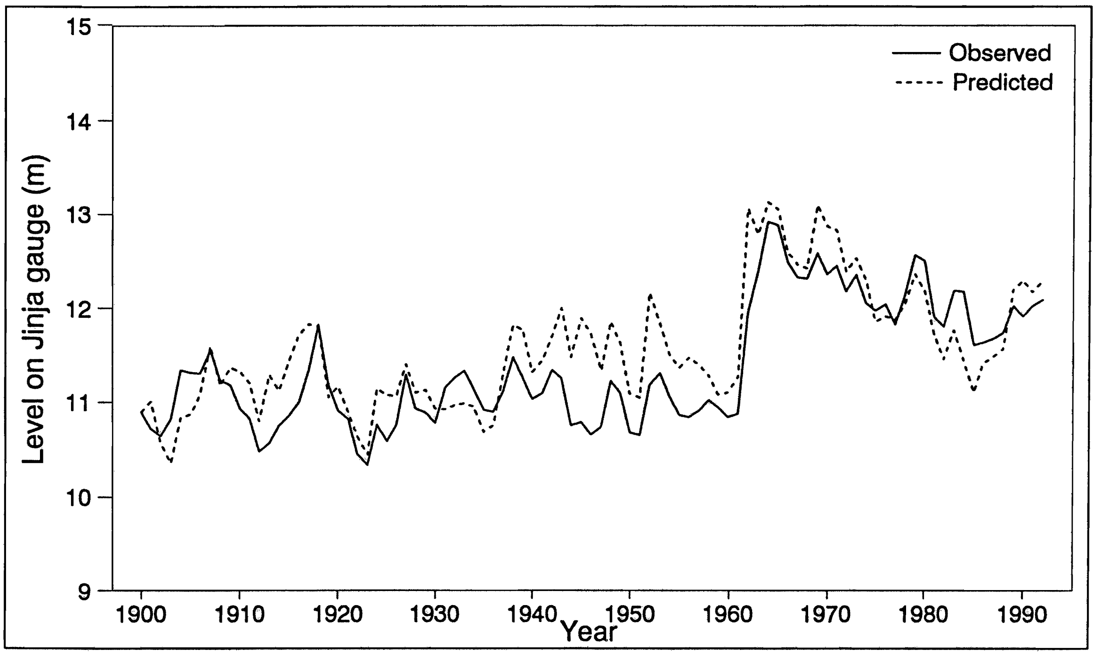


Figure 4.5

Idealised lake response for start levels of 10.5m and 12.0m and annual net basin supply values of 0m, 0.5m and 1.0m

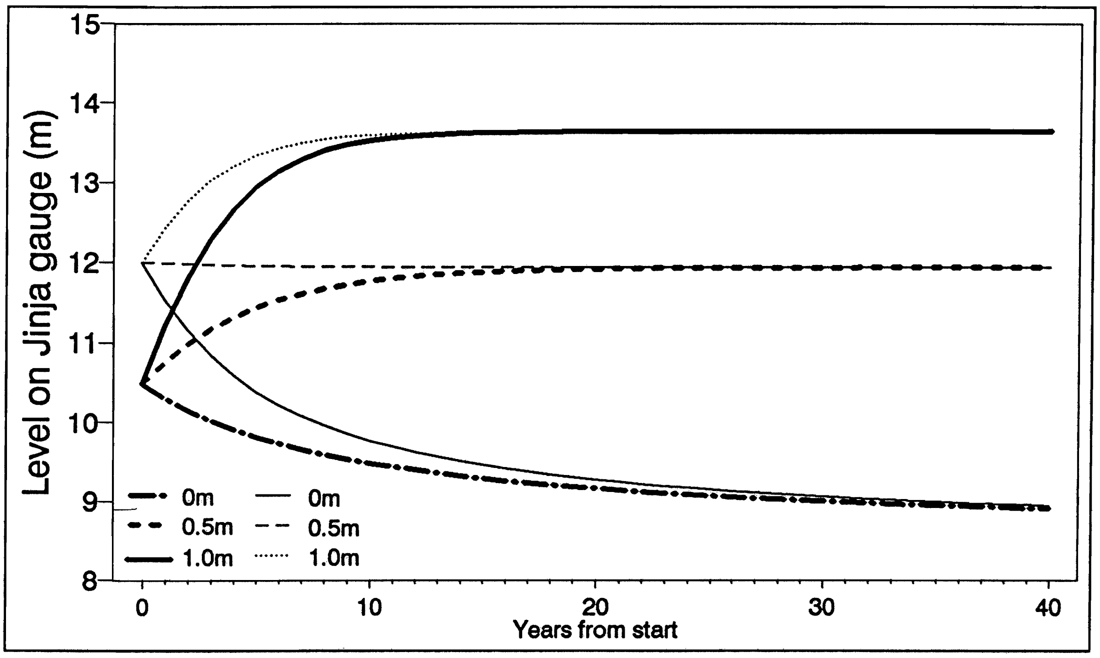


Figure 4.6

(b) Response to a rainfall impulse

Changes in lake level arise from natural variations in lake rainfall so it is interesting to consider the response of the lake to temporary changes in rainfall occurring during a long period of constant rainfall. For these simulations, the background annual lake rainfall has been chosen to yield an equilibrium lake level of 12.0 m, which is typical of the observed levels in recent years. The short lived increases and decreases in rainfall assumed represent a 10% increase or decrease for 1 or 5 years in a row, and a 50% change for 3 years. Figure 4.7 shows the predicted lake response using the linear inflow model. During the period of change, the level rises or falls at a rate dependent on the size of the change. The annual rate of change is most rapid in the first year but progressively decreases due to the compensating increase or decrease in outflows as levels rise or fall. A 10% change for 5 years causes a change in levels of about 0.5 m and a change of 50% for 3 years causes a change of more than 2 m. It is interesting that, according to this model, levels drop more rapidly for a given change than they rise as a result of the increased slope of the Agreed Curve at low lake levels. This result may at first seem surprising and, in reality, some modification to this response may occur due to the lag between changes in rainfall and changes in inflow. However, the observed lake level record does seem to confirm that, with the exception of the 1961-64 rise, falls in level can occur as rapidly as rises.

To place these results in context, it is helpful to consider the magnitude of the natural variations in the lake rainfall series. Figure 4.8 shows the annual departures from the mean in the implied lake rainfall series calculated from the observed net basin supply and the linear inflow model. The annual mean of this series is about 1730 mm and the standard deviation about 270 mm. It can be seen that sustained changes of 10-20% lasting up to 5 years are common, so that changes of more than 1 m in levels are also likely to be common. The largest change occurred between 1961 and 1964 when the implied lake rainfall increased to about 2300 mm from an average of about 1600 mm in the preceding 4 years, representing an increase of more than 40% for 4 years. There is some evidence of a long term periodicity in this series, although, as will be shown in Section 6.2, this is much less evident in the lake rainfall series derived directly from the shore based stations. In part, this periodicity may arise from the simple inflow model used to derive this series.

(c) Transition between equilibrium levels

A shift in climate or a progressive change in land use may, over long periods, result in a change in the mean net basin supply. It is therefore interesting to consider the transition of the lake between two periods with different net basin supply. Again, a start level of 12.0 m - equivalent to a net basin supply of about 0.5 m - has been assumed in the simulations, and inflows have been estimated from the linear model. The changes considered are increases or decreases of 10% and 20% in rainfall, and a 50% change in the runoff coefficient k.

The results of these simulations are shown in Figure 4.9 and suggest that a long term shift of about 10% in rainfall causes a change of about 0.5 m in equilibrium lake level. A further similar rise occurs for an additional 10% increase, and an even greater fall of about 1 m for an additional decrease of 10%. The effect of a 50% change in runoff coefficient is similar to that of a 10% change in rainfall. This indicates that the lake water balance is about 5 times more sensitive to long term changes in rainfall than in runoff coefficient, and suggests that a major change in land use has only the same effect as a minor change in climate. Similar results are obtained using the polynomial inflow model. A more rigorous assessment of the comparative sensitivity to runoff and climate is presented in the next section.

Idealised lake response to changes in rainfall of 10% for 1 year and 5 years and 50% for 3 years, for a start equilibrium level of 12.0m

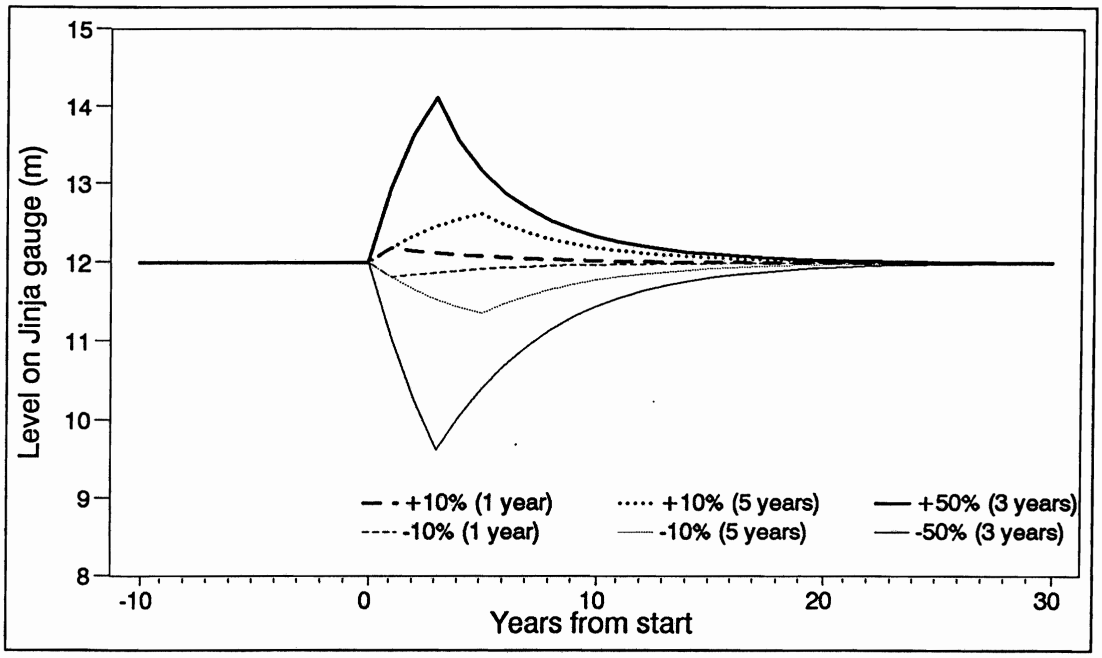


Figure 4.7

Departure from mean series for the implied lake rainfall in the period 1900-91. Also shown are lines representing a 10% departure from the mean.

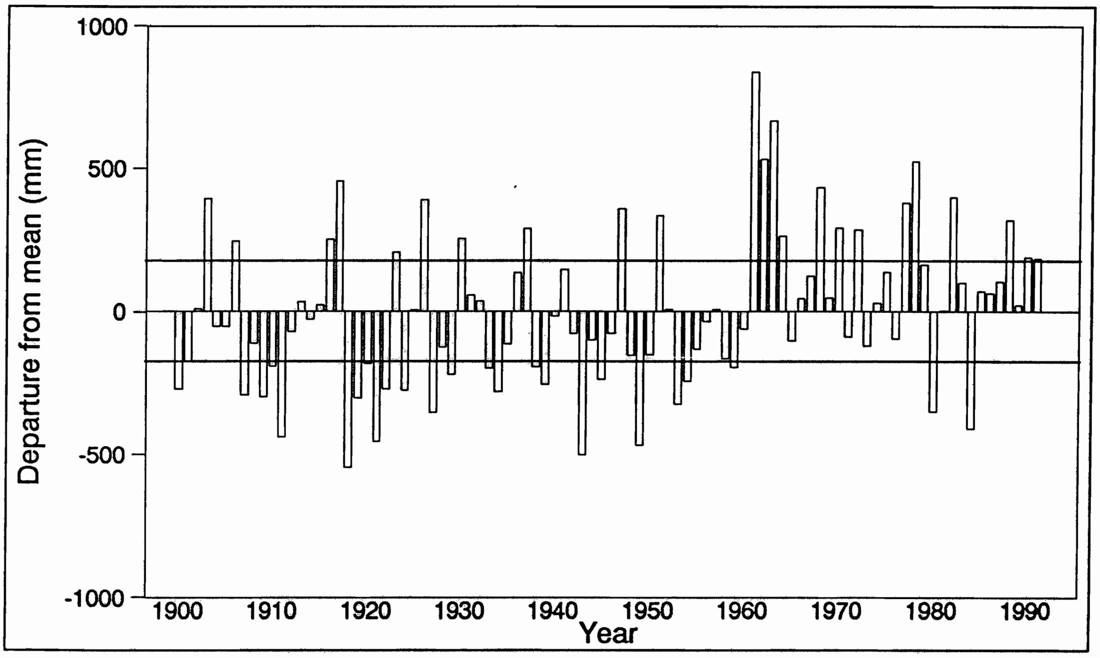


Figure 4.8

Idealised lake response to long term changes of 10% and 20% in rainfall and 50% in runoff coefficient for a start equilibrium level of 12.0m

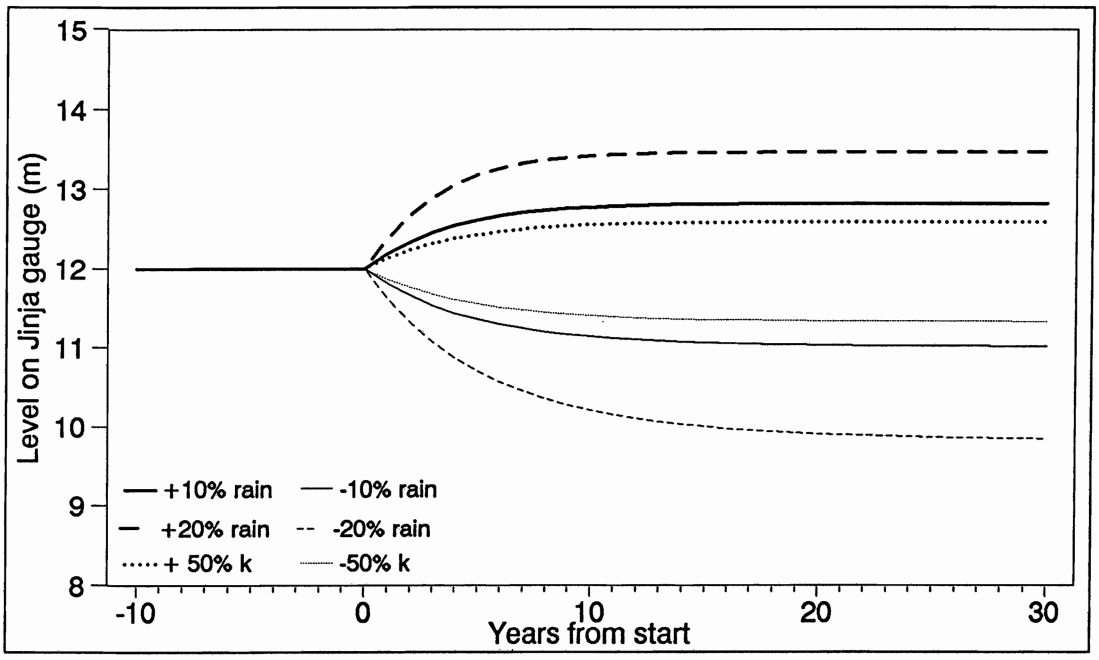


Figure 4.9

(d) Estimates of equilibrium level

By definition, the equilibrium level is the level at which the outflow matches the net basin supply to the lake. Figure 4.10 shows the implied relationship between equilibrium level and net basin supply for the current Agreed Curve. As mentioned earlier, the current lake level of about 12.0 metres would correspond to an equilibrium net basin supply of about 0.5 m. This would imply an annual lake rainfall of about 1810 mm for both the linear and polynomial inflow models.

Figure 4.11 shows estimates for the sensitivity of the equilibrium lake level to sustained changes in rainfall and net basin supply assuming the linear inflow model. The multiplier varies between about 2 and 15 over the range of levels over which the Agreed Curve is defined. So, for example, for an equilibrium level of 12.0 m, the multiplier is about 5 for rainfall and 4 for net basin supply, so a sustained change of 0.1 m in either component would cause a change of about 0.4-0.5 m in equilibrium level. For the implied current annual average lake rainfall of about 1.8 m, a 0.1 m change would represent a shift of about 5%. The simulations presented earlier suggest that this new level would eventually be reached provided the change lasted at least 5-10 years. The corresponding change in outflow would in fact be independent of the equilibrium level and is roughly 2500 times the change in annual rainfall if the outflow is in m^3s^{-1} and the change in rainfall is in metres. So, for example, a sustained change of 0.1 m in rainfall would cause approximately a 250 m^3s^{-1} change in outflows, or roughly 25% at current lake levels.

These results help to confirm the extreme sensitivity of lake levels and outflows to minor shifts in rainfall and net basin supply. This sensitivity also affects estimates of the sustainable long term power output from Owen Falls dam. The turbines at the dam are currently rated at about 0.15 MW/m^3s^{-1}, which suggests a sensitivity of about 375 MW per metre change in long term annual rainfall. A long term shift of about 0.1 m in rainfall, equivalent to about 5% of the current annual average rainfall, would therefore cause a change of about 37.5 MW in the power output from the dam. This represents about 25% of the current installed capacity at the dam. This interesting result could possibly be developed further but this falls outside the scope of the present study.

Similar arguments can also be used to estimate the sensitivity of lake levels to changes in runoff coefficient. For a given fractional change in the runoff parameter k, and the same fractional change in rainfall, simulations show that the ratio of the changes in lake levels would be about 14% for the linear inflow model using the best estimate of 0.16 for the runoff coefficient obtained earlier. For the polynomial inflow model, the comparative sensitivity would be slightly less at about 10%, since changes in rainfall have an even greater effect according to this model. These results therefore suggest that a small change in rainfall has about 7-10 times the effect of an equal change in runoff coefficient. For the above example of an equilibrium level of 12.0 m, and a fractional change in rainfall of about 5%, the same percentage change in runoff to the lake would cause a change of less than 0.1 m in levels compared to the change of 0.5 m due to the 5% change in rainfall. Alternatively, a 35-50% change in runoff would be required to achieve the same change in equilibrium level.

(e) The lake response time

To estimate the response time of the lake, two approaches seem reasonable. The first is to define the response time as the time taken for the lake level to approach to within an arbitrary distance from the equilibrium level, where this distance is given by a fraction, p say, of the

Relationship between lake equilibrium levels and the annual net basin supply

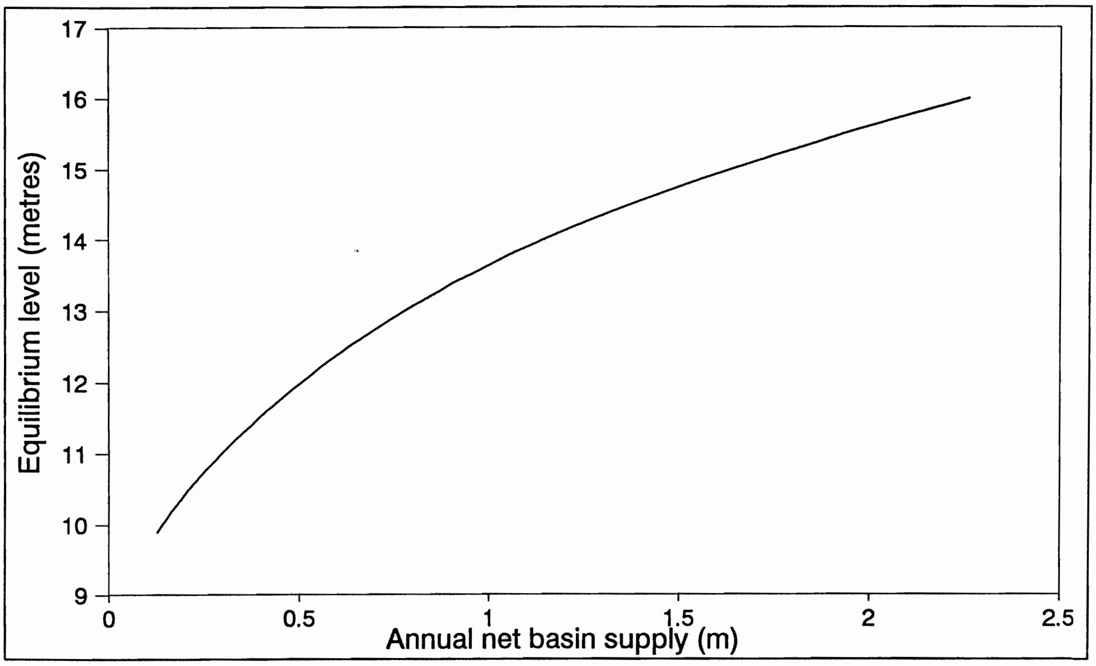


Figure 4.10

Estimated sensitivity of lake levels to changes in rainfall and net basin supply

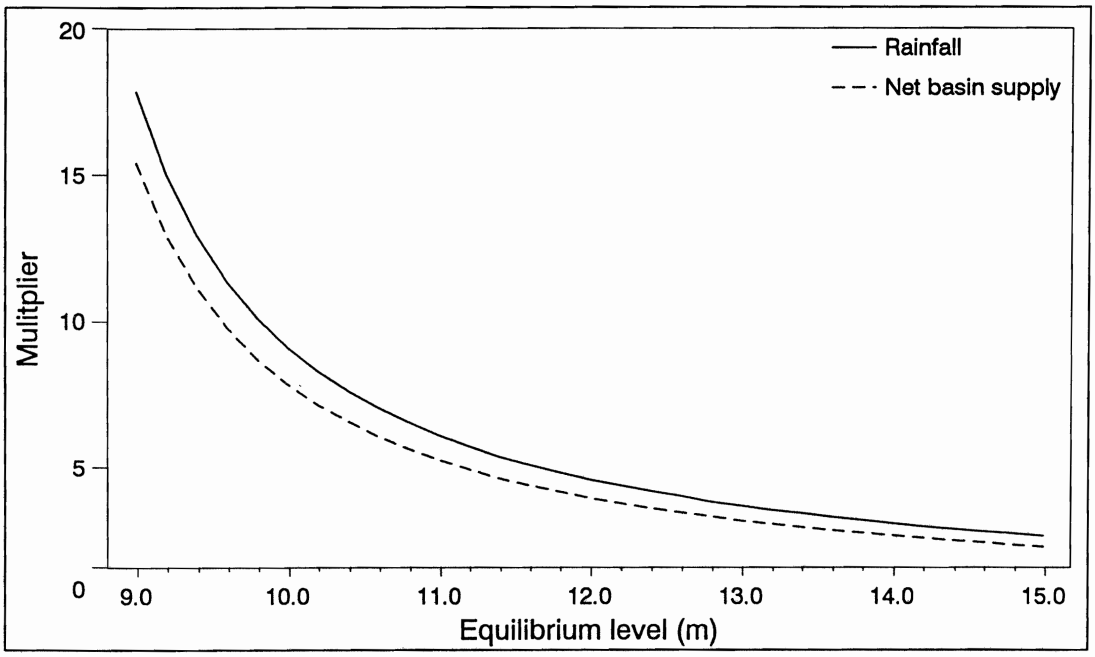


Figure 4.11

original difference between the start level and the equilibrium level. Values for this measure of response time have been computed for $p = 1\%$ and are plotted in Figure 4.12. As an example, the response time would be about 18 years for a net basin supply of 0.5 m and an equilibrium level of 12 m.

A second, more useful, approach is to estimate the time taken for the lake level to approach within an arbitrary distance in metres, z say, of the equilibrium level. If this distance is defined as the typical month to month variation in lake levels, then this gives an estimate of the time taken for lake levels to reach a value which cannot be easily distinguished from the lake level by field measurements. From Figure 3.2, the median month to month variation is about 0.1 m, and this provides a rational length scale for estimating the response time of the lake.

Estimated response times calculated using this approach are shown in Figure 4.12 for a range of starting levels and assuming $z = 0.1$ m. The curves show the expected behaviour, with the response time increasing as the equilibrium lake level decreases. As expected, as the start level approaches the equilibrium level, the response time drops to zero. For equilibrium levels much greater than the start level, all curves tend towards a common response time of about 10 years. For very low equilibrium levels, the response times tend towards 30 years or more. As an example, if the start level is 12 m, the time taken to reach an equilibrium level of 14 m would be about 9 years and the time taken to reach an equilibrium level of 10 m would be about 21 years.

(f) Application of results

The annual water balance model, together with the idealised equilibrium results obtained in this section, allow a novel interpretation to be made of the response of the lake this century. For the equilibrium results to be valid, the net basin supply should be constant, or varying over a time scale much less than the typical lake response time. Given that the response time is about 10 years, then it might be expected that equilibrium levels will be reached in periods when the net basin supply is either constant for periods of 10 years or more, or varying rapidly about a mean over timescales of much less than 10 years, say 1-2 years.

An inspection of the observed net basin supply series (Figure 4.3) shows that there have been several such periods since records first began, and these are shown in Figure 4.13, together with the implied equilibrium levels. Towards the end of long periods of constant net basin supply, the lake might be expected to be approaching the corresponding equilibrium level, while, near the start of these periods, or in periods when the net basin supply is varying, the lake will be in transition towards these levels from the most recent peak or minimum level reached. Predicted transition lake levels, calculated using the annual water balance model, are shown for several such transition periods, and appear to agree reasonably well with observed levels in these periods.

This interpretation of the lake behaviour suggests that, in the early part of this century, up to about 1925, the net basin supply only reached a constant value for short periods of up to about 5 years. Consequently, the lake level was constantly in transition between equilibrium states which were never reached. From the mid 1920s to the early 1940s. the net basin supply varied rapidly about a mean of about 0.33 m, equivalent to an equilibrium level of about 11.2 m, and then, up to about 1960, dropped to about 0.29 m, equivalent to an equilibrium level of 11.0 m. The increased rainfall between 1961 and 1964 then caused the net basin supply to rise to about 1.08 m, with a corresponding equilibrium level of about 13.9 m. This

Estimated lake response times for p=0.01 and for z=0.1m,
(start levels 11.0m, 12.0m, 14.0m)

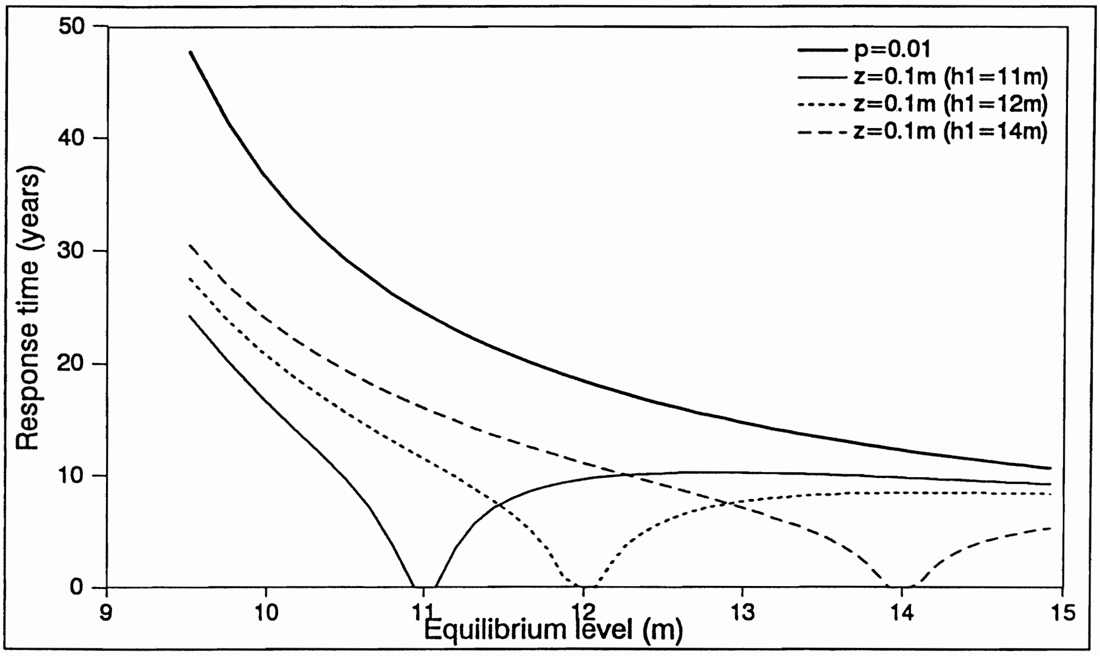


Figure 4.12

Idealised interpretation of the relationship between lake levels and net basin supply for the period 1900 - 91

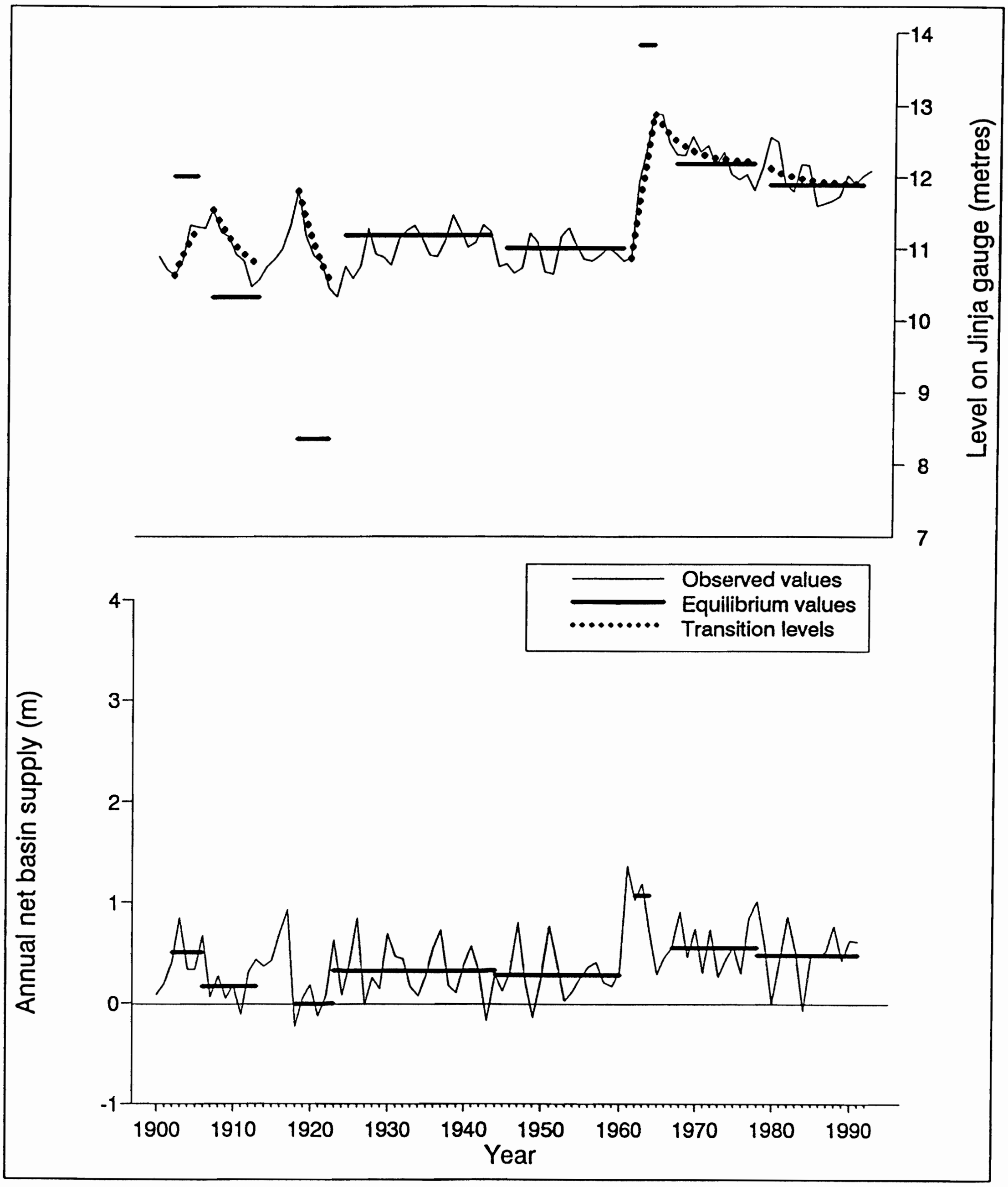


Figure 4.13

level was never reached, however, because, in the period 1965-77, the net basin supply dropped to a mean of about 0.56 m, with the result that the lake level approached the corresponding equilibrium level of about 12.2 m towards the end of this period. Since then, with the exception of a short lived rise around 1979-80, the net basin supply has entered a rapidly varying phase with a slightly lower mean of about 0.48 m, resulting in an apparent equilibrium level of about 11.9 m under present conditions.

This view of the lake response suggests that lake levels are constantly in transition between a succession of equilibrium states, which are only ever reached if the net basin supply, or lake rainfall, can be considered constant for periods of several years or more. Significantly, the lake has only approached equilibrium for a few short periods since the rains of 1961 to 1964 and levels appear to have been on a downwards trend since that time. These results have clear implications for estimates of future lake levels and these are discussed further in Section 6.2. For the moment, the good agreement between predicted and observed levels can be taken as further evidence that the annual water balance model developed in this section gives a good representation of the actual behaviour of the lake and, in particular, can be used to estimate the sensitivity of lake levels to possible changes in runoff caused by land use change. Estimates of the actual changes in runoff which may have occurred due to land use change are given in Section 6.2.

5. Monthly water balance model

The main outcome of the previous Institute of Hydrology studies (1984, 1985) was a monthly water balance model which seemed to give excellent predictions of water levels in the main calibration period 1956-78 and reasonable predictions in the period 1925-55. This model was used in conjunction with a stochastic rainfall generation model to estimate the likely future behaviour of the lake and, in particular, the risks of overtopping at Owen Falls dam.

One of the main aims of the present study has been to assess the suitability of this model for use in future studies of the impacts of land use change on lake levels. Using additional data collected during a visit to East Africa, the simulation period has been extended from 1979 up to 1990, providing a useful test of the model outside the period for which it was calibrated. Also, it has been possible to make a more detailed evaluation of the performance of the model than was possible in the time available in the earlier studies.

The evaluation work is described in Section 5.1 together with some possible improvements which could be made to the model. These include simplifying the method used to estimate the lake rainfall and using an alternative rainfall runoff model to estimate tributary inflows. The effects of these changes are discussed in Section 5.2 and recommendations are made for the best model to use in assessments of the likely future impacts of land use change on lake levels. Some first estimates for the impacts of land use change are given in Section 6.

5.1 EVALUATION OF THE MODEL

Data and constraints

The IH2 model had two main components; a model for the lake rainfall and a rainfall runoff model for the tributary inflows. The resulting lake rainfall and tributary inflow series, combined with Penman estimates for the average monthly evaporation, gave an estimate for the monthly net basin supply series. Lake levels were then calculated assuming that outflows could be estimated from the Agreed Curve. The lake rainfall model was based on equal weighting of the scaled rainfalls for the eight lakeshore rainfall stations discussed in Section 4.1. The rainfall runoff model related observed flows in the main tributaries to rainfall in the respective catchment areas and was used to hindcast flows in these tributaries back to 1925. Flows in ungauged tributaries and from areas below the main gauging stations were derived by ratio from the gauged and partially gauged areas assuming typical runoff coefficients. The annual evaporation was assumed to be constant on the grounds that the only way of hindcasting a variation from year to year would be as an inverse function of rainfall; wetter years would have lower lake evaporation and vice-versa. It was argued that if this function is reasonably linear, the result would be the same as a linear transformation of rainfall.

The structure of the model was governed primarily by the data available for the lake catchment at the time. This restricted the simulations to the period 1925 to 1978. Before 1925, only a limited amount of rainfall data was available for the lakeshore stations and hardly any data was available for the tributary catchments. The main calibration period chosen was the period 1956-78 for which measured outflows were available as were measured tributary inflows for the Kagera and for the four main tributaries in the northeastern part of the lake catchment. These tributaries accounted for about 40% of the total lake catchment area and about 50% of the total inflow to the lake in this period.

The most difficult quantity to estimate was the lake rainfall. Rainfall is the most important and variable item in the lake balance, being about five times larger than tributary inflows and about four times larger than the net basin supply. If a consistent, homogeneous dataset was to be used for the whole 1925-78 simulation period, then only the eight lakeshore stations were available to estimate the lake rainfall. This procedure was likened to attempting to estimate the rainfall for an area the size of southern England from only eight raingauges situated around the perimeter. Unfortunately, the spatial distribution of rainfall over the lake is unknown although several attempts have been made to estimate this distribution using atmospheric circulation models and satellite data (see Sections 3.2 and 5.2). In recent decades, many more rainfall records have become available but the use of a lake rainfall series based on a variable, and generally increasing, number of records would make the description of fluctuations over time more difficult to interpret. In deciding to use only eight lakeshore stations, the IH2 study took the view that continuity of record is more important than use of all the information available in any given period. A consistent measure of lake rainfall should therefore rely only on those gauges that have been in operation for most, if not all, of the years since 1925.

The lake rainfall model was based on a method first proposed by de Baulny and Baker (1970). De Baulny and Baker derived a set of monthly weighting factors which accounted for both the differences between the shore based stations and the lake rainfall and the seasonal variations in the distribution of rainfall around the lake. In the IH2 study, this approach was rejected on the grounds that these factors had been distorted by the need to scale the rainfall whilst simultaneously describing the relative influence of the different stations on the lake rainfall. It was concluded that the scaling and combining processes should be separated while accepting that the same eight stations must form the basis of the lake rainfall series. The term scaling here means converting the monthly rainfall values for each station into ratios representing the departures from normal. The term combining means the process of averaging these ratios for all eight stations and then applying a correction factor which represents the differences between the rainfall measured at the lakeshore stations and the actual rainfall over the lake.

After much experimentation, a procedure was used in which overall monthly combination factors were derived from the statistics (mean and standard deviation) of the implied rainfall over the period of the simulations. The implied rainfall is simply the rainfall implied by the observed net basin supply and the predicted tributary inflows and evaporation. This method ensures that the water balance over the whole simulation is satisfied and that the predicted start and end levels match the observed levels exactly. However, there is no constraint on the differences which may develop between observed and predicted levels over the period of the simulations. This approach effectively treats the lake as a giant raingauge and provides perhaps the only rational means of estimating the long term statistics of the lake rainfall from the limited data available. One possible disadvantage is that all errors and omissions in the water balance are lumped into the estimated rainfall; however, this can also be an advantage as the model calibrations based on this rainfall allow implicitly for these errors.

In the final simulations, equal rather than monthly varying weighting factors were used for all eight stations as this caused only a slight decrease in the performance of the model. This is equivalent to saying that the seasonal distribution and monthly variance of the true lake rainfall are equally represented by the records from each of the eight lakeshore stations. This procedure also avoids problems associated with the combination of subsets of the data in periods when records are missing for one or more of the lakeshore stations. Several scaling methods were considered and the final method used was to divide the departures from the monthly means for each station by the monthly standard deviations for each station. These scaled values were then combined by averaging and then reversing the scaling procedure using the monthly mean and standard deviation of the implied rainfall over the same period. Some enhancement of the standard deviation of the final series was made to allow for the tendency of this process to produce less variable rainfall than was indicated by the implied series.

Using this method, two rainfall series were produced for use in the lake water balance simulations. The first was based on the statistics of the implied rainfall in the period 1956-78 for which most of the other components of the lake balance were known to a reasonable accuracy. The second covered the full period 1925-78 and was based solely on the modelled inflows and outflows. These two series have been updated to 1990 in the present study using additional data collected during a visit to East Africa but using the original scaling and combination factors from the IH2 study. For convenience, the series will be referred to as **Rain A** and **Rain B** respectively in some of the following discussion.

Accuracy of the water balance

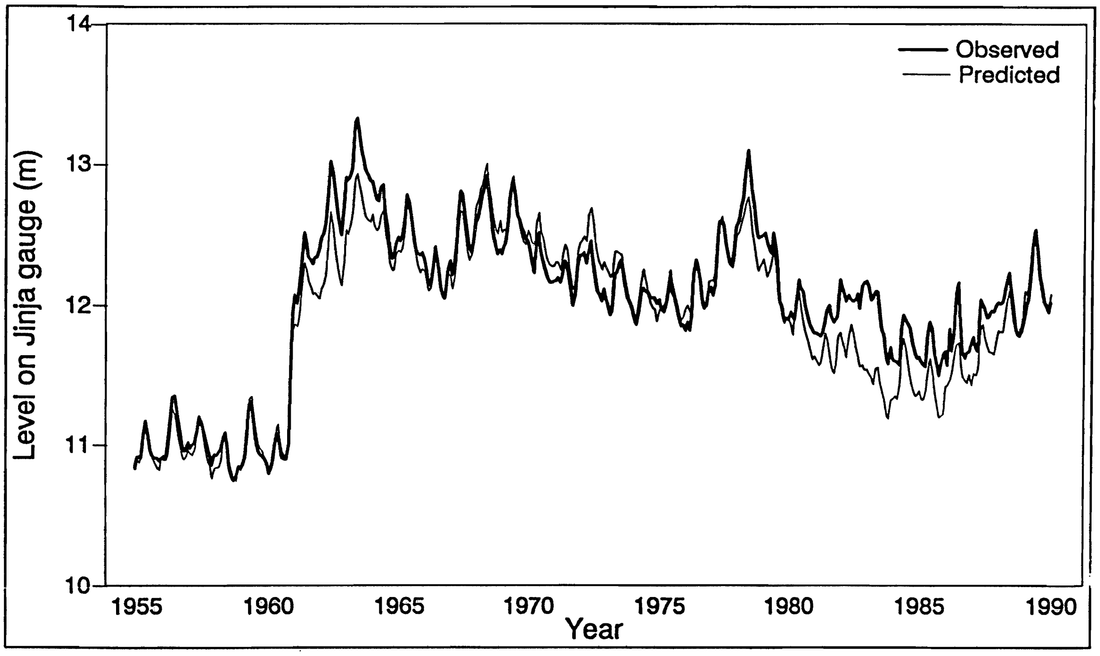
Since the lake rainfall model ensures that the lake levels at the start and end of each simulation period are the same as the actual levels, the main test of the water balance model is that the simulated response of the lake in the intermediate months and years resembles the actual lake level fluctuations. Simulated levels up to 1978 have already been shown in Figure 2.3 for the two rainfall series. Because of the method used to calculate the two series, there were inevitably differences in the common period 1956 to 1978 and this is one possible objection to this approach. Also, the lake level predictions based on the implied rainfall for the whole period did not reproduce the sharp rise in lake levels in the early 1960s as well as that based on the more accurate implied rainfall for the later period only.

The two simulations have been updated to 1990 in the present study using the full Rain A and Rain B series. Figure 5.1 shows a comparison of the observed and predicted levels for the two periods. It can be seen that the model continues to provide reasonable estimates of the fluctuations in lake levels, but that levels are underestimated by some 0.1-0.5 m in the early to mid 1980s. The 1956-78 calibration factors give slightly better results. Part of the reason for these underestimates may be that less rainfall data has been available in recent years than in the time the Hydromet Survey project was operating, and this lack of data may have introduced some bias into the results. In particular, the most recent data located for Kagondo was 1983 and for Kalangala was 1977.

As expected, better results are obtained if the scaling and combination factors in the lake rainfall model are recalculated from the statistics of the implied rainfall for the whole of the periods 1956-90 and 1925-90. A slight improvement also results if seasonal weighting factors are used and the stations Kagondo and Kalangala are omitted from the analysis throughout. Figure 5.2 shows the results for two such further simulations. The 1925-90 simulation used all eight lakeshore stations and the optimum seasonal weighting factors from the IH2 study whilst the 1956-90 simulation used a revised version of these factors which omitted Kagondo and Kalangala. Both simulations gave better predicted levels for the 1980s and, as remarked in the IH2 study, inclusion of the seasonal weighting factors improves the modelling of the 1961-64 rise in levels.

These results show that the model continues to perform reasonably well in the extended period 1979-90. However, a more stringent and arguably more useful presentation of the results would be to make a direct comparison of the predicted and observed net basin supply

Comparison of observed and predicted levels (a) 1956-90 using the Rain B series
(b) 1925-90 using the Rain A series



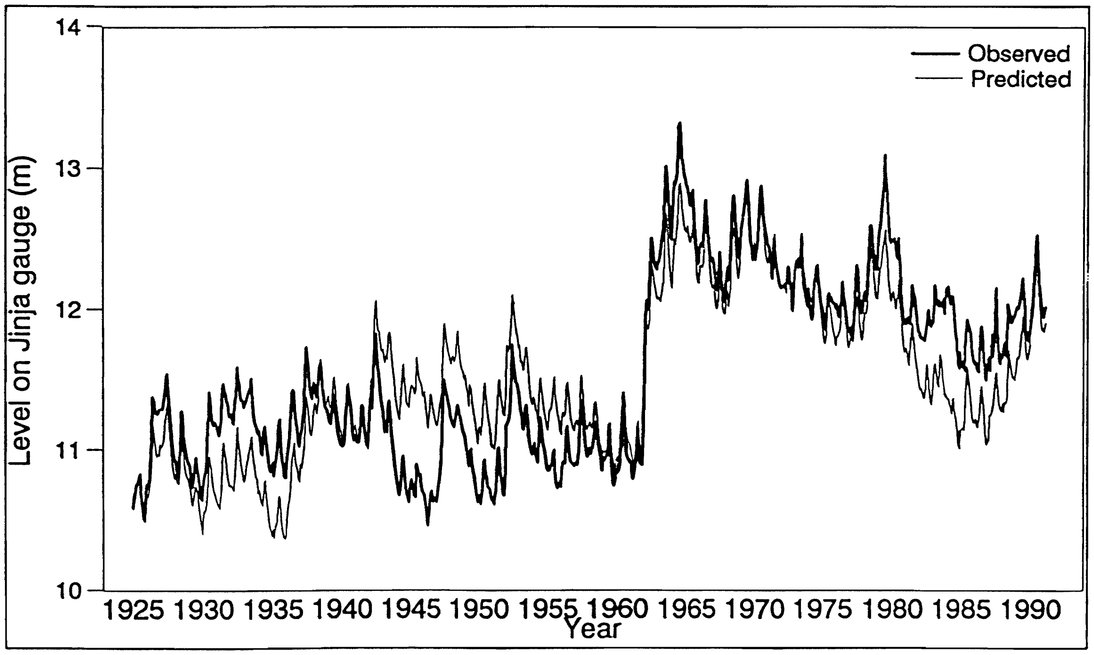
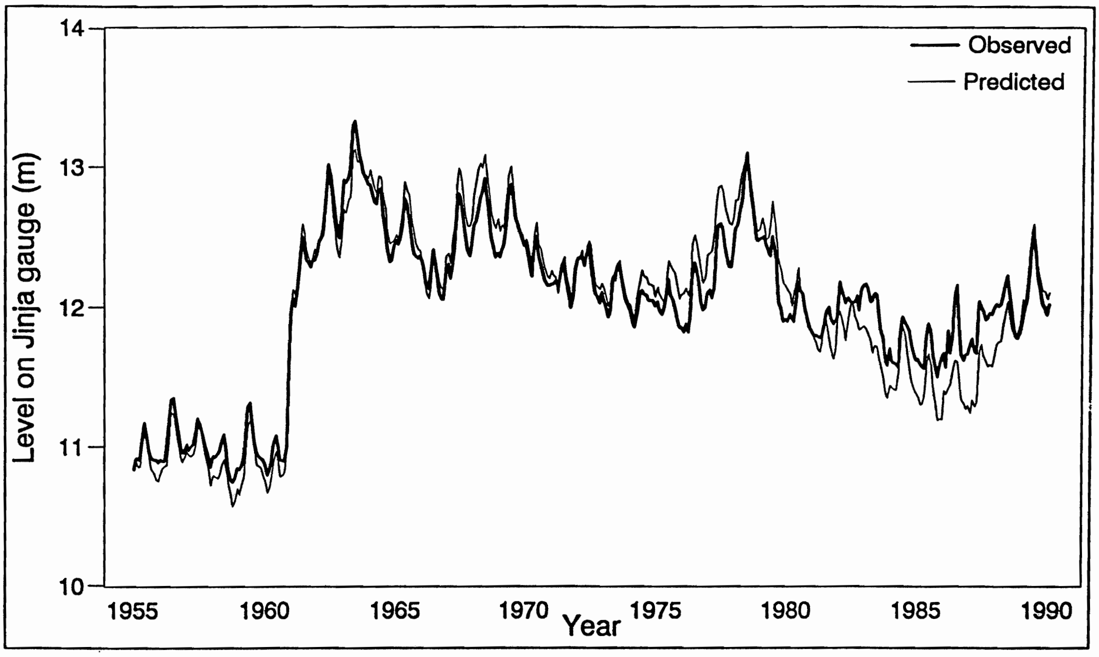


Figure 5.1

Simulations of Figure 5.1 repeated after re-scaling over the whole period and using seasonally varying weighting factors

(a)



(b)

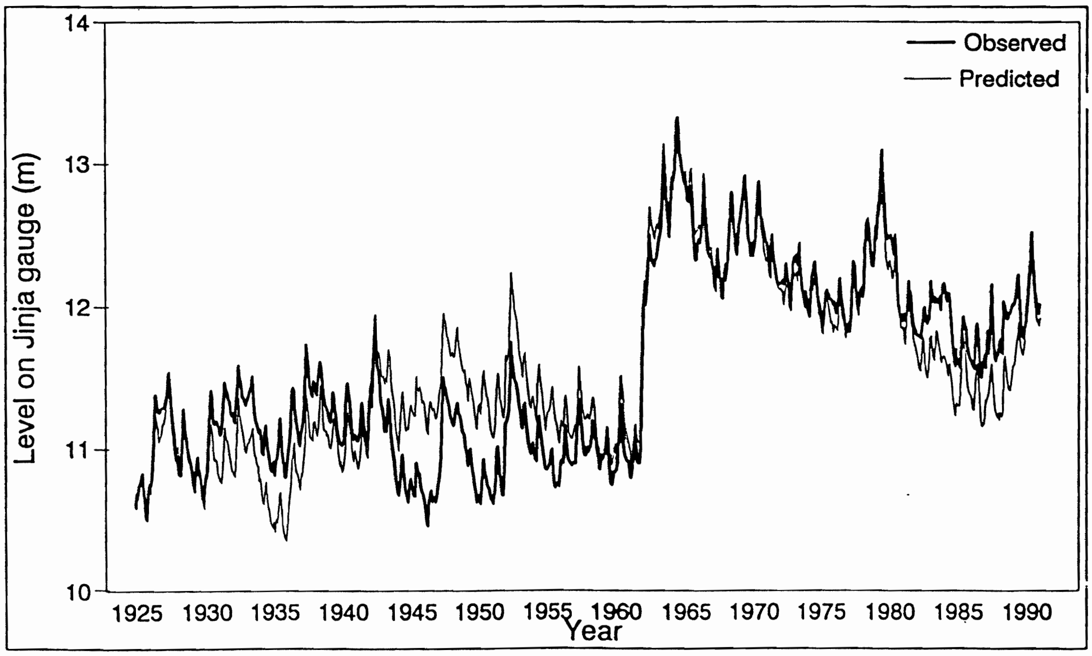


Figure 5.2

series. The problem with a comparison of levels alone is that, due to the link between levels and outflows implied by the Agreed Curve, some of the errors in the calculations also appear in the predicted outflow series. The predicted levels alone therefore do not give a full picture of the performance of the model. Figure 5.3 shows the annual differences between the predicted and observed net basin supply for the Rain A and Rain B series. When compared in this way, the differences between the two simulations are much less marked than in a comparison of predicted levels alone. Note that, for these preliminary comparisons, only approximate estimates were used for the tributary inflows in recent years (1979-90).

By contrast, the cumulative errors in each series (Figure 5.4) follow noticeably different patterns in the two cases. As expected, the cumulative error is zero over the period used to derive the respective implied rainfalls and rainfall scaling factors. However, the series based on Rain B does not define the lake balance well over the period up to 1955 although it of course does better than the series based on Rain A for the period 1956 to 1978. Both series perform equally well for the extended period up to 1990. The periods showing the highest rate of accumulation of error appear to be 1925 to 1934, when the predicted net basin supply is lower than the observed values, and from 1935 to 1955 when the opposite is true. Tables 5.1 to 5.3 show the mean values of the main components in the water balance over these and various other periods as well as the errors in the water balance expressed as a percentage of the individual components. In the tables, the observed net basin supply is referred to as the Basin Supply (outflow) series and the predicted value is referred to as the Basin Supply (inflow) series. As an example, the error over the period 1935 to 1955 when using the Rain A series amounts to an average of about 6,000 MCM/year over this 21 year period. The total error of about 126,000 MCM would be equivalent to a rise in lake level of about 1.9 m assuming a typical lake area of about 67,000 km^2 and no compensating adjustment to outflow. In terms of outflow alone the disparity would be equivalent to an underestimate of about 29% and, in terms of lake rainfall or evaporation alone, the disparity would be equivalent to an overestimate of only about 5-6%.

From the data available, it is impossible to determine the main source of these errors. However, possible explanations include:

(1) The concept of a single set of monthly average rainfall scaling factors does not always work because in the past there have been changes in the rainfall regime in some months affecting only part of the lake and covering different numbers of years.

(2) Unidentified or unexplained errors in the period 1925 to 1934 are hindering a more effective analysis of the rest of the record.

(3) Errors in rainfall are too small to draw any realistic conclusions, and the apparent trends in the series of errors are fortuitous.

(4) Changes in land use around the lake or in the contributing basins have caused variations in the total tributary inflow to the lake between the period 1925-55 and the period 1956-78 over which the rainfall runoff model was calibrated.

(5) The hypothesis advanced by Acres (1990) is correct and outflows before 1954 have been underestimated by 30% or more (see Section 2.4 and Appendix A).

The last two explanations do not seem to be supported by results presented elsewhere in this report. For example, an explanation in terms of errors in the outflow series seems unlikely

Annual errors in the predicted net basin supply series calculated using the Rain A and Rain B series (1925 - 90)

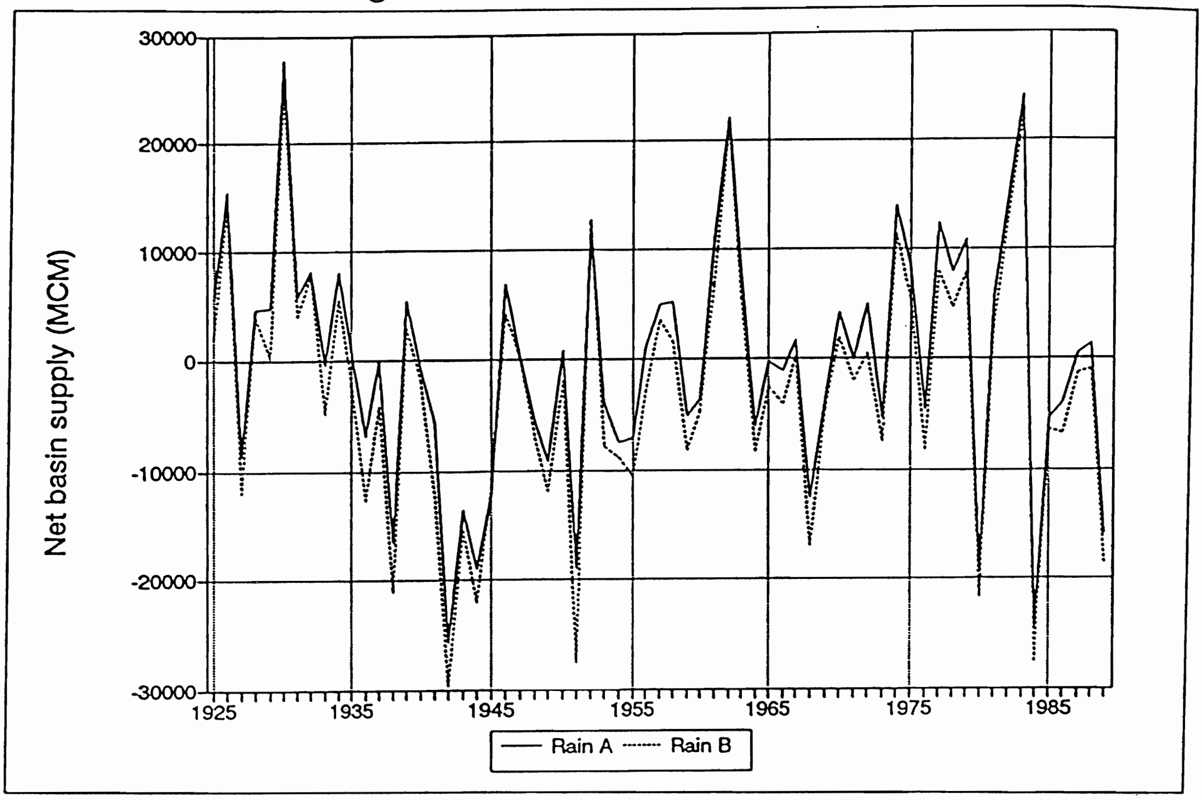


Figure 5.3

Cumulative errors in the predicted net basin supply series calculated using the Rain A and Rain B series (1925 -90)

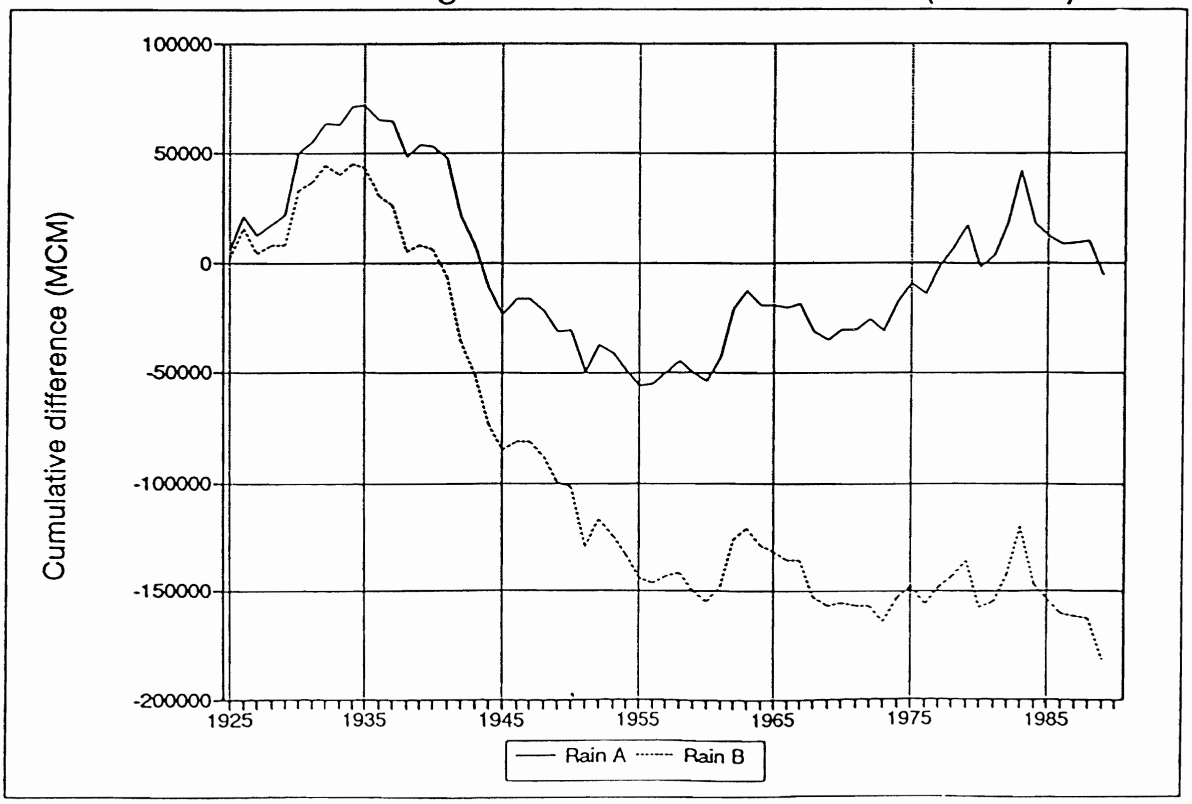


Figure 5.4

Summary of Lake Victoria water balance for selected periods

Period		1900-24 mean	1925-34 mean	1935-55 mean	1956-60 mean	1961-64 mean	1965-78 mean	1979-89 mean	1965-89 mean	1956-78 mean
Lake level (end Dec)	m	10.95	11.05	11.01	10.92	12.53	12.26	11.92	12.11	12.01
Lake area	km2	66772	66829	66819	66740	67798	67790	67542	67681	67563
Change in lake storage	mcm	-826	2198	-254	400	33911	-1557	-4004	-2634	5037
Outflow	mcm	20395	21453	21184	19611	38606	39671	34863	37556	35125
Tributary inflow	mcm		15253	19591	16396	31248	22906	24000	23387	22942
Lake rainfall (IH - Rain A)	mm		1614	1706	1642	2076	1793	1713	1758	1809
Lake rainfall (IH - Rain B)			1653	1750	1682	2111	1834	1748	1796	1849
Lake rainfall (de Baulny & Baker)	mm		1587	1668	1586	1922	1734	1808	1739	1734
Lake evaporation	mm		1595	1595	1595	1595	1595	1595	1595	1595
Basin supply (inflow) Rain A	mcm		16520	26992	19544	63799	36315	31947	34393	37449
Basin supply (inflow) Rain B			19122	29942	22167	66140	39141	34313	37017	40146
Basin supply (outflow)	mcm	19569	23651	20930	20011	72517	38114	30859	34922	40162

Table 5.1

Lake balance errors expressed in terms of the component variables

Period		1900-24 mean	1925-34 mean	1935-55 mean	1956-60 mean	1961-64 mean	1965-78 mean	1979-89 mean	1965-89 mean	1956-78 mean
Basin supply (inflow)	mcm		16520	26992	19544	63799	36315	31947	34393	37449
Basin supply (outflow)	mcm	19569	23651	20930	20011	72517	38114	30859	34922	40162
Error in water balance BS(inflow) - BS(outflow)	mcm		-7131	6062	-467	-8718	-1799	1088	-529	-2713
Error as percentage of:										
Outflow	%		33	-29	2	23	5	-3	1	8
Lake rainfall (IH - Rain A)	%		-7	5	-0	-6	-1	1	-0	-2
Tributary inflow	%		-47	31	-3	-28	-8	5	-2	-12
Lake evaporation	%		7	-6	0	8	2	-1	0	3

Notes:
A positive percentage error indicates a possible overestimate of the relevant variable.
In each case all other variables are assumed to be accurate.

Table 5.2

Lake balance errors expressed in terms of the component variables

Period		1900-24 mean	1925-34 mean	1935-55 mean	1956-60 mean	1961-64 mean	1965-78 mean	1979-89 mean	1965-89 mean	1956-78 mean
Basin supply (inflow)	mcm		19122	29942	22167	66140	39141	34313	37017	40146
Basin supply (outflow)	mcm	19569	23651	20930	20011	72517	38114	30859	34922	40162
Error in water balance BS(inflow) - BS(outflow)	mcm		-4529	9011	2157	-6377	1027	3455	2095	-15
Error as percentage of:										
Outflow	%		21	-43	-11	17	-3	-10	-6	0
Lake rainfall (IH - Rain B)	%		-4	8	2	-4	1	3	2	-0
Tributary inflow	%		-30	46	13	-20	4	14	9	-0
Lake evaporation	%		4	-8	-2	6	-1	-3	-2	0

Notes:
A positive percentage error indicates a possible overestimate of the relevant variable.
In each case all other variables are assumed to be accurate.

Table 5.3

in view of the results of the comparisons presented in Section 3.3, which seem to show beyond reasonable doubt that the pre-1954 outflow record is substantially correct (see also Appendix A). An explanation in terms of inflow also seems unlikely because, as will be shown in Section 6, the impact to date of land use changes is probably negligible. Furthermore, the implied errors in the inflow and outflow components are not consistent throughout the period from 1925. For example, if outflows were underestimated for 1935 to 1955, it seems odd that they appear to be overestimated from 1925 to 1934. The same Agreed Curve was used to derive outflows from known, and accurate, lake levels for both periods. It is therefore much more likely that the major part of the error lies in the estimates of lake rainfall.

An idea of the natural variations in lake rainfall can be obtained from Table 5.4, which compares the mean monthly rainfall at the eight lakeshore stations for two consecutive periods of about 20 years. These comparisons show that the mean lakeshore rainfall can differ markedly over this timescale, and seem to confirm the theory (see Section 3.2) that, since 1961, there has been a significant shift in the climate over the lake. These results suggest that this change has been mainly in the climate of the northern and eastern part of the lake, resulting in an increase in rainfall during the months of October, November and March. However, Table 5.4 also shows that there have been contemporary reductions in rainfall at several stations in some other months. There is as yet no physical explanation for these changes, nor is it possible to determine whether the representativeness of each station in terms of lake rainfall is stable or varying over the period 1925-90. Given these problems in estimating the rainfall over the lake, implied errors of only 5-10% could be considered small.

These results therefore suggest that the most likely cause of the errors in the predicted net basin supply is small yet persistent errors in estimates of the lake rainfall. Tables 5.1-5.3 confirm that errors of only a few percent in rainfall can cause quite significant errors in the lake water balance. This result was also found from the sensitivity studies described in Section 4.2. The sensitivity to rainfall may be further enhanced if, as might be expected, evaporation is lower in wetter years and higher in drier years. The variation in the difference between rainfall and evaporation would then be greater than the variation in rainfall alone from one period to another. Thus the nominal errors in rainfall alone could be less than those shown yet give the same result in terms of lake water balance error.

These arguments suggest the following conclusions:

1. Errors in the lake water balance arise primarily from relatively small errors in the estimates of lake rainfall.

2. As the errors in rainfall estimates appear to be consistent from year to year within periods of several years, they probably arise from shifts of climate whose effect on lake rainfall cannot be effectively defined.

3. If these conclusions are correct, there is again little support for the Acres hypothesis that outflows were substantially underestimated in the years before 1954. Also, if the Acres hypothesis is valid, some explanation must be found for the contrary result obtained for the period 1925 to 1934.

4. The water balance of the lake is uncertain to the extent that it does not, and possibly cannot, provide an unequivocal judgement on the likely accuracy of the lake rainfall, tributary inflows or the Agreed Curve. Most hydrologists would concur with a

Comparison of mean monthly rainfall in different periods (mm)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
JINJA	1935-55	56	63	108	212	166	70	54	101	89	87	111	103	1221
	1956-78	64	85	141	195	140	69	70	83	100	141	161	87	1336
	difference	8	22	33	-17	-26	-1	15	-17	12	53	50	-16	114
ENTEBBE	1935-55	68	82	162	268	281	114	73	78	83	77	139	117	1541
	1956-78	88	101	179	260	238	121	69	79	72	126	178	112	1623
	difference	20	19	17	-9	-43	7	-4	1	-11	49	39	-4	82
KALANGALA	1935-55	115	138	232	373	352	234	139	116	113	123	187	197	2332
	1956-78	135	137	239	340	322	162	96	94	114	159	210	200	2214
	difference	21	-1	7	-33	-30	-72	-43	-22	1	35	23	4	-118
BUKOBA	1935-55	144	153	229	366	311	83	51	75	117	141	175	204	2049
	1956-78	150	180	254	398	316	89	51	66	102	153	195	193	2147
	difference	6	27	25	32	6	6	-0	-9	-15	12	20	-11	97
KAGONDO	1935-55	132	132	216	311	244	29	24	55	91	122	173	160	1690
	1956-78	119	152	219	362	234	47	26	40	94	115	201	161	1770
	difference	-13	20	3	51	-10	18	2	-16	3	-7	28	0	80
MWANZA	1935-55	95	103	143	172	101	17	9	20	43	41	122	147	1012
	1956-78	102	114	156	177	71	16	15	21	25	99	158	146	1100
	difference	8	11	12	5	-30	-1	7	1	-18	57	36	-1	88
MUSOMA	1935-55	62	63	120	189	107	30	17	18	29	35	65	69	804
	1956-78	59	84	123	182	101	24	21	22	31	53	117	78	895
	difference	-3	21	3	-7	-6	-6	4	4	2	18	52	9	91
KISUMU	1935-55	55	76	152	196	177	99	68	92	73	63	91	106	1248
	1956-78	71	98	155	234	175	79	63	90	84	87	139	102	1376
	difference	16	22	3	38	-2	-20	-5	-2	11	24	47	-4	128
LAKE	1935-55	136	142	207	290	227	71	38	78	99	118	148	197	1750
	1956-78	147	159	226	295	209	62	37	69	96	147	210	192	1849
	difference	11	18	20	4	-18	-9	-1	-9	-3	29	62	-4	99

Notes:
This comparison is based on the IH lake rainfall series defined in their second report.

Table 5.4

judgement that a small error in lake rainfall is more likely than a large error in inflows or outflows. In practice there are likely to be minor errors in all these variables.

Possible improvements to the model

Despite these uncertainties, the IH2 water balance model continues to give a good representation of the observed lake levels and the net basin supply in recent years. The main constraints on modelling the historical water balance remain the quality and availability of data, rather than the sophistication of the modelling techniques used. However, with the benefit of hindsight, some aspects of the model might be simplified or improved while still obtaining a satisfactory water balance.

The main questions concern the lake rainfall model. Two possible objections might be made to the method of using the implied rainfall to calibrate the model. The first is that the resulting estimates of lake rainfall vary according to the period picked to estimate the implied rainfall. Although the differences are very small, this method is difficult to justify to non specialists. The second objection is the use of the arbitrary factor applied to the overall standard deviation in order to retain the observed variability in the series. In the following section, an attempt is made to derive an alternative net rainfall model which estimates both the rainfall and evaporation together.

There are fewer possibilities for improving estimates for the remaining terms in the input side of the water balance. As remarked earlier, there seems little chance of hindcasting a plausible lake evaporation record, and the monthly average Penman estimates are probably the best that can presently be achieved. The main constraints on improving the tributary inflow estimates are the lack of observed flow data for calibration and the quality of the catchment rainfall estimates. The difficulty in estimating the catchment rainfalls is again lack of suitable long term data and it seems unlikely that these estimates can be much improved. However, to provide a cross-check on the IH2 estimates, some alternative tributary inflow estimates have been derived using a different rainfall runoff model. Also, a new best estimate of the total inflow record has been derived using additional observed flow data located in the present study.

5.2 REVISED MODEL

Rainfall and evaporation

Rainfall data for the lakeshore and lake island stations suggest that a successful monthly lake rainfall model must include some allowance for seasonal variations in rainfall and multiplying factors to allow for the differences between rainfall at the shore based stations and over the lake. The most convincing way to combine the data from the lakeshore stations would be to derive weighting factors based on seasonal isohyetal rainfall maps for the lake and the surrounding catchment, However, despite many attempts, no truly convincing isohyetal maps have yet been constructed for the region. The main difficulties are that rainfall gradients are high near the lake shore (of the order 10 mm/km in the northwestern sector of the lake) and that very little data is available from over the lake surface.

During the Hydromet Survey project, several attempts were made to construct seasonal isohyetal maps from the limited data available from island stations and satellite pictures of cloud cover of the lake. The resulting estimates of lake rainfall generally seemed much too low in the main test period of 1950-79 (Kite, 1981). The other main approach has been to use the results of atmospheric circulation models as a guide (e.g. Datta, 1980). However, these models necessarily give a much simplified, average view of the interactions between the lake circulation and the larger scale atmospheric movements over the region. A recent example (Flohn and Burkhardt, 1985) relies heavily on the results of a limited six month run of rainfall data obtained from Nabuyonge island during the Hydromet Survey project (Figure 5.5). This map, if correct, shows that the peak annual rainfall approaches 3 m over the southwest portion of the lake.

There is even less information on the variation in evaporation over the lake surface. The Penman equation provides probably the most reliable way of estimating lake evaporation over timescales of 1 month or more. In the absence of better information, the IH2 study estimated the total lake evaporation as the average of Penman estimates of evaporation from several of the lakeshore stations. A better method would be to account for the variations in evaporation over the lake surface and for the influence of cloud cover and rainfall on evaporation. From the data available for the lakeshore stations, there do appear to be significant variations in evaporation around the lake, with much higher evaporation in the drier, warmer regions to the south and east. There also appears to be some link between evaporation and rainfall. An indication of this trend can be obtained by comparing the monthly average rainfall and Penman evaporation at each of the lakeshore stations. Comparisons for two stations at opposite sides of the lake are shown in Figure 5.6 and suggest that the evaporation may drop by up to 10% in wet months compared to drier months. However, with current knowledge, there is no obvious way of generalising these results to the whole lake or over time.

In the future, it may be possible to improve estimates of the rainfall and evaporation distribution using satellite imagery and improved measurements over the lake. Until that time, the only alternative approach is to infer the implied values from the remaining components in the lake water balance. Since the evaporation cannot be specified with any certainty, it seems sensible to model both the rainfall and evaporation together as net rainfall. This is the approach taken for the revised model. To calibrate the method, the period 1969-78 has been chosen as this period has the most complete data coverage, with outflows measured at Owen Falls dam and about 80% of the lake catchment gauged (see Section 4.1). Figure 5.7 shows the average seasonal variations in the implied net rainfall for this period together with the average rainfall for the lakeshore stations. Here, the lakeshore average rainfall has been calculated simply by averaging the monthly data from the lakeshore stations, but omitting Kagondo and Kalangala due to the lack of data for these stations in recent years. It can be seen that there is a close link between the implied net rainfall and the rainfall measured at the 6 lakeshore stations. This result is confirmed by correlation plots of the individual monthly values, some examples of which are shown in Figure 5.8. Best fit straight lines fitted to these correlation plots suggest the following values for the slope and intercepts:

Isohyetal map based on a model of the atmospheric circulation over the lake

(Flohn and Burkhardt, 1985)

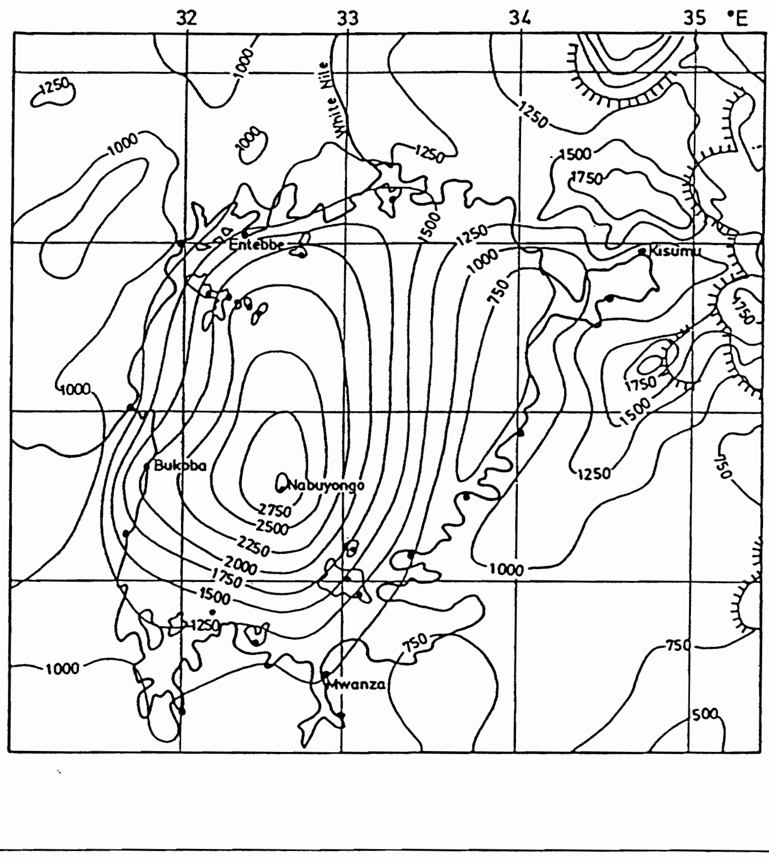
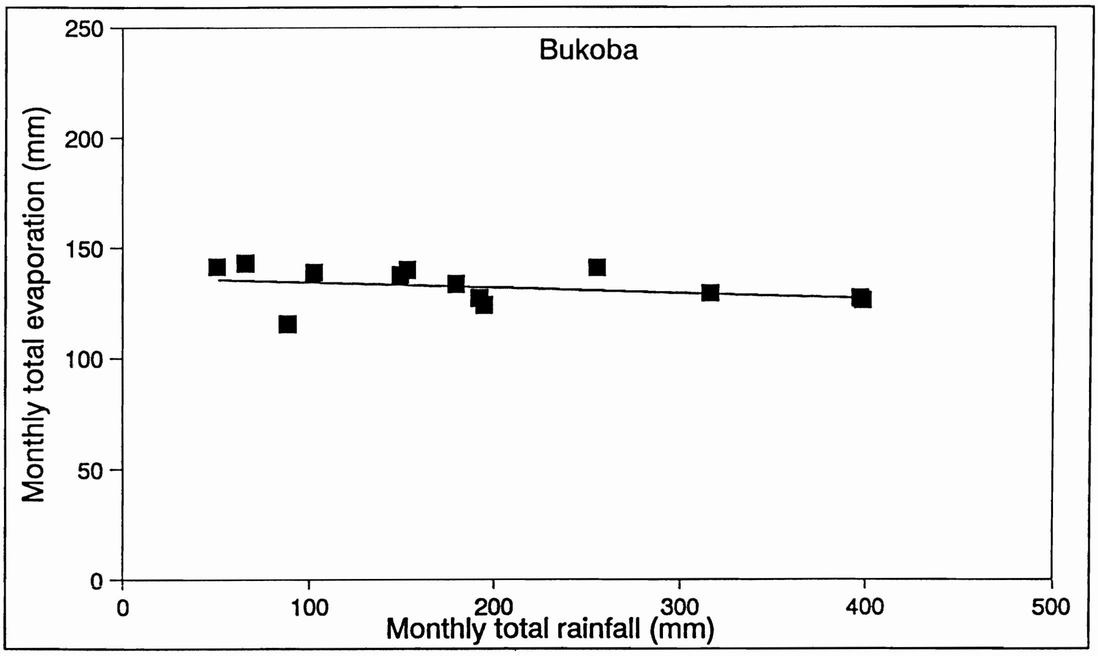


Figure 5.5

The relationship between average monthly rainfall and Penman evaporation for two lakeshore stations (1956 - 78)



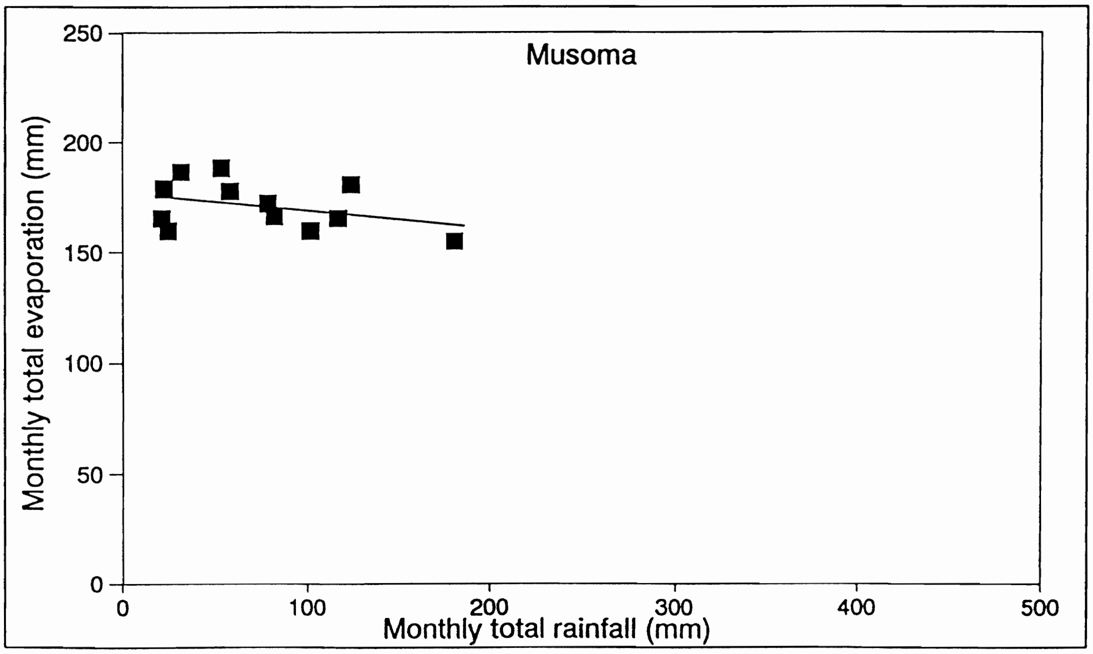


Figure 5.6

Average seasonal variations in the lakeshore rainfall and implied net rainfall for the period 1969 - 78

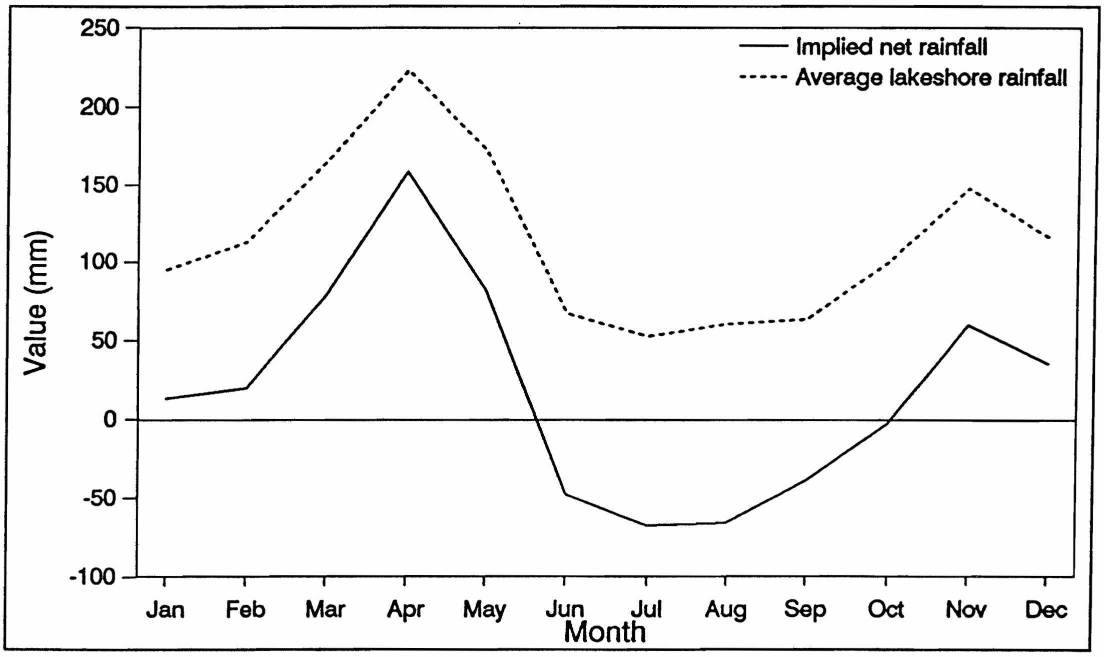


Figure 5.7

Seasonal relationship between monthly implied net rainfall and lakeshore rainfall
(1969 - 78)

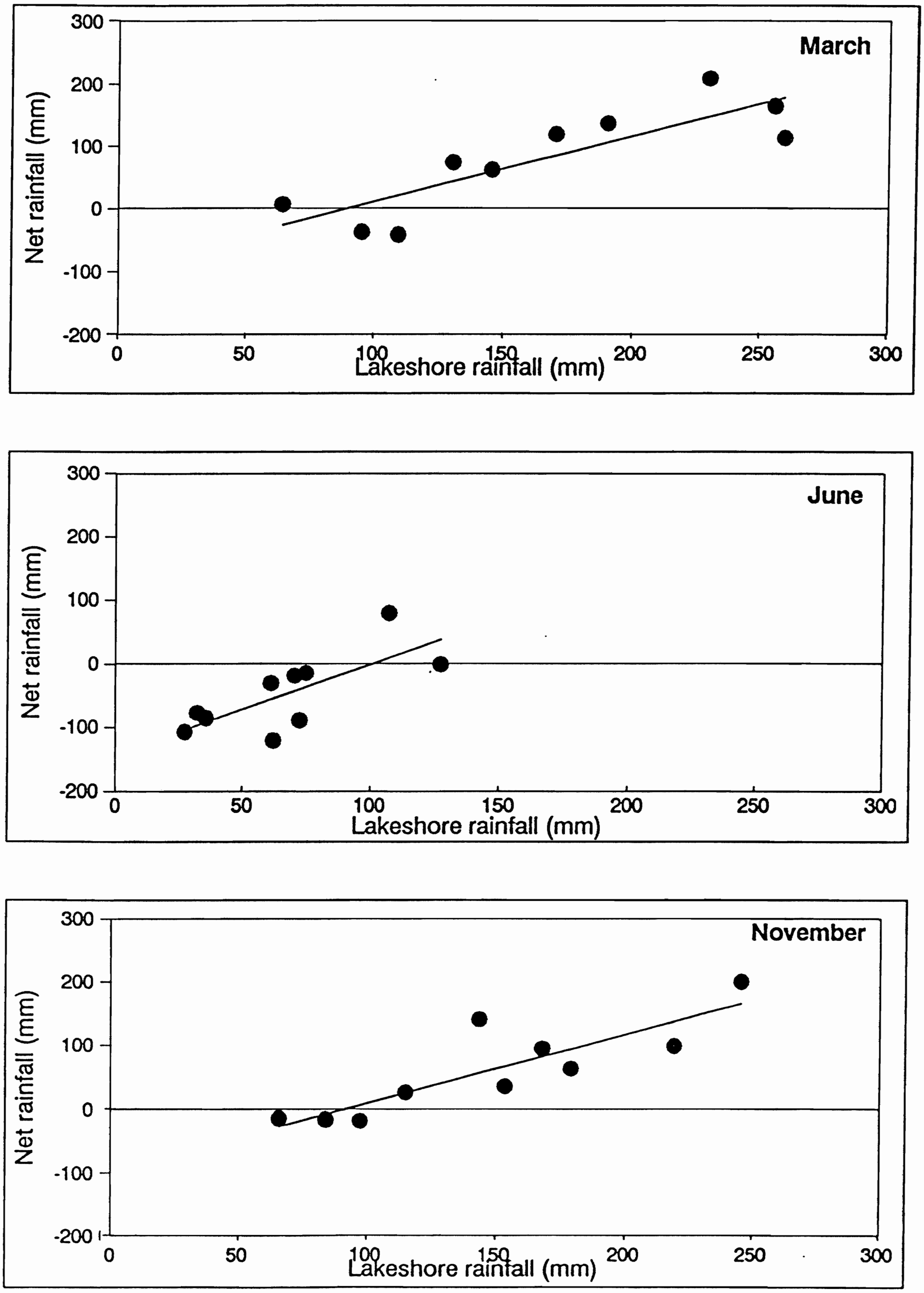


Figure 5.8

	Intercept	Slope
Jan	-150	1.72
Feb	-107	1.13
Mar	-94	1.05
Apr	-94	1.13
May	-53	0.78
Jun	-143	1.41
Jul	-136	1.30
Aug	-133	1.10
Sep	-63	0.38
Oct	-146	1.44
Nov	-98	1.07
Dec	-93	1.11

These parameters provide a basis for estimating the net rainfall for the lake from the average rainfall measured at the 6 chosen lakeshore stations. From Figure 5.9, it can be seen that this method gives a good representation of the monthly net rainfall over the calibration period. Also, over the longer period 1925-90, the annual variations (Figure 5.10) are very similar to those implied by the IH2 rainfall series (Rain A) and the annual lake rainfall model described in Section 4.1. It therefore seems that this alternative method for estimating the monthly net rainfall gives results of comparable accuracy to those given by the IH2 scaling and combination method. The method also relies solely on observed data for a short calibration period (1969-78) and so can provide a more objective test of the water balance model over the full simulation period.

Using this new series, it is interesting to see whether the suspected change in rainfall regime in March, October and November discussed earlier is also reflected in the net rainfall series. If anything, this change should be more apparent due to the amplifying effect of decreases in evaporation in wetter months and increases in drier months. Figure 5.11(a) shows the variations in net rainfall in the period 1925-90 for three averaging periods: March-May, June-September, October-December. For the first of these periods, the March-May wet season, there seems to have been a slight increase in the 1960s which has now subsided while, for the June-September dry season, there was no change in the early 1960s. For the October-December wet season, though, the change is very marked and appears to have persisted up to the present. The long term increase in net rainfall on the lake is about 30 mm/month, equivalent to about 100 mm/year, or about 5% of annual rainfall, for these three months alone. This seasonal increase would indeed seem to be one of the main reasons for the persistent increase in lake levels since the early 1960s. There is, of course, no way of knowing if this is a permanent change or if the rainfall regime might change to pre-1961 conditions or some completely new state in the future.

As a further check on this important result, independent estimates of net rainfall have been calculated using the observed net basin supply derived in Section 3.3 and a best estimate for the inflow record which is derived in the following section. Figure 5.11(b) shows the variations in these estimates of net rainfall from 1925 to 1990 for the same three seasons shown in Figure 5.11(a). The results are very similar and again indicate that, since the early 1960s, there has been a significant and sustained increase in the net rainfall during the months of October to December. Thus the same conclusion is reached using both the modelled net rainfall series (based on rainfall data for the lakeshore stations) and the implied net rainfall series (based on observed inflows, outflows and lake levels).

Comparison of predicted and implied monthly net rainfall for the period 1969 - 78

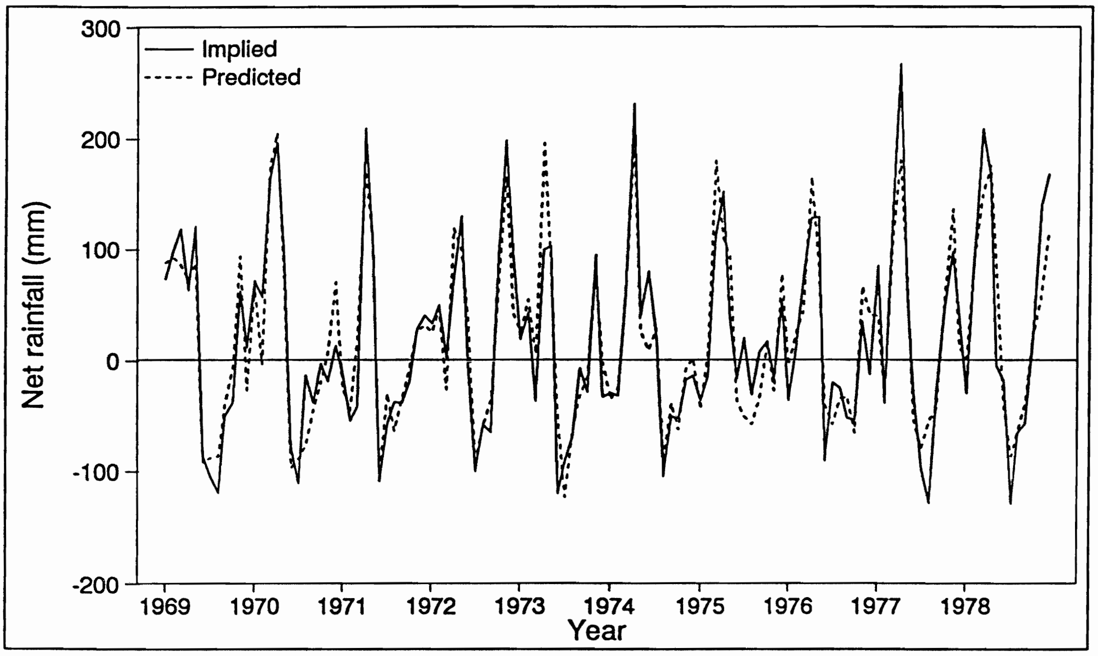


Figure 5.9

Comparison of annual total lake net rainfalls for three models
for the period 1925 - 90

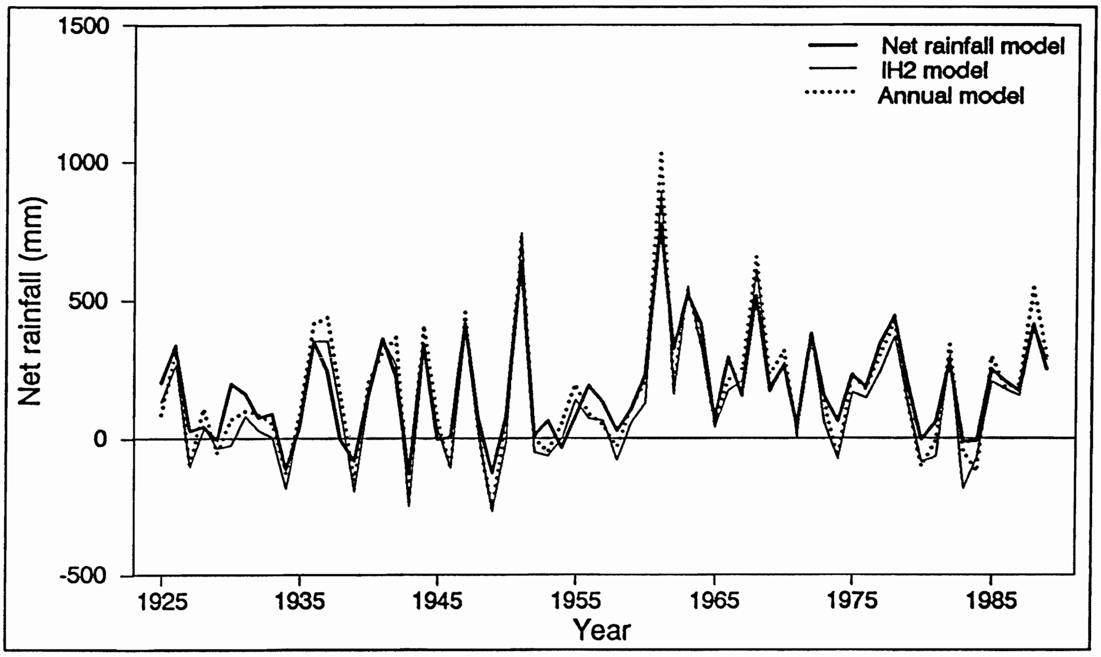
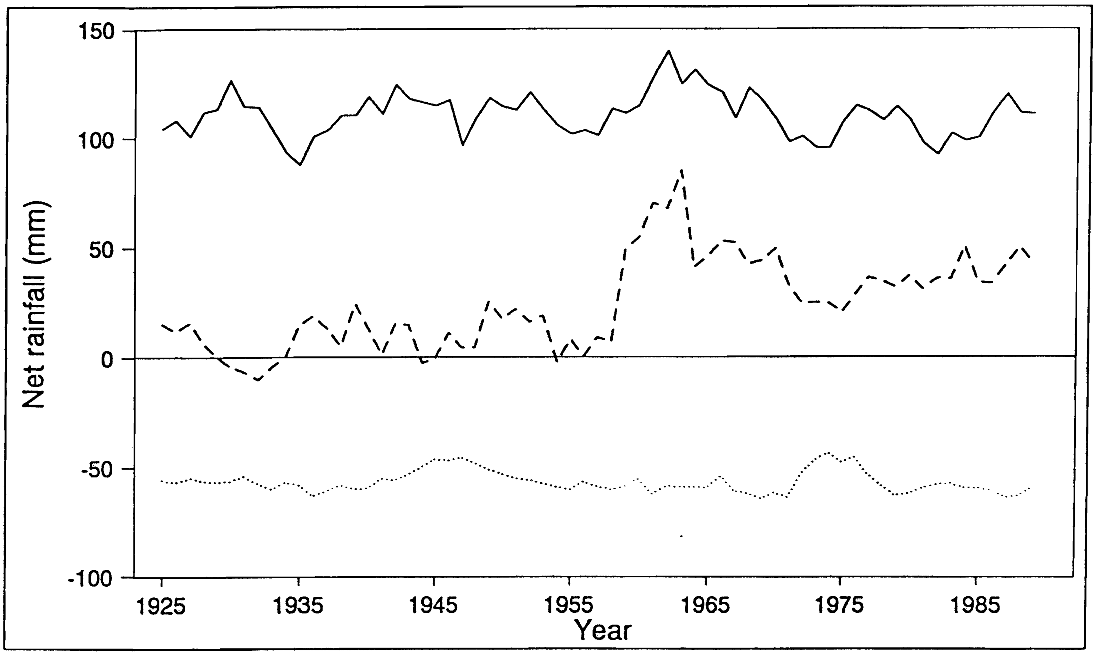


Figure 5.10

Variations in the net rainfall in the period 1925 - 90

(a) Based on lakeshore rainfall (5 year moving average)



(b) Based on observed inflows and net basin supply (5 year moving average)

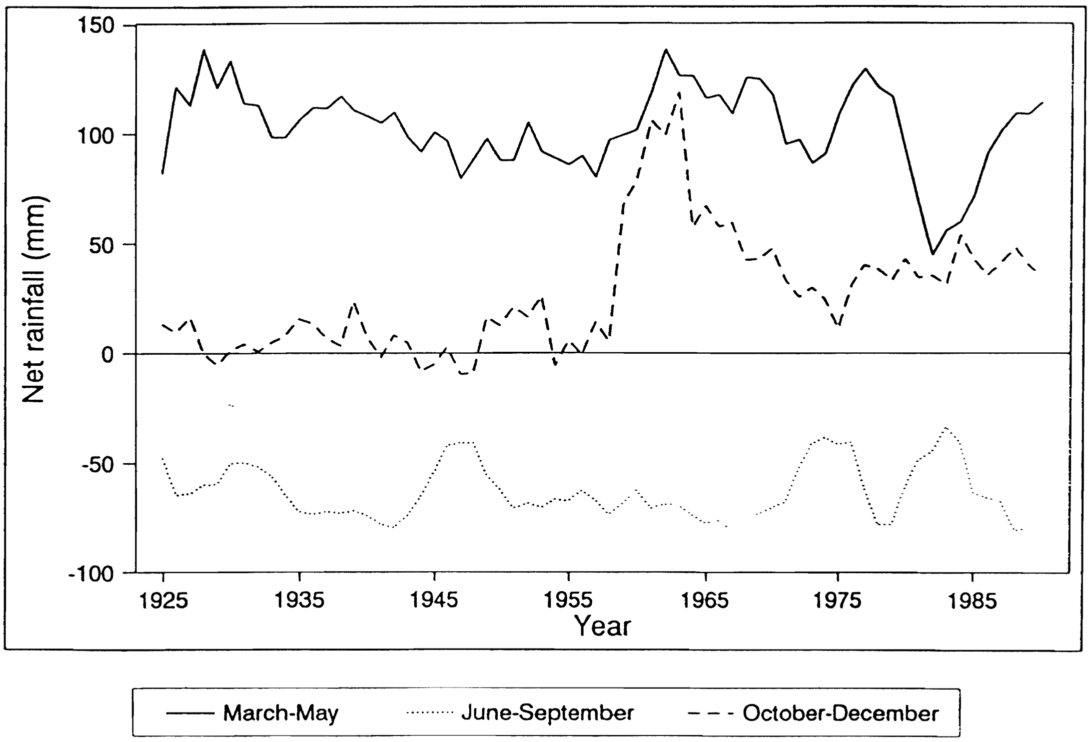


Figure 5.11

An additional conclusion from this comparison is that the seasonal distribution predicted by the net rainfall model appears to be broadly correct throughout the period 1925-90. Thus the use of only a short calibration period for this model (1969-78) - after the rains of 1961 to 1964 - does not appear to have introduced any major bias into the predicted net rainfall values. This also implies that the seasonal relationship between the lake rainfall and lakeshore rainfall must have remained reasonably constant in the period 1925-90, which provides additional confidence in the results given by the net rainfall model.

Tributary inflows

The IH2 study used a simple conceptual rainfall runoff model to hindcast inflows back to 1925 for 5 major rivers in the lake catchment. The total inflow was then estimated by applying monthly scaling factors to these flows. These factors were estimated from flow data for the period 1969-78, in which most of the lake catchment was gauged and hence reasonably accurate estimates were available for the total inflow. The aim in the present study has been to update the total inflow and catchment rainfall series as far as possible and to provide an independent check on the hindcasting work by using a different rainfall runoff model. The IH2 study included a very careful assessment of the original data and of suitable methods for estimating the ungauged runoff and it was not felt necessary to repeat this work here other than to make a few spot checks on the accuracy of the calculations.

The new total inflow record is based as far as possible on observed data. During the 1969-78 period, approximately 20 of the main tributaries of Lake Victoria were gauged, together accounting for about 80% of the 194,000 km^2 catchment area (WMO, 1982). Before 1969, only the river Kagera and four of the main (northeastern) Kenyan tributaries were gauged accounting for about 40% of the catchment area and about 50% of the total inflow. These tributaries were the Nzoia, Yala, Sondu and Awach Kaboun. Gauging started in 1956 on these tributaries and in 1940 on the Kagera. A search for more recent data showed that regular measurements have only been made on the Kagera in recent years. Monthly mean levels were obtained for the Nyakanyasi gauging station up to 1984 and were converted to flows using an implied rating based on observed monthly levels and flows for the period 1973-1978. Monthly flows for the period 1985-89 were obtained for the Rusomo Falls station in Rwanda and values for Nyakanyasi further downstream were estimated by a simple correlation model. Flows were also estimated for the period 1933-39 from some previously overlooked level data for the Kyaka Ferry gauging station reported in the Nile Year Books (Hurst, various years). For the remaining gauging stations in the catchment, only some limited monthly mean level data was available covering the period up to 1984. Again, implicit ratings were developed to convert these levels into approximate flows.

Two methods have been used to compile the total inflow record. For the period 1969-78, the estimates from the IH2 study have been used which are based on the total gauged inflow with some allowance for the inflow from the remaining ungauged 20% of the catchment. These estimates were also used in developing the net rainfall model discussed above. For the remainder of the period 1925-90, the total inflows have been estimated by scaling the inflows from the 4 northeastern tributaries and the Kagera, again using the method developed during the IH2 study. To obtain a full record for each of these 5 rivers, missing periods of data have been infilled using a rainfall runoff model. For the Kagera, infilling was necessary for the period 1925-33 and for 1990 while, for the northeastern tributaries, infilling was required for the periods 1925-55 and 1985-90.

Figure 5.12 shows the structure of the model used for this infilling work. The model - called HYRROM - is a simple 9 parameter conceptual rainfall runoff model developed at the Institute of Hydrology. The model has four main stores which control the translation of rainfall into runoff. An efficient optimisation routine allows the model to be calibrated to obtain a good match between the catchment rainfall and any available observed flow data. The philosophy underlying HYRROM is that the model is simple enough to apply when the data are of limited accuracy yet includes some representation of real catchment processes. Although it is by no means the best or most sophisticated model available, HYRROM has been shown to give good results on a wide range of catchment sizes and types.

To run the model, estimates are required for the catchment average rainfall and potential evaporation. Both the rainfall and evaporation values from the IH2 report were used here. The catchment rainfall series were extended from 1978 to 1990 using the same averaging process used to derive the IH2 values. Typically, each series is based on data for 5-6 raingauges scattered around the catchment. The model was optimised against various 4 year periods from the measured flow data for each catchment and a set of typical parameter values was derived from these analyses. For future reference, these values are summarised in Table 5.5.

Figure 5.13 shows a comparison of the observed and predicted monthly total inflows from the 4 northeastern tributaries for the period 1956-78. The agreement is reasonable, particularly during low flow periods. The average predicted annual inflow over this period was 5,100 MCM compared to the observed value of 5,270 MCM. Figure 5.14 shows that, for each of the 4 catchments, the average seasonal errors are generally lower than those obtained from the IH2 model. The best improvements are in the months of January and February. HYRROM was also applied to the Kagera but no great improvement was noted over the IH2 model.

The infilled records for the 5 catchments were used to generate a new total inflow record for the period 1925-90. Figure 5.15 compares this record with that given by the IH2 rainfall runoff model. It can be seen that the IH2 record tended to overestimate flows slightly during periods of recession but otherwise gave a reasonable representation of the seasonal variations in inflows. As expected, both records show a marked increase in lake inflows in the period 1961-64 as a result of the increased rainfall in this period. An inspection of the individual inflow records shows that the main increases in the Kenyan tributaries were in late 1961 and 1962 while the increased inflows from the Kagera occurred mainly in 1963 and 1964. This difference results partly from the large storage in lakes and swamps in the Kagera basin, and partly because 1963 was an unusually wet year in the Kagera catchment.

For the new record, the overall average annual inflow is about 20,000 MCM. For the period 1925-60, before the sudden rise in inflows, the average is about 17,000 MCM and, for the period 1965-90 after the rise, the average has increased to 22,500 MCM. The standard deviations for these three periods are 910, 700 and 910 MCM respectively. These results suggest that, in parallel with the apparent shift in rainfall patterns since 1961-64, there has been an associated increase in tributary inflows of about 5,500 MCM per year, or about 80 mm/year when expressed in depth over the lake surface. In terms of the annual lake rainfall, this increase represents roughly an additional 5% change above that due to the direct rainfall on the lake surface.

Structure of HYRROM model

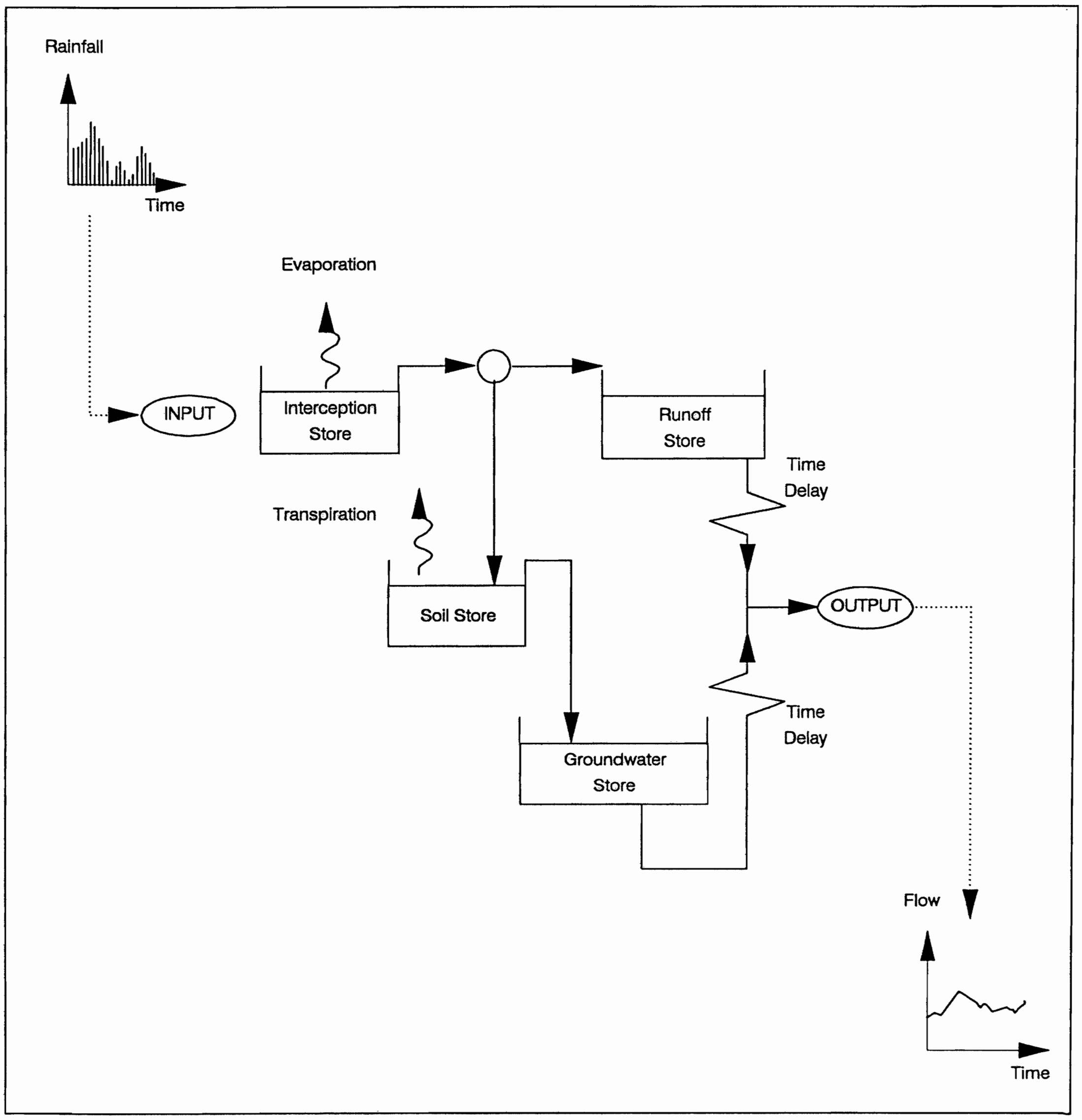


Figure 5.12

Comparison of the observed and modelled total inflow
from four northeastern tributaries (1956 -78)

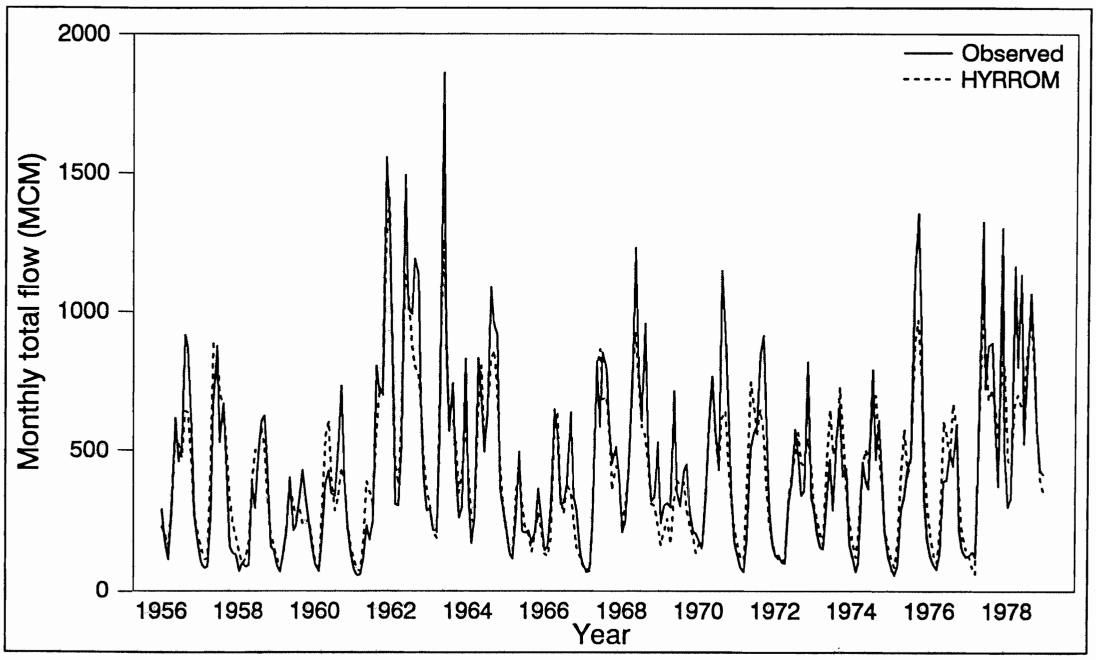
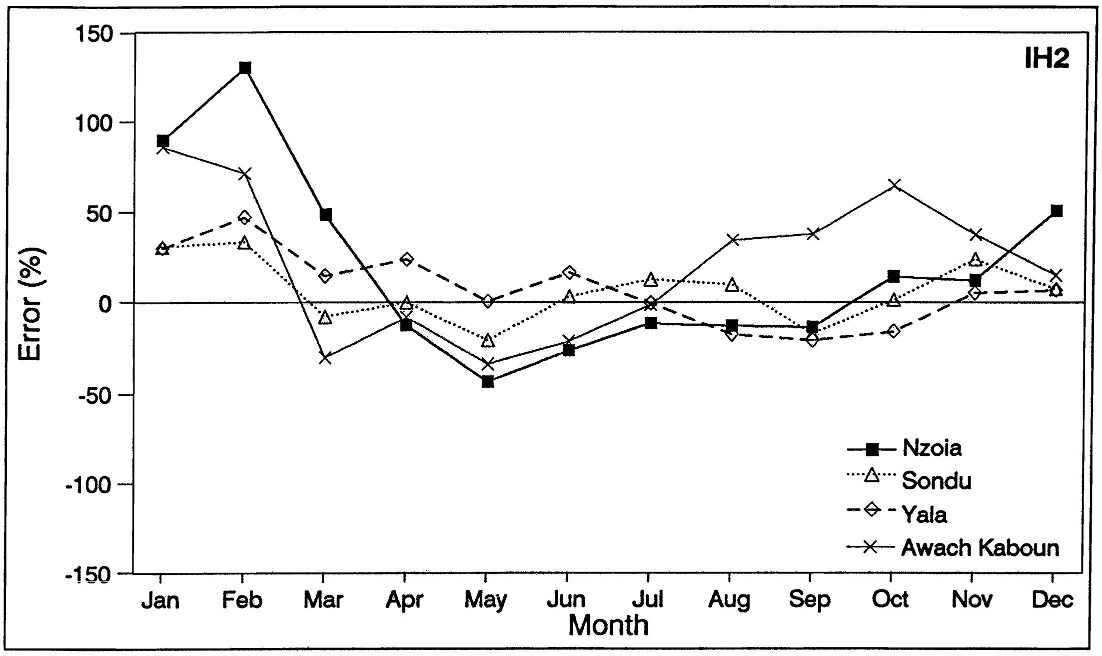


Figure 5.13

Seasonal variations in errors for the modelled inflows, calculated using the IH2 and HYRROM models (1956 - 78)



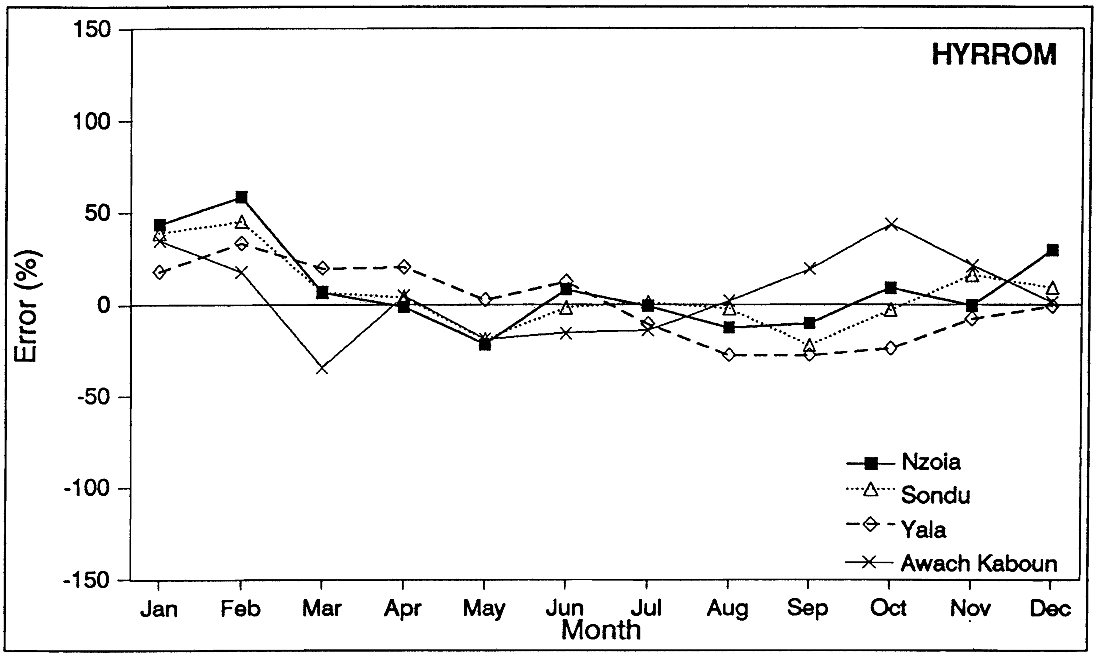


Figure 5.14

Comparison of IH2 modelled total inflows with the best estimate derived in the present study (1925 - 90)

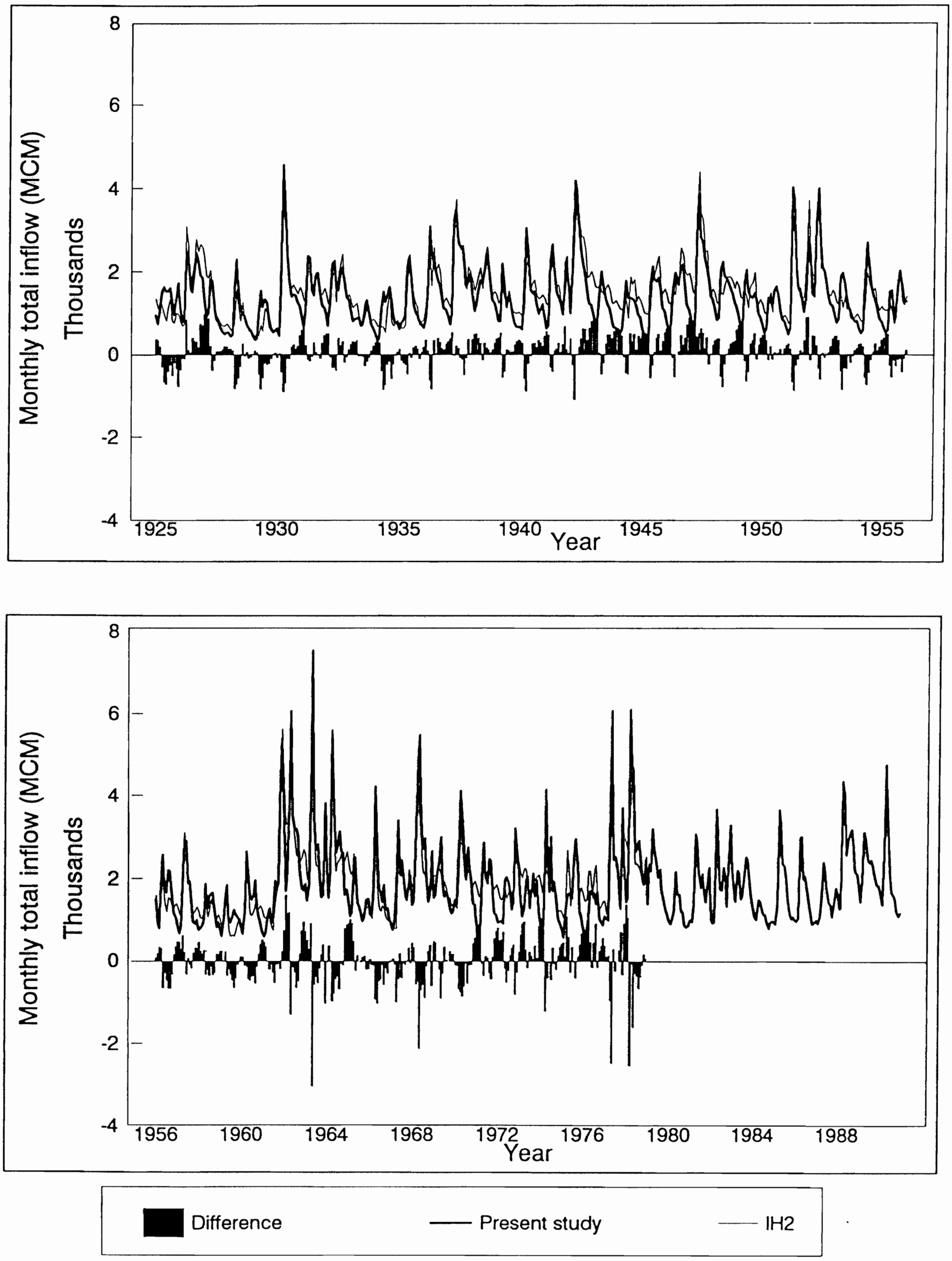


Figure 5.15

Summary of HYRROM parameters

Catchment	Nzoia	Yala	Sondu	Awach Kaboun	Kagera
Area (km^2)	11900	2650	3230	610	56000
SS	1.63	1.20	1.70	2.61	0.53
RC	0.56	0.25	0.35	0.86	0.46
RDEL	0.0	0.005	0.0	0.2	2.86
RX	1.0	1.0	1.02	1.0	1.08
RK	0.02	0.04	0.05	0.05	0.02
FC	0.58	0.75	0.41	0.80	0.76
GSU	190	500	230	901	1204
GSP	2.96	1.54	1.56	1.70	1.0
GDEL	0.0	0.03	0.01	0.01	12.9

PARAMETER	NAME
SS	Size of the vegetation interception and surface detention store (in millimetres)
RC	Surface runoff partitioning factor
RDEL	Routing store delay (in days)
RX	Routing store index
RK	Routing store factor
FC	Penman open water evaporation factor
GDEL	Groundwater store delay (in days)
GSP	Groundwater store index
GSU	Groundwater store factor

Table 5.5

Revised water balance 1925-90

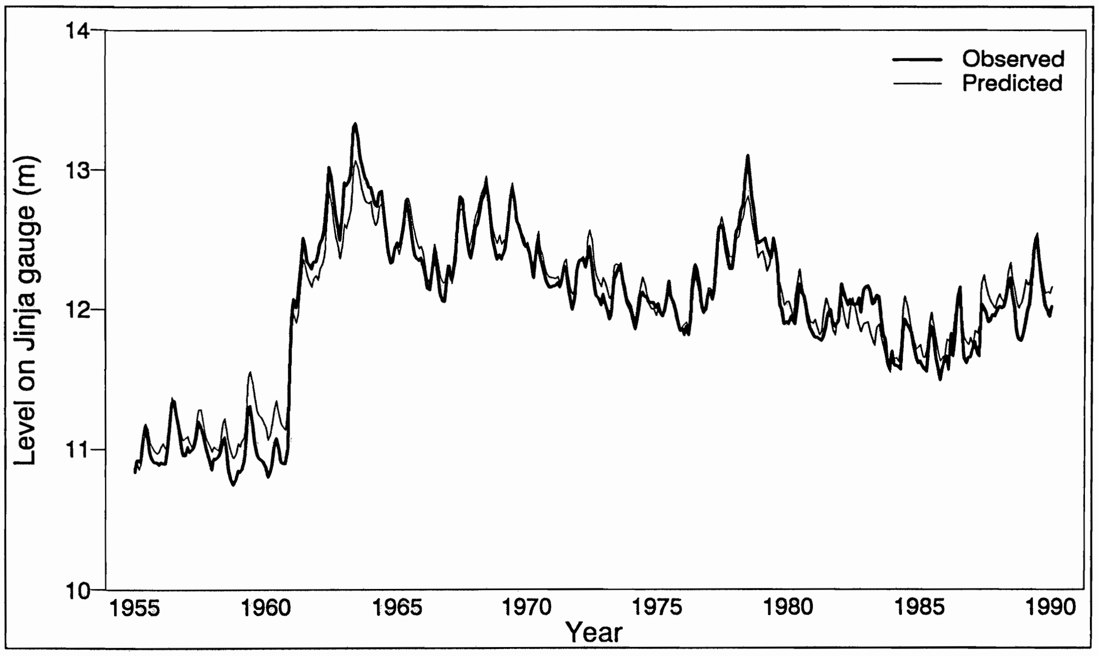
The revised inflow record and the net rainfall model allow a new, updated estimate to be made for the monthly net basin supply series and the lake water balance in the period 1925-90. Figure 5.16 shows the estimated levels using this new series for the periods 1956-90 and 1925-90. The revised model seems to give excellent predictions of levels in the periods 1925-42 and 1962-90, but overestimates levels in the period 1943-61 by some 0.2-0.5 m. Levels at the end of each simulation are surprisingly close to the observed levels considering that, unlike in the IH2 study, there was no constraint on the overall water balance. Overall, the accuracy of the estimated levels is comparable with that given by the IH2 model (Figures 5.1 and 5.2), although the timing of the main errors has shifted. The revised water balance for selected periods is summarised in Table 5.6.

Figure 5.17 shows a more stringent comparison in terms of the cumulative error in the predicted net basin supply. Also shown is the error series for the IH2 Rain A series combined with the IH2 rainfall runoff model. For the IH2 series, some minor differences will be noted between this plot and Figure 5.4 since the observed net basin supply here is based on the best estimate of the observed flows derived in Section 3.3 (Record D) rather than on the Agreed Curve. Also, the tributary inflows in the period 1979-90 have been re-calculated using the full IH2 rainfall runoff model.

These comparisons show that the cumulative errors in the two series are similar but occur in different periods. As suggested by the lake level predictions, the main accumulation of errors for the new series occurs between 1943 and 1961, with very small errors outside this period. The rate of accumulation of error in this period is very similar to that of the IH2 model and is of the order 100 mm per year. This is roughly equivalent to a 5% error in estimates of the lake rainfall. The 1925-34 errors discussed earlier seem to have been almost eliminated in the revised model.

These encouraging results suggest that the revised model developed here gives very similar results to the original IH2 lake rainfall model. Either of these models could therefore be used in assessing the likely impacts of land use change on lake levels. Also, the revised tributary inflow series should prove useful in helping to calibrate process-based models of the impacts of land use change on runoff into the lake. The remaining uncertainties in the water balance almost certainly arise from minor errors in the estimates of the net rainfall. As discussed earlier, these errors probably arise from a combination of deficiencies in the data and actual shifts from year to year in the distribution of rainfall and evaporation around the lake. In particular, the net rainfall component was calibrated for a period (1969-78) after the apparent shift in October-November rainfalls which occurred after 1961-64, so cannot be expected to perform as well for earlier periods.

Comparison of observed and predicted levels
using the revised water balance model (a) 1956-90 (b) 1925-90



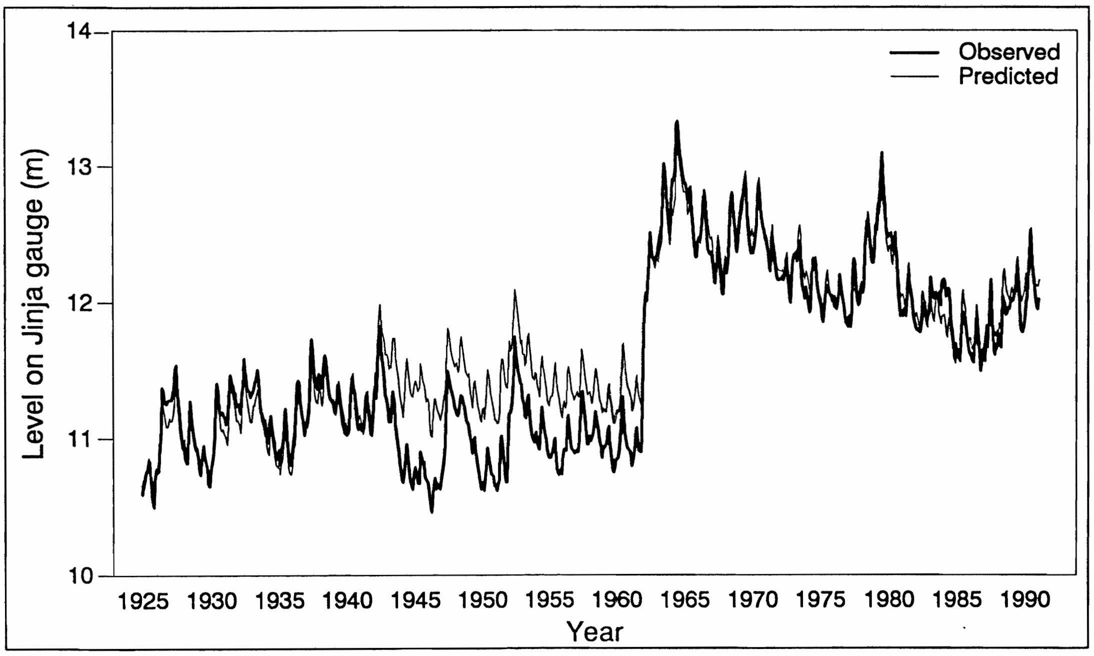


Figure 5.16

Cumulative errors in the predicted net basin supply series calculated using the revised water balance model (1925-90)

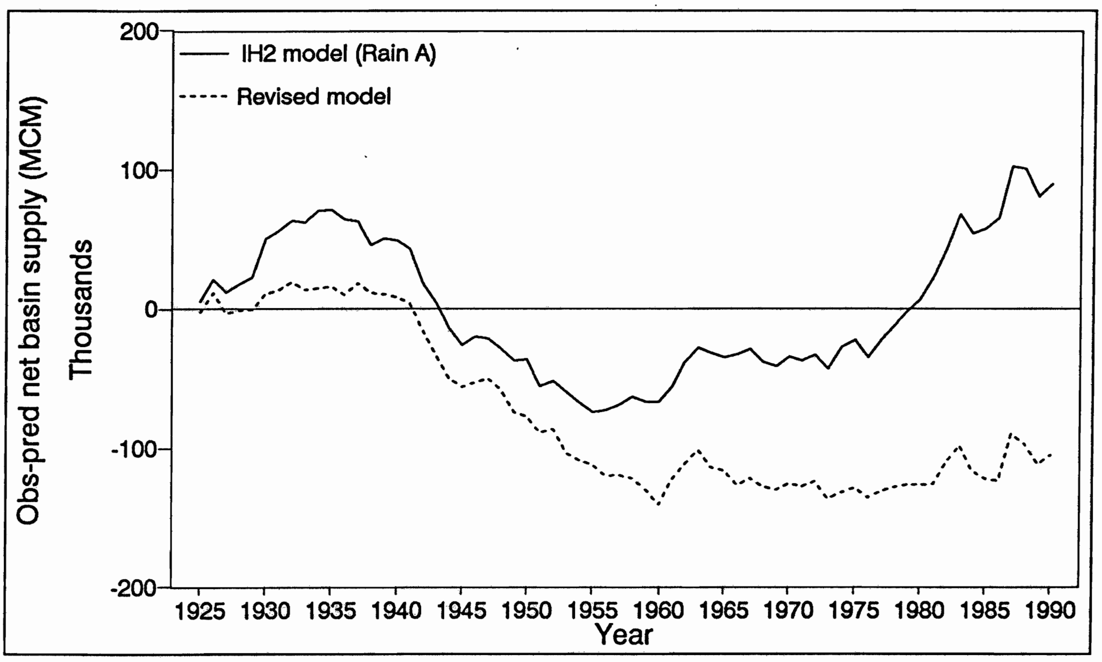


Figure 5.17

Revised water balance for selected periods 1925 - 92
(IH2 values in brackets)

Period	Net rainfall (mm)	Inflow (mm)	Outflow (mm)	Net basin supply (mm) Predicted	Error
1925-55	120 (66)	250 (275)	350	370 (341)	55
1956-78	260 (235)	340 (342)	550	600 (577)	10
1925-78	180 (138)	290 (304)	440	470 (442)	35
1925-60	120	250	360	370	60
1965-90	210	340	570	550	-5
1925-90	180	300	450	480	25

Table 5.6

6. Impacts of land use change

Previous studies on Lake Victoria have generally sought to explain the fluctuations in lake levels this century in terms of variations in climate or the influence of Owen Falls dam. Little work has been done on assessing the possible impacts of land use change on inflows and hence on lake levels.

Over this century, there has been a rapid growth in the population of the countries surrounding the lake with increasing urbanisation and many associated changes in agricultural practices. It seems likely that these changes must have had some effect on the tributary inflows to the lake and hence on lake water levels. This section presents a preliminary assessment of the magnitude of these changes and their likely impact on the water balance of the lake.

The discussion begins with a description of the existing land use in the lake catchment and the changes which have been experienced this century and over longer time scales. In the time available, it has only been possible to perform a brief review of the literature on this subject; however, this has been sufficient to obtain order of magnitude estimates of the likely impacts of land use changes on tributary inflows to the lake. The effects of these changes on the water balance of the lake are discussed in Section 6.2. Tentative estimates are also presented for possible future changes in land use and the impact these changes might have on future lake levels. These results are interpreted with the assistance of stochastic models of the likely variations in lake levels due to natural variations in climate alone.

6.1 ESTIMATES OF LAND USE CHANGE

Lake Victoria has a catchment area of about 194,000 km^2 representing about three times the surface area of the lake (67,000 km^2). The catchment includes northern Tanzania and western Kenya and most of Rwanda and Burundi. Only a small proportion of the inflow to the lake originates in Uganda. Land surface types range from highland forests in the headwaters of the Kagera and the Kenyan tributaries to open savannah and grasslands in the low lying regions immediately to the south and east of the lake. The highland forests in Rwanda and Burundi have been all but cleared and lowland forest remains only in the form of a few isolated patches along the Ugandan and Tanzanian shores. Extensive areas of swamp and marshlands are found in the lower parts of the Kagera catchment to the west of the lake.

There have been very few detailed surveys of land use in the lake catchment but one of the best seems to be that due to Morgan (1969) which is based on data collected up to the late 1960s. Figure 6.1 shows a map based on the results of this study. The most intensively cultivated regions lie around the lake margins, on the slopes of the Kenyan highlands and in Rwanda and Burundi. Much of the remaining low lying land is used for animal grazing, especially to the south east of the lake. The main cities lie in Rwanda and Burundi and around the lake shore.

The main increases in population and associated changes in land use have occurred this century. However, there is some evidence that extensive clearance of natural vegetation for cultivation began as long ago as 3,000 BP (Kendall, 1969). Over such long time scales, variations in climate have also had a dramatic effect on the vegetation cover in the catchment.

Map of estimated land use in the lake catchment in the 1960's

(Morgan, 1969)

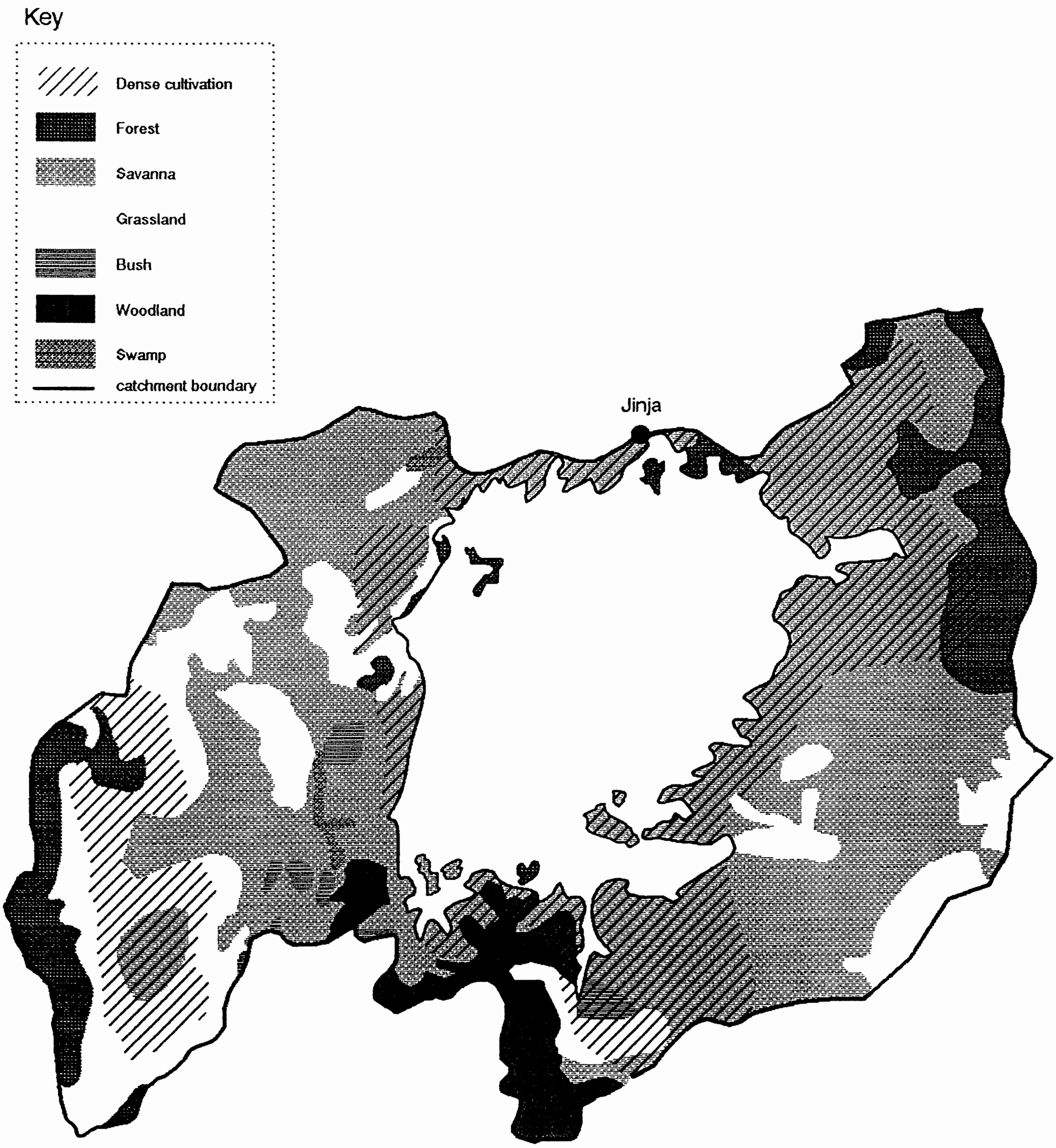


Figure 6.1

Pollen analyses and other techniques suggest that, within the Holocene period (the last 11,000 years), the region has been subject to several wetter 'pluvial' periods, an important one beginning around 9,500 BP (Butzer *et al.*, 1972). There have also been relatively dry periods such as the Younger Dryas from 11,000 to 10,000 years BP (Roberts, 1990). From 12,000 BP, the lake basin appears to have been extensively forested then, between 7,000 and 6,000 years BP, there was a shift from evergreen to semi-deciduous forest. In the past 3,000 years, the forests have became progressively less abundant (Kendall, 1969) with the result that, at present, only a small proportion of the lake catchment has extensive forest cover.

The main interest in this study is to estimate the rate at which land use is changing in the catchment. This then allows an assessment to be made of the impact of these changes up to the present and allows projections to be made of likely future changes. One of the main factors influencing the rate of change is the rate of population growth. Some approximate estimates of population growth in the period 1957-90 are shown in Table 6.1. The population figures for the lake catchment have been estimated from the total population of each country and the fractional area of the country within the lake catchment. In these calculations, the proportion of the population living in the lake catchment has been assumed to remain constant in time. These estimates indicate that the population of both the lake catchment and the region as a whole has doubled over the last 20 years and trebled since 1957. The most densely populated part of the catchment is the Kenyan portion; between 1970 and 1989, the population density increased from about 19 to 41 people km^{-2} in the country as a whole and is currently approximately 300 people km^{-2} in the lake catchment region (EIU, 1991). These results indicate that major changes in land use are likely to occur if the population continues growing at the present rate.

The types of changes which may occur include changes in agricultural practices, such as the clearance of natural vegetation for cultivation, land and swamp drainage, increased irrigation and land degradation due to overgrazing, and changes resulting from increasing urbanisation, such as an increase in the area of impermeable surfaces, vegetation clearance, improved land drainage and road construction. Changes in hydrological regime may also arise as a result of abstractions by industry and the construction of hydropower schemes and sewerage systems. The following sections present some preliminary assessments of the magnitude of each these types of change in the catchment of Lake Victoria.

Vegetation cover

Table 6.2 gives some recent estimates of the main changes in vegetation cover which are believed to have occurred in the lake catchment in the past 25 years (UNEP, 1991). The dominant trend in East Africa over this period has been an increase in the area of land under crops. The increased cultivated area amounts to some 40,000 km^2 in the region as a whole, and it is reasonable to assume that much of this change has been concentrated in the Lake Victoria catchment as this is the major high rainfall zone in East Africa.

In Kenya and Tanzania the increase in cultivated land has occurred mainly as a result of deforestation and most of the 2-6% change indicated in productive land has probably been concentrated in the forested upland regions in the lake catchment. In Kenya, montane forests are increasingly being cleared to make way for plantation crops, especially coffee and tea. This activity has been mainly concentrated on the Nandi Hills around Kericho while, further north in the Kitale area, maize is the dominant crop. This pattern of increasing cultivation of both subsistence and cash crops has been repeated throughout the Lake Victoria catchment (Morgan, 1969). In Tanzania coffee production is dominant in the Bukoba region whilst irrigated cotton production occurs in conjunction with cattle rearing to the south of the lake

Population change in the Lake Victoria catchment and East Africa 1957 - 1990

	% Total Popn in Lake Victoria Catchment	Population of Lake Victoria Catchment (and Total Population) in millions					
		1957		1970		1990	
Burundi	75	-	-	2.6	(3.5)	4.1	(5.5)
Kenya	39	2.8	(7.3)	4.4	(11.2)	9.8	(25.1)
Rwanda	75	-	-	2.8	(3.7)	5.4	(7.2)
Tanzania	25	2.3	(8.9)	3.4	(13.5)	6.9	(27.3)
Uganda	40	2.5	(6.2)	4.0	(9.8)	7.4	(18.4)
TOTAL	41	-	-	17.2	(41.7)	33.6	(83.5)

Sources: Morgan (1969) and UNEP (1991)

Table 6.1

Land use change in East Africa 1966/68 - 1986/88

Country	Total productive area (10^3 km^2)		Land use as % total productive area					
			Crops		Pasture		Forest	
	1966/68	1986/88	66/8	86/8	66/8	86/8	66/8	86/8
Burundi	17.2	23.4	61	57	36	40	3	3
Kenya	102.6	96.9	18	24	41	41	41	35
Rwanda	21.8	22.3	31	52	40	22	29	26
Tanzania	841.7	824.0	5	6	42	43	53	51
Uganda	162.0	174.0	30	39	30	28	40	33

Source: UNEP (1991)

Table 6.2

around Mwanza. The Ugandan shore of the lake is also an important area for the production of cash crops. Some recent deforestation has also occurred in Rwanda but the main change has been an increase in cropland at the expense of land for pasture. In Burundi there has been not only an increase in cultivated land but also pastures and even forests with a resulting large fall in the area of unproductive 'other' land. This may represent a deliberate reversal of the process of deforestation which has left the country almost entirely devoid of forests.

Catchment studies suggest that the clearance of natural vegetation and, in particular, forests will lead to increased flood flows and reduced baseflows. However, very few studies have been made in conditions appropriate to the Lake Victoria catchment. Research into the hydrological impacts of deforestation has been concentrated mainly on the highlands of Kenya and to a lesser extent Tanzania. For example, during the 1960s, a number of experimental catchments were established to investigate the effects of land use change including the change from tall rain forest to tea estates and forest clearance for subsistence cultivation (Pereira, 1962, Blackie *et al.*, 1979).

The impact of clearing tall rain forest and the subsequent cultivation of tea plantations was investigated by comparing two subcatchments in the Kericho region of Kenya. This area falls within the Lake Victoria catchment. The two main differences between the cleared and the forested plots (Dagg and Blackie, 1965) were that transpiration losses were lower in the cleared plot and stormflow runoff from the cleared slopes was greater than from the forested plot. The stormflow runoff was found to increase by between 120% and 300% according to rainfall intensity. However, after a period of about 5 years, the tea plants on the cleared land had become sufficiently established to minimise any difference in the hydrological behaviour of the two plots (Blackie, 1972). The main conclusion was that the change in land use from forest to tea is of hydrological significance only during the period that the land is relatively bare (Blackie, 1979).

The impact of forest clearance for subsistence cultivation was investigated at a similar experimental site in the Mbeya region of southern Tanzania (Edwards, 1979a). The research team again expected to find a reduction in dry season flows and an increase in peak flows but the data suggested that the change from forest to cultivated land had little impact on the hydrology of the site. This result was attributed to the high permeability of the local soil which allowed most of the incident rainwater to enter the ground as storage, even on the cleared slope. This surprising conclusion illustrates the importance of taking local factors into account (in this case soil type) when considering the impact of land use change on a region wide scale.

Other experimental work in the region has investigated the influence of land use on sediment production (Ongweny, 1979; Dunne, 1979). Studies on Mount Kenya and the Abedares found that sediment yield increases progressively from undisturbed forest to cultivated and grazing land due to increased overland flows. The clearing of forests to make way for roads is a particularly important factor in the increase in overland flow and sediment yield (Ongweny, 1979). Some limited experimental studies have also been made of the impact of grazing on an area of semi-arid rangeland in Atumatak, Uganda (Edwards, 1979b). Two enclosures were used, one of which was allowed to recover from overgrazing by the removal of all livestock while the other remained grazed. The ungrazed enclosure underwent rapid re-vegetation, which led to a reduction in peak flows during flash floods. Total runoff was also reduced as rainwater was able to percolate deeper into the soil. This suggests that, as livestock rearing is intensified or moves onto marginal land, the hydrology of these areas is likely to change to a regime of greater runoff and more rapid and larger flood peaks. However, the most heavily grazed areas of the lake catchment are not classed as being in serious danger of desertification (UNEP, 1992) although there is some evidence of overgrazing to the southeast of the lake. These areas also have the lowest annual rainfall within the catchment, so the hydrological importance of overgrazing is likely to be limited mainly to increased peak flows during flash flooding.

Of all the changes in vegetation cover which have occurred in the lake catchment, it seems likely that the greatest hydrological impact arises from the clearing of the forests in Kenya to make way for cultivation. As both a gradual process over the last 3,000 years and a more rapid one as tea and coffee plantations have been established this change is likely to have increased the runoff to Lake Victoria. Of particular importance is the fact that the regions which have been subjected to the most recent deforestation lie in the zones of greatest rainfall which is where most of the runoff to the lake originates. For example, Vowinckel and Orvig (1979) estimate that as much as 60% of total annual runoff in East African catchments comes from deforested slopes. In conjunction with the increase in runoff, deforestation may also have led to the establishment of a more responsive hydrological regime in the catchment. Storm flow peaks are likely to be greater and lag times reduced.

From the results presented by Dagg and Blackie (1965), it seems reasonable to assume that, in the Kenyan highlands, complete clearance of forests can result in roughly a 2-3 fold increase in runoff in the period when the soil remains bare. After a few years, the effect becomes negligible due to the rapid growth of crops or natural vegetation in the cleared areas. Figure 6.1 suggests that, in the 1960s, about 25% of the Kenyan catchments were forested and Table 6.2 indicates that there has been a reduction of about 1/7 (=15%) since then in this cover, or about 0.5% per year. An approximate estimate of the resulting change in runoff can be obtained by assuming that this change has occurred gradually over this period, that the effect of each clearance becomes negligible after 5 years and that runoff is increased by the worst case of 3 times while the land is bare.

Approximate calculations then suggest that this would have caused a sustained increase of about 5% in runoff at worst. Since the Kenyan catchments contribute about 35% of the total inflow to Lake Victoria, the total effect on inflows to the lake would be a sustained increase of about 2%. The effect on lake levels is therefore likely to be small although, locally, other impacts, such as loss of habitat and increased erosion, are likely to be severe. A similar change might be expected from the forested areas in Rwanda and Burundi since the forests occupy a similar proportion of the catchment and the river Kagera contributes a similar proportion of the total lake inflow.

Irrigation and land drainage

Table 6.3 gives some recent estimates of the increase in irrigated land in East Africa over the last 25 years. With the information available, it is not possible to estimate the percentage of this irrigated land lying within the lake catchment. However, even if all the irrigated land were in the lake basin, the total area currently under irrigation would represent only about 1% of the total catchment area. The main changes have occurred on the lower uplands in Kenya where intensive cultivation of sugar and cotton has increased and often requires irrigation, usually on a small scale. Irrigation is also used in zones of rice production such as in the swamps around the mouth of the Yala River (Morgan, 1969).

A preliminary assessment of future irrigation requirements in the lake catchment was performed as part of the Hydromet Survey project (WMO, 1982). In this study, water requirements were estimated on the basis of information supplied independently by each of

Area of irrigated land, East Africa 1966/68 - 1986/88

Country	Area Irrigated (10^3 ha)		% of Arable land	
	1966/68	1986/88	1966/68	1986/88
Burundi	18	69	2	5
Kenya	20	46	1	2
Rwanda	4	4	1	-
Tanzania	32	147	1	3
Uganda	4	9	-	-
TOTAL	78	275	-	-

Source: UNEP (1991)

Table 6.3

the countries in the lake catchment. Estimated annual requirements were expected to reach about 10, 210, 80 and 250 MCM for Burundi, Kenya, Rwanda and Tanzania respectively by the year 1980 and 100, 900, 330, 2280 MCM by the year 2000. Assuming that these very tentative estimates are correct, and that these changes all apply to the lake catchment, the proportion of lake inflows used for irrigation will have risen to about 15% by the year 2000 from a proportion of about 2% in 1980 and, by interpolation, about 10% at present, assuming the worst case of irrigation losses of 100%. In practice, a proportion of these flows is likely to return to the lake via increased baseflows and improved drainage.

Land drainage often occurs in conjunction with irrigation schemes but the hydrological impacts are difficult to determine. One immediate effect is to cause a fall in the local water table and hence baseflows. Also, annual runoff may be expected to increase as a result of drainage and clearance, with less evaporation from standing bodies of water and a reduction in transpiration from swamp vegetation. Flows in the dry season may, however, decrease as the water stored in the system from the wet season is reduced. The construction of drainage ditches aids in the more rapid and efficient transport of rainfall to the stream channel network. The clearance of swamps may be expected to have a similar effect, reducing the storage time in a river system. These land use practices are therefore likely to lead to a changed hydrological regime in which peak flows are both more instantaneous and higher. No figures are available for the area of land which has been drained in the lake catchment; however, this area is likely to be much less than the area under irrigation and the net hydrological impact is likely to be small when compared to the impact of the irrigated areas.

Major engineering works

There is normally a close link between the need for water engineering schemes and the urban population. Table 6.4 summarises the increase in the urban population in East Africa between 1970 and 1988. The proportion of the population living in urban areas has more than doubled in each country other than Uganda. In Tanzania the increase has been in the order of 450% in only 18 years. The rate of urban growth has apparently stabilised at around 7% across the region. Similar rates of increase presumably also apply to the towns in the Lake Victoria catchment. The population of Kisumu, for example, increased from 153,000 to 185,000 between 1979 and 1989 (EIU, 1991). Other cities which may have benefited from rural to urban migration include Kitale and Mwanza. In addition to the rapid growth of urban areas there has been an associated expansion of the national and regional road networks, leading to an acceleration of the destruction of natural habitats. This expansion has taken the form of both an increase in the number of roads and the proportion which are paved. Between 1978 and 1984-85 the total length of road in Tanzania increased from 45,000 km to 81,800 km whilst in Uganda the proportion of roads that were paved rose from 9% to 22% (UNEP, 1991).

Increased urbanisation often causes major hydrological changes related to the removal of vegetation and the construction of buildings, roads and other surfaces from impermeable materials. Typical effects are a reduction in evapotranspiration, an increase in runoff and a fall in groundwater levels. Runoff is dominated by overland flow off the impermeable surfaces to gutters and drainage channels so that annual total and storm flows may be expected to increase. The fall in the water table can result in lower dry season flows, however, as the baseflow component is reduced. These changes may also be accompanied by changes arising from the construction of sewerage systems for the removal of waste water and storm water runoff. The impact of a sewerage network is to increase the speed at which water and waste may be discharged from an urban area to an outlet into, say, a nearby river channel. This factor, along with the fact that there is an increased amount of storm water

Urbanisation in East Africa 1970 - 1988

Country	Urban Population (%)		Annual Growth Rate (%)	
	1970	1988	1970	1988
Burundi	2	7	1.6	7.7
Kenya	10	23	8.4	7.3
Rwanda	3	7	7.7	7.4
Tanzania	7	32	12.0	7.9
Uganda	8	10	4.1	6.1

Source: UNEP (1991)

Table 6.4

population increases continue at the present rate, this rate of change may increase in the next century. These changes may also be accompanied by a marked change in the seasonal distribution of inflows to the lake.

These estimates, although very crude, do at least give an idea of the likely magnitude of the changes in inflows and provide a starting point for a more detailed assessment. It is now of interest to estimate the impact of these changes on lake levels by means of the water balance models developed earlier in this study.

6.2 EFFECTS ON THE LAKE WATER BALANCE

Impact to date

Considering first the impact in recent years, the sensitivity studies described in Section 4 suggest that a 10% decrease in inflows would have only a small effect on lake levels. Figure 4.13 suggests that, since about 1979, the net basin supply has been oscillating about a mean of about 0.48 m, corresponding to a lake equilibrium level of about 11.9 m, and Table 5.6 suggests that the mean lake inflow has been about 0.34 m in terms of equivalent depth over the lake. If land use changes have caused a 10% drop in inflows, then the natural net basin supply in the absence of the land use changes should have been about 0.51 m, corresponding to a lake equilibrium level of about 12.0 m. The difference in levels is only about 0.1 m, which is within the normal month to month variations in lake levels due to seasonal variations in rainfall (see Figure 3.2). This result suggests that the impact of land use change to date has been negligible. In particular, the high levels of recent years cannot be attributed to changes in land use.

Viewed in terms of flows, this change in inflows would imply that outflows, and hence flows in the Victoria Nile, are some 60 m^3s^{-1}, or about 6%, lower than they would have been if the land use changes had not occurred. For comparison, the sensitivity studies in Section 4.2 indicated that a similar result could arise from a shift in mean rainfall of only 10-15% the fractional change in runoff, corresponding to a sustained change of only about 1% in the lake rainfall. These results suggest that any changes in lake levels due to land use change may be very difficult to disentangle from the natural variations in levels due to long term shifts in rainfall. Nevertheless, the changes are real and should be considered in planning any developments in the lake basin which are likely to have a significant effect on the total inflow into the lake. The likely cumulative effect of smaller developments should also be considered. Seasonal changes in the inflow pattern may also have some additional effect but a detailed assessment must await the development of process-based rainfall runoff models for the lake catchment which explicitly account for the impacts of land use change on runoff.

Methods for assessing future impacts

To assess the impact of future land use changes on lake levels, it is necessary to consider first the changes which may arise from natural variations in climate alone. Several possible approaches could be used. The most obvious is to attempt to extrapolate the observed lake level or outflow records into the future or to develop stochastic models based on these records. However, an inspection of these two records suggests that any attempt to predict future levels based on these records alone will be doomed to failure due to the sudden jump in levels and outflows between 1961 and 1964. This jump either has to be removed before performing the simulations and then replaced afterwards, or a large and unrealistic linear trend component has to be accepted in the results. If the jump is removed, the question then arises of the appropriate timing, duration and magnitude of the jump which should be reinserted after the simulations have been completed. Some discussion of these problems and the results obtained using this approach is given by Kite (1982) and Salas (1982).

A more productive approach is to attempt to model the future behaviour of the net basin supply series. The simplest approach is to identify some portion of this record as being 'typical' of the sequence and to assign a subjective probability to the chance that this portion will re-occur in the future. The portion selected can then be replayed through a lake water balance model to estimate future lake levels. This is essentially the approach taken by Acres (1990) in their recent assessment of the future hydropower potential of Owen Falls dam (see Appendix A).

A more sophisticated approach is to develop stochastic models for the net basin supply. Each of the simulated sequences can then be run through a water balance model and, if sufficient realisations are performed, objective estimates can be made of the probability of future lake levels. This is the approach used in the two previous Institute of Hydrology studies (1984, 1985). Several options are available for modelling the net basin supply series. The simplest is to take the observed sequence and either to build up new sequences by random sampling, or to develop a model for generating new sequences based on the statistics of the observed sequence. The second of these approaches was used in the IH2 study. A more convincing approach, also used in the IH2 study, is to attempt to model the observed net basin supply series using rainfall data alone and a rainfall-runoff model. This then yields results which are independent of the accuracy of the observed lake level and outflow records, and is also perhaps the only plausible method for assessing the impact of land use or climate changes on the lake water balance. In the IH2 study, a multivariate model was developed which modelled the joint statistics of the 8 lakeshore rainfall stations used to estimate lake rainfall and the 5 catchment rainfall series used as input to the conceptual rainfall runoff model. Some allowance was also made for the observed serial correlation between monthly rainfall values.

The IH2 model was used mainly to estimate the likelihood of the Owen Falls dam being overtopped and the effects of possible alternative regulation plans for Lake Victoria. Some thought was given to using this model in the present studies but this was not thought to be necessary since such a complex model is normally only required for engineering design studies. It is also worth noting that the model was based on the statistics of the observed rainfall series, so provided these have not changed significantly since the 1925-78 period used in the IH2 study, the results of the simulations should still apply. Some comparisons with these results are made in the following section and several suggestions for future studies of this type are made in Section 7. Encouragingly, a visual comparison of the most recent rainfall data with the pre-1978 data (e.g. Figure 4.8, 5.11) suggests that there has not recently been any significant change in either the long term mean or the natural variability of this series.

After reviewing all available methods for estimating future lake levels, the method chosen in this study was an intermediate approach which should be sufficient to estimate the sensitivity of lake levels to land use change without necessarily providing statistically rigorous probabilities for the estimated levels. In fact, as will be shown, the results of the simulations agree surprising well with the results of the more sophisticated IH2 studies. The method uses the annual water balance model developed in Section 4.1 together with a large number of realisations of the net basin supply series based on the predicted net basin supply calculated using the linear inflow model. Each series is generated by sampling random years from the full 92 year lakeshore rainfall series and merging these years to form a new sequence.

This approach is valid provided that there is no significant serial correlation between consecutive years. This seems to be confirmed by Figure 6.2, which shows the dependence of the autocorrelation coefficient for this series on lag time (N) where the coefficient is defined as the lag N covariance divided by the variance of the series. Also shown are lines representing departures of two standard deviations from the mean. These lines give a scale against which to judge the degree of autocorrelation. It can be seen that there is no statistically significant relationship between adjacent years and that the autocorrelation varies randomly about zero as the lag time increases. For this preliminary assessment of the impact of land use change, it therefore seems reasonable to use unconstrained random sampling to build each new realisation of the net basin supply. It should be noted, however, that the autocorrelation coefficient is only one measure of the time dependence in a series and that a more detailed analysis might reveal additional features in the series. This point is discussed further in Section 7.

Future levels in the absence of further land use change

Figure 6.3 shows an example of the results obtained from the annual water balance model for 1000 realisations assuming the runoff coefficient k remains at 0.16 throughout the simulation. The simulations were performed for a period of 50 years for a start level of 12.0 m, which is typical of the lake level in recent years. It was assumed throughout that releases from Owen Falls dam continue to be set according to the current Agreed Curve. The plot shows the levels which will be exceeded 10%, 50% and 90% of the time for each year in the simulation. Also shown are the maximum and minimum levels reached in any one year.

The results suggest that, after an adjustment period of 5-10 years, levels will tend to an equilibrium level consistent with the assumed exceedance probability. The equilibrium 10%, 50% and 90% levels reached are about 12.14 m, 11.62 m and 11.13 m and the maximum and minimum equilibrium levels are 13.10 m and 10.38 m. For 1000 realisations, the maximum and minimum levels equate to non exceedance probabilities of 99.9% and 0.1% respectively. In any one year, the maximum level reached was 13.45 m and the minimum level reached was 10.08 m. It should be remembered that these are annual levels, so the instantaneous maximum and minimum levels in any one year would be more extreme than this. For comparison, in the period 1896 to 1991, the maximum and minimum observed annual mean lake levels were 10.45 m and 13.04 m. This suggests that the stochastic model must have successfully generated rainfall sequences in which several of the wettest and driest years from the observed sequence occurred in rapid succession.

Table 6.5 compares the results of this simulation with the equilibrium results from the IH2 multivariate model. Very similar response curves were also generated by this model. The IH2 estimates were presented in the form of the highest and lowest expected levels within a year and these values have been averaged for comparison with the present model. The agreement is reasonably good, especially considering that the models used different datasets and different stochastic generation techniques. The predicted median (50%) levels agree to within about 0.1 m and even the extreme levels are at worst 0.3 m apart. The main difference is that the absolute maximum and minimum levels reached are about 0.6-0.7 m more extreme. Part of this difference is of course due to including a representation of the seasonal variations in rainfall, and hence levels, in the IH2 model. A repeat of the present simulations using the polynomial inflow model (Section 4.1) indicated similar median levels but differences of up to 0.4-0.8 m in the maximum/minimum levels in any one year.

Before describing the effect of changes in inflow on these results, it is helpful to consider the predicted median equilibrium levels a little further. If sufficient realisations are performed, Autocorrelation coefficient for the annual lake rainfall series 1900 - 91

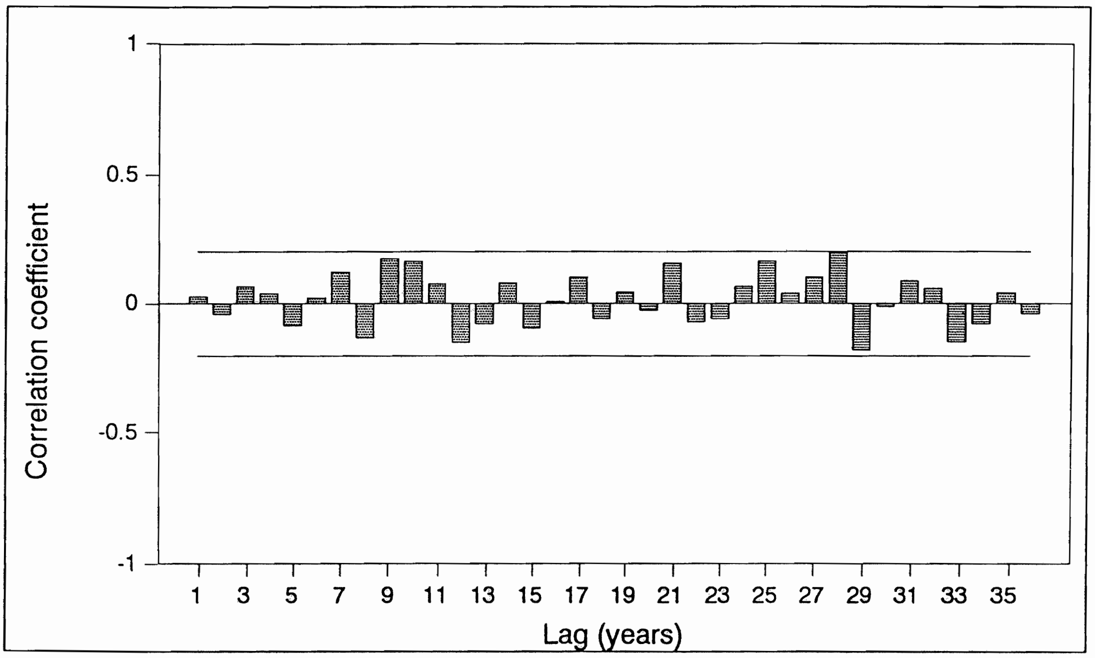


Figure 6.2

Predicted lake level non - exceedance probabilities for a start level of 12.0m assuming no further land use change

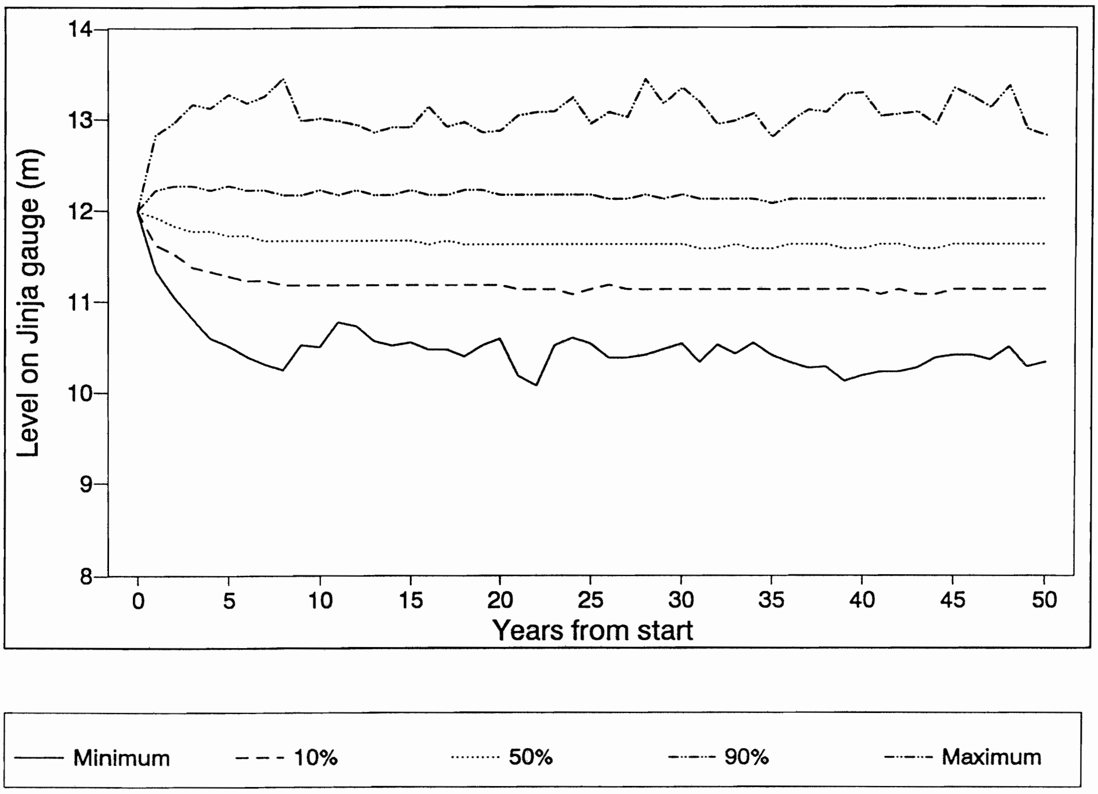


Figure 6.3

Comparison of stochastic modelling results from the IH2 and present studies

Non exceedance	Annual Model		IH2 Model			Difference
probability %	Equil	Max/min	Highest	Lowest	Mean	
0.1	10.48	10.28	10.30	9.86	10.08	-0.30
1	10.72	10.58	10.61	10.22	10.42	-0.30
10	11.13	11.08	11.09	10.68	10.89	-0.24
50	11.62	11.58	11.71	11.28	11.50	-0.12
90	12.14	12.28	12.35	11.90	12.13	-0.01
99	12.65	12.78	12.88	12.40	12.64	-0.01
99.9	13.10	13.48	13.28	12.80	13.04	-0.06
Max	13.10	13.45	13.79			
Min	10.38	10.08		9.41		

Table 6.5

the median equilibrium level should approach the level corresponding to a net basin supply equal to the mean of the net basin supply series used as input. For the period 1900-90, the mean net basin supply is about 0.40 m which would correspond to an equilibrium level of about 11.5 m using the current Agreed Curve, which is similar to the median equilibrium level generated by the stochastic model. Also, the time taken to reach this level was about 5-10 years as indicated by the response time estimates given in Section 4.2. Estimates of the median of future levels can therefore be made simply from inspection of the net basin supply series. For a completely random series, of course, the median level would also correspond to the most likely expected level.

From Figure 4.13, there have been several periods this century in which the net basin supply was more or less constant. Several possible future scenarios can be envisaged based on this record. Statistically, the most likely value for the net basin supply is the mean of the whole series which, in this case, is about 0.40 m, corresponding to an equilibrium level of about 11.5 m. If the 1961-64 rains are viewed as a freak event, with a return period much greater than 100 years, the net basin supply reduces to about 0.37 m corresponding to an equilibrium level of 11.4 m. If, as discussed in Sections 3.2 and 5.2, the 1961-64 period marked the start of a regional shift in rainfall patterns, then the net basin supply from that time is about 0.52 m, corresponding to an equilibrium level of about 12.0 m. Alternatively, the current net basin supply of about 0.48 m might continue for some years in which case the equilibrium level would tend towards 11.9 m.

For all these scenarios, the likely range only covers the levels 11.4 to 12.0 m, with corresponding outflows of about 800 to 1100 m^3s^{-1}. The results presented in Section 4.2 indicate that the time taken to reach these levels from the current level of about 12.0 m would be about 10 years. The results presented in Table 6.5 should also apply to within an accuracy of about 0.3 m. However, it must again be emphasised that these results are only indicative and are not intended for input to engineering design studies. Also, the stochastic model takes no account of possible long term shifts in climate, such as that which appears to have occurred since 1961-64. For example, there is always the possibility of a shift to a completely new rainfall regime, or a return to the low rainfall conditions of the 1940s and 1950s. With current knowledge, it is not clear how such changes could be accounted for in estimating future lake levels.

Impacts of land use change on future lake levels

These baseline results can now be used to estimate the likely impacts of future land use changes on future lake levels. For the first simulation, the best estimates given earlier were assumed, namely a reduction in inflows of about 1% per year up to the year 2000 and beyond. The simulations have only been performed for a planning horizon of 30 years because of the tentative nature of these estimates. The resulting non exceedance curves (Figure 6.4) are similar to those obtained in the absence of any change (Figure 6.3) but are shifted downwards by about 0.3 m after 30 years. The implied effect of these changes is therefore to cause a 0.1 m reduction in levels after 10 years over the levels which would have been obtained if no further changes in land use had taken place. In interpreting these results, it is of course worth remembering the results from Section 4 which suggest that similar changes would result from a sustained reduction of about 3-5% in mean rainfall over the full 30 years.

Overall, these results suggest that changes in land use are unlikely to have a severe impact over the type of planning horizon used in engineering design studies. Nevertheless, the impact is sufficient to cause a noticeable change in outflows and further studies would be worthwhile

Predicted lake level exceedance probabilities for a start level of 12.0m assuming a 1%/year reduction in inflows

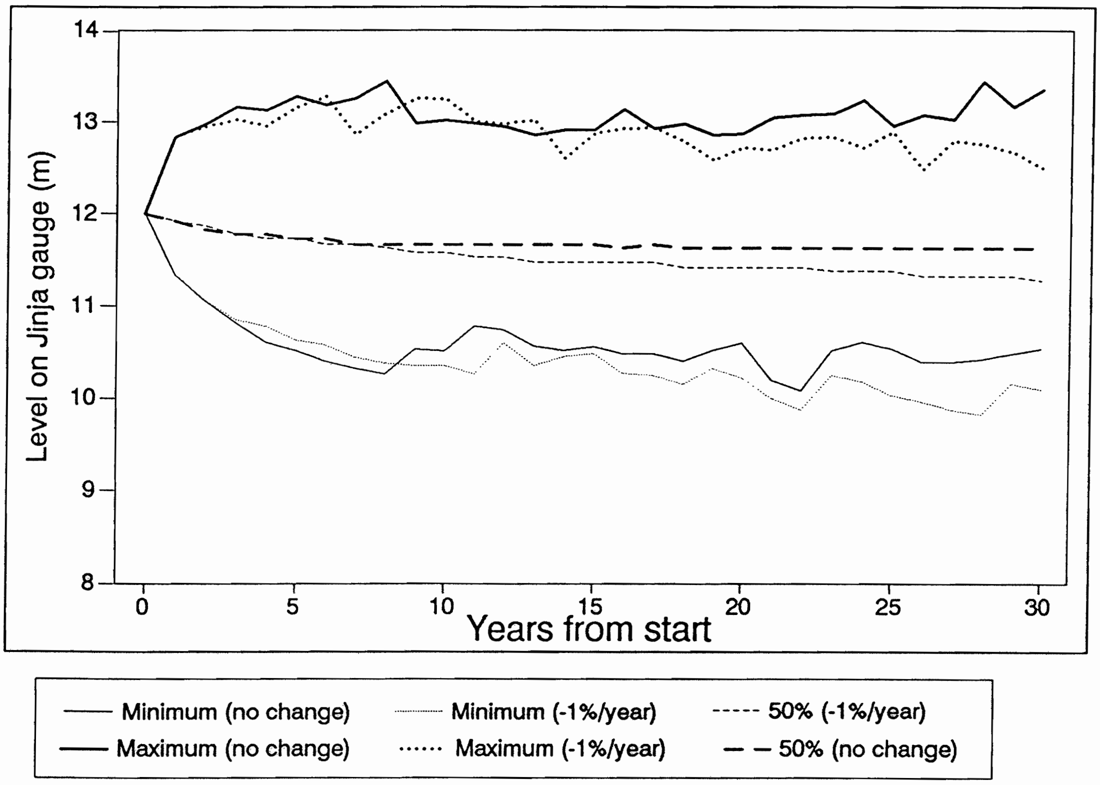


Figure 6.4

to obtain better estimates of past and planned land use changes in the lake catchment. Process-based models and more accurate land use assessments should also assist with obtaining better estimates of the impact of these changes on inflows to the lake. Some suggestions for future studies of this type are given in Section 7.

As a final comment, it is worth noting that all these results assume that releases from Owen Falls dam continue to be set according to the Agreed Curve. A discussion of alternative regulation plans falls outside the scope of this study. However, for general interest, some illustrative examples have been prepared showing the effects of operating the lake as a regulating reservoir, again assuming a start level of 12.0 m. Three simplistic plans have been assumed, in which outflows are set at 700 m^3s^{-1}, 900 m^3s^{-1} and 1100 m^3s^{-1} throughout the simulation. To avoid the lake draining down, releases have been constrained to follow the Agreed Curve if levels drop below an arbitrary level, taken here to be 10.5 m, which is roughly the minimum annual mean value observed this century. Again, only 200 realisations have been used in each simulation. The median equilibrium levels for these simulations are shown in Figure 6.5. The long term sustainable flow at current levels would appear to be slightly less than 900 m^3s^{-1}. The 700 m^3s^{-1} case causes a rapid and sustained rise in levels while a flow of 1100 m^3s^{-1} causes levels to drop quickly down to the floor level specified. The 10% non exceedance lines are all close to the minimum level specified of 10.5 m, indicating that shortfalls in releases would have a return period of less than 1 in 10 years. In reality, of course, the operating policy would also allow outflows to be adjusted according to the levels reached. Some further discussion of more practical regulation plans is given by Kite (1984) and Okidi (1990).

Predicted 10% and 50% exceedance lines for three assumed regulation plans

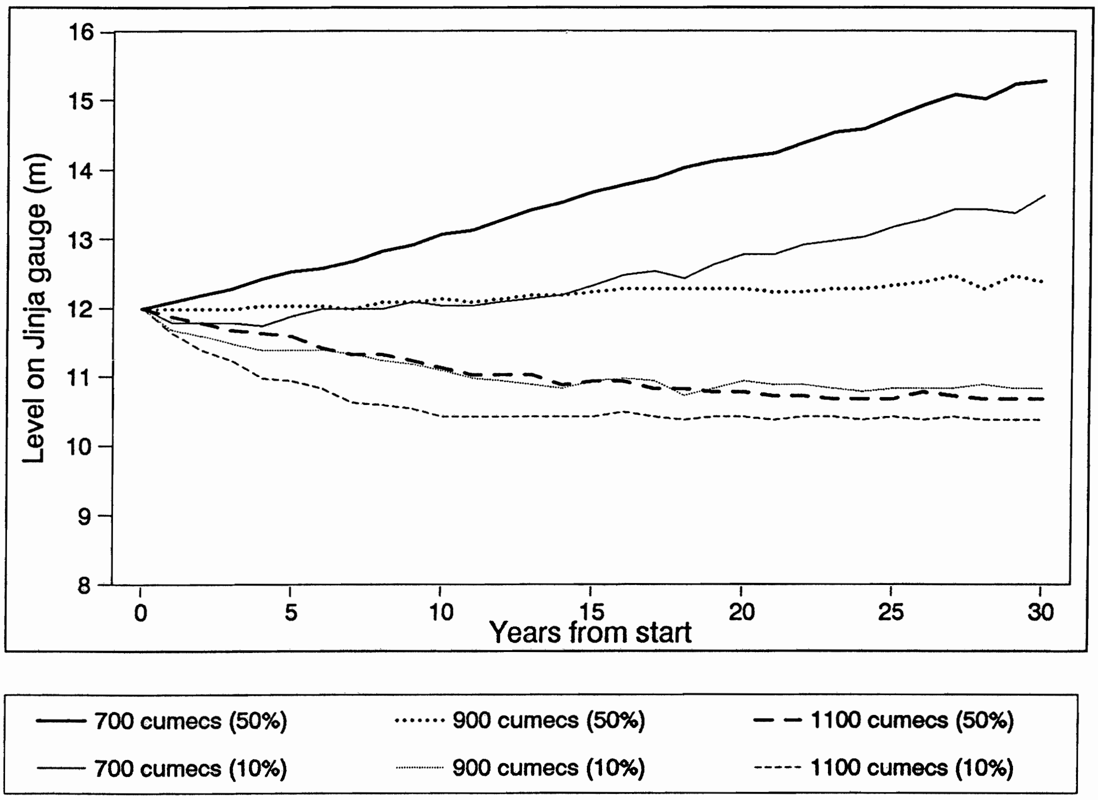


Figure 6.5

7. Discussion and conclusions

Several aspects of the hydrology of Lake Victoria have been investigated in this study using water balance models and regional comparisons of data. The main findings relate to the availability and quality of data for the lake and its catchment, the historical response of the lake this century and the sensitivity of the lake to changes in the main components in the water balance. A preliminary assessment has also been made of the likely impacts of past and future land use changes on lake levels.

The main results of this study are summarised below together with some suggestions for future work:

Regional analysis of data
A regional analysis of rainfall and lake level data for East Africa shows a consistent picture over the whole of this century. Until 1960, rainfall over the region varied by only a few percent about the long term mean. Rainfall was below average for several years in the 1940s and 1950s. Unusually heavy rains in late 1961 were recorded as far afield as northern Kenya and Malawi and caused abrupt rises in several lakes in the region including Lake Victoria. Inflows to Lake Victoria also increased in 1961 and continued to rise until 1964, partly as a result of unusually high inflows from the Kagera in 1963 and 1964. Since 1964, there appears to have been a persistent region-wide increase of about 5-10% in rainfall due mainly due to increased rainfall in the October-December rainy season. The level of Lake Victoria has continued to be high (but slowly declining) due to this increased rainfall. There is also some evidence that lake levels were as high in 1878, but dropped rapidly in the next few years as a result of a prolonged period of low rainfall.

The lake outflow record
The outflow from Lake Victoria approximately doubled as a result of the 1961-64 increase in lake levels and the Agreed Curve operating policy in use at the time. This change, and other smaller variations this century, is mirrored in all the Nile flow records down to the Sudd swamps and even downstream at Malakal. There is no evidence, as implied by the conclusions of the Acres (1990) study, that flows in the upper Nile dropped suddenly in 1954 with the onset of operations at Owen Falls dam.

As a further check on the outflow record and the Agreed Curve, detailed comparisons have been made of the recorded turbine/sluice releases at Owen Falls dam, contemporary discharge measurements at Namasagali and the outflows estimated from the Agreed Curve. This work suggests that, before 1961, discharges at Namasagali were possibly over-estimated by up to 5%, suggesting a small error in the Agreed Curve in the opposite direction to that suggested by Acres. There is some evidence of an increase in these errors at the higher river levels since 1961 but this issue is irrelevant to discussions on the accuracy of the current Agreed Curve since this was established on the basis of measurements in the 1940s and early 1950s, and hydraulic model tests during the 1960s.

These comparisons also show that, on a monthly basis, there have often been large differences between the actual releases at Owen Falls dam and the releases required by the Agreed Curve operating policy. However, on an annual basis, these differences have usually been eliminated by making compensatory releases at a later date. These comparisons also confirm that, during the main construction phase of the dam (1952-53), flows were substantially reduced to allow construction work to proceed. On the basis of these studies, revised outflow and observed net basin supply series have been estimated for use in evaluating the water balance models described below.

Water balance models

Two types of water balance models have been used in this study; a simple annual model and a more sophisticated monthly model. The annual model has proved useful in sensitivity studies of the lake response and the monthly model has helped to improve understanding of the historic lake water balance.

The monthly model is based on the model developed in the IH2 study, but uses an alternative method for estimating the contribution from the lake rainfall. Rather than attempting to model the lake rainfall and evaporation separately, the net contribution - the net rainfall - has been modelled directly. Also, rather than estimating the individual contributions from each rainfall station, the model has been calibrated in terms of the average of all stations. The calibration period chosen was 1969-78. As part of this work, a new inflow record was produced based as far as possible on observed data for 5 key tributary flows. Missing data were infilled using a conceptual rainfall runoff model. The total inflow was estimated from these 5 flow records using a seasonally varying scaling method developed during the IH2 study. The annual model uses a simpler approach in which the lake rainfall is estimated by applying a single multiplying factor to the average lake shore rainfall. Annual runoff is assumed to scale on the lake rainfall either linearly or using a runoff coefficient which varies with rainfall.

The water balance 1925-90

Simulations for the period 1925-90 using both the IH2 and revised monthly models and the annual model show that satisfactory predictions of levels are obtained throughout, including the recent period 1979-90 not covered by the IH2 study. The revised monthly model has similar performance to the IH2 model in the period 1925-55 and slightly improved performance in the period 1956-90. A more stringent comparison in terms of net basin supply showed that both models accumulate errors of up to 1-2 m in equivalent depth over the lake in some periods, equivalent to a sustained error of about 5% in the lake rainfall in these periods. The most likely cause of these errors is that the model calibrations do not -and, with current knowledge, cannot - allow for occasional shifts in the seasonal pattern or spatial distribution of rainfall and evaporation over the lake, such as that which occurred following the rains of 1961-64.

The overall water balance, in terms of equivalent depth over the lake, gives an annual net rainfall of about 0.18 m, an inflow of 0.30 m, an outflow of 0.45 m and a net basin supply of 0.48 m for the period 1925-90. Values for the periods 1925-60 and 1965-90 are 0.12 m, 0.25 m, 0.36 m, 0.37 m and 0.21 m, 0.34 m, 0.57 m and 0.55 m respectively, showing that the net basin supply has increased by about 0.18 m, or 180 mm between the two periods.An examination of the monthly net rainfall series suggests that this change has occurred mainly in the October-December rainy season. This is clearly the reason for the relatively high lake levels since the rains of 1961-64.

The water balance over the whole century

Using the annual water balance model it has been possible to relate the variations in the level of Lake Victoria over the whole century solely to variations in rainfall. These studies suggest that, up to 1925, the lake was in transition between a succession of equilibrium levels, causing levels to rise and fall in rapid succession. A stable period of low rainfall and net basin supply then persisted up to 1960. Following the rise of 1961-64, levels have been in a slow decline towards a new equilibrium level corresponding to the current net basin supply, which is about 0.1-0.2 m above pre-1961 values. The more sophisticated monthly water balance studies from 1925 also achieve a good match between predicted and observed lake levels using only lakeshore and catchment rainfall data as input. There is therefore no need to hypothesise any significant influence on levels from Owen Falls dam as some previous studies have done.

Sensitivity studies

Modelling studies confirm previous results which have shown the extreme sensitivity of the lake to fluctuations in the lake rainfall. An approximate model suggests that, for a given change in lake rainfall - z metres say - sustained over a period of several years, levels will change by about 5 z metres, outflows by about 2500 z (in m^3s^{-1}) and potential power output by about 375 z (in MW). So, for example, a sustained 100 mm increase in lake rainfall, equivalent to an increase of about 5%, would cause a rise of about 0.5 m in levels, 250 m^3s^{-1} in outflows and (potentially) a 37.5 MW increase in hydropower output.

These approximate results are largely confirmed by the monthly and annual water balance models. Changes in level seem to occur over a timescale of about 10 years at current levels, this being the time taken for levels to rise or fall to values which cannot be easily distinguished from the natural seasonal variations in lake level. This response time increases as lake levels drop, and is about 20 years at levels of 10 m.

These studies also suggest that levels are much less sensitive to changes in tributary inflows. A given small percentage change in inflow causes approximately 10-15% of the change in level for an equal percentage change in lake rainfall. So, for example, a sustained 5% increase in rainfall would have roughly the same effect as a sustained 35-50% increase in inflow. The implication of this result is that it may be difficult to disentangle the effects of land use changes on levels from the effect of long term changes in rainfall.

Future lake levels

To provide a baseline against which to judge the impacts of land use change, future lake levels were estimated using the annual water balance model and a simple stochastic rainfall generation model. These simulations suggest that the most likely outcome is that lake levels will decline over the next few years to an equilibrium level of about 11.5 m, corresponding to an outflow of about 850 m^3s^{-1}. Slightly different results are obtained if the rains of 1961-64 are viewed as a freak event or as marking a change in climate; however, the overall range is still only 11.4-12.0 m. Absolute maximum and minimum levels in any one year are about 10.1 m and 13.5 m. These results agree reasonably with the much more sophisticated stochastic simulations performed in the IH2 study.

Impacts of land use change

A preliminary review has assessed the likely impacts of several types of land use change on inflows into the lake. From the limited data available, the most likely causes of changed inflows are deforestation in the headwaters of the Kagera and Kenyan tributaries, increased irrigation, and new hydropower developments, particularly in the Kagera basin. The overall effect of these changes to date was assessed as a reduction in inflows of about 10%. The water balance simulations suggest that this has caused lake levels to be about 0.1-0.2 m lower than they would have been in the absence of any change. The high lake levels of recent years therefore cannot be attributed to the effects of land use change.

The rate of change appears to be accelerating and was estimated to be currently equivalent to a reduction in inflows of about 1% per year. The stochastic simulations of future levels were repeated assuming that reductions continue at this rate for the next 30 years. The overall drop in levels, compared to the case of no further change, was about 0.3 m. It must be emphasised, however, that these estimates are very approximate, and are only intended to provide a starting point for a more detailed assessment.

Suggestions for future work

This study has suggested several topics which could lead to a better understanding of the hydrology of Lake Victoria:

(a) Impacts of land use change

The work described in this report provides a useful starting point for more detailed studies of the impacts of land use change on Lake Victoria. The two priorities now are to improve the estimates of current and projected land use in the catchment and to develop process-based models which can give better estimates of the impact on inflows. Archived maps, aerial photos and satellite images could all be used to quantify changes in land use over this century. Future changes could be estimated by contacting planning authorities in the lake catchment and reviewing reports on proposed developments. The development of process based models is one of the main objectives of the wider "Water Balance of African Lakes" study referred to in the introduction to this report.

(b) Net rainfall studies

The main uncertainty in the lake water balance is the net contribution of rainfall and evaporation. The priority is to re-establish the lakeshore and lake island meteorological stations established during the Hydromet Survey project, together with the tributary gauging stations. This might be possible within the framework of the existing Hydromet Survey project.

Satellite images of cloud cover, possibly combined with atmospheric circulation models, could also improve understanding of the distribution of rainfall over the lake. Direct estimates of rainfall could also be obtained from remotely sensed estimates of cloud temperature (cold cloud duration), although some research work would be needed to apply this technique over a large water surface with its own climate like Lake Victoria. Similarly, it might be possible to estimate the distribution of evaporation from remotely sensed estimates of water temperature. Modern turbulence measurement techniques, such as those recently used by the Institute of Hydrology over a tropical lake in Indonesia, could also be used to directly measure lake evaporation in order to calibrate longer term Penman estimates of evaporation. The emphasis in all these studies should be on assessing the variations from year to year, rather than obtaining only instantaneous estimates. The emphasis should therefore be on long term monitoring of the behaviour of the lake.

(c) Water balance of the upper Nile

A better understanding of the hydrology of the upper Nile basin could improve confidence in the outflow record for Lake Victoria, as well as being an interesting and useful research topic. There is also the possibility of using downstream stations such as Mongalla as a basis for estimating the true lake outflow record before 1940.

A mixture of water balance models, channel routing models and rainfall runoff models could be used to model each of the main lakes and rivers in the system. A review of similar previous studies could guide the construction of an appropriate model for the whole basin. The model could be used to improve understanding of the historic variations in flows and levels in the Upper Nile and for feasibility studies of alternative hydropower developments and regulation plans for the Upper Nile. Particular issues might be the likely impacts on the levels of Lakes Victoria, Kyoga and Albert and the implications on the flow regime in the Sudd.

(d) Implications for hydropower development

To provide a basis for future planning, it would be interesting to use the projections of water levels and flows from this study and the IH2 study to assess the long term hydropower potential for the Owen Falls dam site. Comparisons with previous studies could also be made although - in the case of the Acres study - this would require considerable additional information on the methods and data series used. Alternative dam sites and regulation plans might also be investigated and, with input from an economist, least cost development options could be identified. The long standing question of the need for a spillway at Owen Falls dam could also be considered further. The projections of future levels could also be refined further using the methods outlined in the next section.

(e) Improved estimates of future lake levels

The approximate stochastic simulations described in this report were intended to provide a basis for estimating the changes in levels due to land use change, and not to provide rigorous statistical estimates of lake levels for use in engineering design studies. The IH2 studies remain the most comprehensive assessment of likely future lake levels. Future studies could include a more detailed review of the stochastic models used in the IH2 study and an update of the simulations to include the data from 1979 to the present. The review should include an assessment of the degree of serial correlation (persistence) in the net basin supply and lake rainfall series and the evidence for periodicity in these series. Also, the possible impacts of land use change and current climate change scenarios should be considered. Some thought would also need to be given as to the likelihood of future regional shifts in climate such as that which occurred following the rains of 1961-64. Possible future variations in lake water temperature should also be considered since this affects both the lake rainfall and evaporation.

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Appendix A Review of the hydrological aspects of the Acres report

The Acres International study (see Section 2.4) is to our knowledge the only major study of the hydrology of Lake Victoria in recent years. However, the conclusions reached about some aspects of the lake water balance were radically different to those reached in any previous work. As part of the present study, a careful assessment has been made of the findings of the Acres work as they relate to the water balance of Lake Victoria. The main conclusions from this assessment are summarised in this Appendix. The operational and planning aspects of the Acres study are not reviewed here except where they affect understanding of the water balance of the lake.

A.1 SUMMARY OF THE ACRES FINDINGS

The Acres studies aimed to identify a 'reference hydrology' for Lake Victoria and the upper Nile defined as a monthly series of the 'inflow available for outflow' (i.e. net basin supply) from which the firm energy potential of Owen Falls and sites downstream could be evaluated. Net basin supply or 'inflow available for outflow' was defined as the sum of observed or estimated lake outflows and observed changes in lake storage. Until 1954, outflows were estimated from the Agreed Curve and thereafter were based on recorded releases (where available) from the Owen Falls dam. Generally the hydrological studies were limited to a review of previous studies, primarily those by WMO (1974) and IH (1984 and 1985), but new work was presented on the derivation of the Agreed Curve.

Acres reached the conclusion that lake outflows before the construction of Owen Falls dam were unreliable and have in the past been seriously underestimated. They concluded that decisions on hydropower development should therefore be based on the higher net basin supply series from 1961 onwards, being representative of the true long term flow regime. Acres estimated that the likelihood of a return to outflows as low as those 'observed' in the period 1900-60 is very small, especially as they also contend that the current Agreed Curve is not a reasonable representation of the natural rating curve for Ripon Falls prior to construction of Owen Falls dam.

These conclusions were supported by the following evidence and interpretation of the results of previous studies:

1. Synthetic rating curves for the pre-construction geometry of Ripon Falls were presented to show that outflows derived by the Agreed Curve could be underestimated by between 19% and 65%. These synthetic ratings were based on hydraulic theory applied to the historical cross-section of the falls insofar as the original profile could be determined.

2. Acres interpretation of the Namasagali and Mbulamuti ratings and the history of Owen Falls construction (cofferdam) and Ripon Falls excavation suggest that the original rating curve for Ripon Falls seriously underestimated the actual lake outflows.

3. The apparent inhomogeneity of the basin supply series since 1900 (i.e. a step change in 1961) and the inability of the WMO (1982) study to draw up a satisfactory water balance description of the lake behaviour over the period 1950-79 were cited as evidence of serious errors in one of the components of the lake balance.

4. Comparative data from other lakes, other rivers and other gauging stations on the Nile were presented to show that the Lake Victoria net basin supply series should be homogeneous i.e. with no sudden changes in the long term mean. This issue was amplified by a discussion of several possible explanations for changes in the observed net basin supply and especially the substantial rise in lake level in the early 1960s, involving both natural and man-made events.

In their field work, Acres were able to confirm that the gauge at Jinja has not been altered over time and that the record of lake levels is consistent over the whole of this century.

A.2 IMPLICATIONS OF THE ACRES ANALYSIS

Although Acres do not present all the implications of their hypothesis that outflows in the early years have been substantially underestimated, it is possible to imply the following:

1. A description of the lake balance (such as that reported in the IH1 and IH2 studies) should not be possible using the historical data.

2. If the IH2 water balance is accepted as broadly correct, then rainfall in the early period must be increased significantly relative to the later period.

3. The lake has not drained down to pre-1961 levels because the Agreed Curve (based on the original Ripon Falls curve) does not allow sufficient outflow to give the expected lake level decline.

4. Observed flows at lower stations on the White Nile, particularly at Mongalla, must have been adjusted historically to give a series consistent with the lake outflow.

5. Substantial increases in outflow would be permissible if the Agreed Curve were to be revised to the 'true' natural curve.

6. Predictions of future lake response based on the use of stochastic rainfall models fitted to the full historical record cannot be valid because of the inhomogeneity of the rainfall or net basin supply series.

Gibb (1990) noted in addition that, if the Acres hypothesis were correct, there should have been a noticeable drop in lake levels and flows in the Upper Nile basin in 1954 when the incorrect Agreed Curve started to be used at the start of operations at Owen Falls dam.

A.3 COMMENTARY ON THE ACRES FINDINGS

A.3.1 General Issues

The Acres findings are very far reaching in their effects and merit careful consideration given the possible investments in hydropower development on the Nile in Uganda over the coming decades and the important contribution the lake outflows make to flows in the main Nile down to Cairo. Acceptance of the high flow regime since 1961 as the basis for planning could result in substantial overestimation of the potential generating capacity at Owen Falls and elsewhere if the Acres findings are not valid. The average flow recommended by Acres is nearly double the average that persisted according to the records over the first five decades of this century.

An accurate description of the hydrology of Lake Victoria and the upper Nile is not straightforward. Otherwise many expensive studies would not have been necessary to try to explain the changes in regime that have taken place, especially the sudden rise in lake levels in the early 1960s. There are uncertainties in all the data, particularly for the components on the inflow side of the lake water balance. For example, estimates of lake rainfall must be derived from the few gauges that have continuous records dating back to the mid-1920s. Flows in the main tributaries excepting the Kagera were not measured until the mid 1950s. Outflows are hindcast from the rating of Ripon Falls based on measurements of flow at the Namasagali station some 75 km downstream in the 1940s and 1950s. The measurements at Namasagali and later at Mbulamuti were made under difficult conditions at sites that are less than ideal. Evaporation is implied from meteorological data from only a few shore stations. Only the lake levels recorded at a number of stations since the late 1800s are generally accepted as accurate.

The excess of rainfall over evaporation is small. Consequently the net basin supply is very sensitive to small changes in rainfall. This effect is further magnified as tributary inflows increase in wet periods and decrease in dry periods, and the lake evaporation is likely to decrease in wet periods and increase in dry periods. It is therefore not surprising that the net basin supply series should have exhibited some unusual variations over the decades as rainfall varied both annually and in its seasonal and spatial distribution. All these considerations make it vital that projections into the future are based on as good a description as possible of the water balance of the lake over the full period for which records are available.

One further general point is that the immense storage in the lake means that lake levels and hence outflows respond slowly to changes in the rainfall regime. Thus the expected flows over short time scales, say up to 10-15 years, must be conditional on the starting level and outflow.

A.3.2 The Agreed Curve

In the Acres report, one of the main reasons cited for doubting the Agreed Curve is the instability of the river section at Namasagali due to shifting control, unsuitable cross-section and possible backwater effects from Lake Kyoga. Except to the extent that these considerations make direct flow measurements difficult, they are largely irrelevant. It is not the stage-discharge curve for Namasagali that is at issue. The flow measurements at Namasagali are taken as a surrogate for flows at Ripon Falls, and are related to lake levels measured on the Jinja gauge. Thus it is the stability of the historical rating of Ripon Falls (i.e. the Agreed Curve) that should be considered and nobody has suggested that this is an issue. There might be some difference between the rating before construction of Owen Falls dam and afterwards as implied by the results of the hydraulic modelling carried out by Acres and discussed below. But this does not invalidate the original Agreed Curve developed from flow measurements at Namasagali mainly in the 1940s and early 1950s. The checks made in Section 3.3 of this report show that there can be little doubt about the accuracy of the discharge measurements themselves, and that the errors in these measurements were most likely of the order 5% in the 1940s and early 1950s, and in the opposite direction to that which Acres suggest.

In their discussion of the Agreed Curve, Acres reproduce the graph of observed discharges against lake level originally compiled by the WMO (1982) study. This shows that the Agreed Curve passes through the mass of points relating to discharge measurements at Namasagali up to 1948, corresponding to lake levels up to about 12.0 m. The Agreed Curve also passes through the points relating to discharge measurements at the nearby station of Mbulamuti in the period 1970 to 1972 when lake levels were in the range 12.0 to 12.5 m. However many of the discharges relating to lake levels above 12.5 m in the period 1968-70 were higher than the curve would suggest.

Acres rightly point out that all observations after the construction of Owen Falls dam should lie on the Agreed Curve as, with minor exceptions, outflows have been controlled to follow the Agreed Curve (see Section 3.3). The 1969 and 1970 gaugings at Namasagali therefore indicate either that flows exceeded (and were allowed to exceed) the Agreed Curve in this period or that the measured discharges were all systematically too high. The first possibility could also suggest that the sluice and turbine ratings at Owen Falls are in error if the excess flows were believed to lie on the Agreed Curve; however, Acres own analysis suggests these ratings overestimate the actual flow by only about 2.4% and the analyses described in Section 3.3 suggest a difference of only about 5% between these ratings and flows measured at Namasagali in the 1950s. The second possibility could suggest (as Acres imply) that for some reason observations at both Namasagali and Mbulumati were in error in the same direction at this time. This could possibly be due to some modification of velocity profiles at the higher water levels after 1961. The analyses described in Section 3.3 suggest that the Namasagali measurements at this time might have been about 10% too high in this period, but that errors in the Mbulamuti measurements were much smaller.

A firm conclusion about this issue could only be reached by locating the daily release records at Owen Falls dam for the periods in which the gauging measurements were made (if these are still available) and then making direct comparisons on a day by day basis. In this context it is interesting that synthetic Ripon Falls rating curves developed by Acres using the HEC-2 hydraulic modelling software suggest that the rating should flatten off to a greater extent than the actual Agreed Curve at high lake levels, indicating that the Agreed Curve does not correctly represent the outflows which would have occurred from the undisturbed Ripon Falls. However, Acres also concluded from these studies that the Agreed Curve underestimated flows by between 19% and 65% at pre-1960 lake levels.

Gibb (1990) also attempted to derive synthetic rating curves for Ripon Falls using hydraulic theory applied to the natural (pre-1951) and present geometry of the falls. Gibb treated Ripon Falls as a compound broad-crested weir and obtained a rating curve that indicated flows about 9% lower than the Agreed Curve when the geometry of the falls was based on 1956 survey data. This rating curve showed reasonable agreement with the Agreed Curve if some deepening of the west channel was made in the model to compensate for the known obstructions by cofferdam material following construction of Owen Falls dam.

Cassidy (1991) reviewed these calculations along with simultaneous flow measurements at the dam and at Namasagali for 1955 and 1956 and reached the following interim conclusions:

1. The HEC-2 model used by Acres to determine the critical depth of flow over Ripon Falls together with the water surface profile upstream of the falls is inappropriate for

a complicated river section such as that at Ripon Falls. HEC-2, developed by the US Army Corps of Engineers, assumes one-dimensional gradually varied flow in a uniform cross-section.

2. The weir discharge coefficient used by Gibb is at the theoretical upper limit for a broad-crested weir. Thus the flows estimated for a given lake level are also an upper limit. It is therefore unlikely that underestimates of the order of 30% can be envisaged as Acres suggest.

3. Estimates of flows at the dam agree to within a few percent with the observed flows at Namasagali based on observations in 1955 and 1956.

In reaching his overall conclusion that the Agreed Curve was confirmed to within a few percent, Cassidy placed most weight on Item 3 above which indicates that gaugings at Namasagali at that time were broadly correct.

Without further survey and gauging, it is impossible to reach a final conclusion on this issue. However, if there are errors in the Agreed Curve - in the sense that it does not fully represent the natural rating of Ripon Falls before construction of Owen Falls dam - it seems much more likely that these errors are at the upper end rather than at the lower end as suggested by Acres (see also Section 3.3).

A.3.3 Comparison With Nile Flows At Downstream Stations

Acres compare the trends in outflows from Lake Victoria with flows at several long term gauging stations in West, Central and East Africa, all of which lie within the typical range of movement of the Intertropical Convergence Zone. The comparisons are made on a cumulative flow basis and the conclusion is reached that only the Lake Victoria outflow record and, possibly, the Kagera record, show significant unexplained changes in slope. This is taken as evidence of a possible error in the Lake Victoria outflow record. However, given the complexity of climatic influences over the vast region of the Nile basin and the equatorial belt, it would be irrationally optimistic to expect all hydrological series to show similar fluctuations over time. Anomalous behaviour is commonly observed in flows of the larger rivers in Africa. The anomalies usually cover different periods and by implication they have different, though possibly inter-related, causes.

Of more importance is a comparison with flows observed at stations lying between Lake Victoria and the Blue Nile, of which Mongalla is the principal station. Acres comment that the cumulative mass curve of flow at Mongalla closely resembles that of the Lake Victoria outflows (e.g. Figure 2.7). This is not surprising since by far the major proportion of the flow at Mongalla originates from the lake basin; however, Acres suggest that the Mongalla record has possibly been adjusted in the past to accord with that of the lake outflows. It is extremely unlikely, though, that adjustments on the scale required by the Acres hypothesis would have been made without considerable reported analysis of the cause of error in some of the many technical papers, books or conference proceedings concerning the hydrology of the Nile.

Both IH (1985) and Gibb (1990), quoting many past and contemporary sources, review the historical evidence for changes in the flow regime of the White Nile, the Bahr el Jebel and the variation of the area covered by the Sudd. Additional results are also presented in Section 3.3 of this report. While some of the Nile flow data may be in error by a small margin representing the difficulties of gauging, there is no doubt that the general increase in flows in recent decades is real and not the result of substantial errors introduced by the acceptance of an erroneous Agreed Curve. Also, as Gibb point out, there is no evidence of a sudden drop in flows in 1954 when the lake releases started to be determined by the supposedly incorrect Agreed Curve.

A.3.4 Variations in lake rainfall

Acres repeatedly comment that the slope of the cumulative mass curves for lake rainfall and net basin supply are constant apart from discontinuities in the early 1960s. From these studies they conclude that the net basin supply as a function of rainfall is greater in the later period, a result that must be due to errors in the measurement of outflow in the early period in the absence of any more plausible explanation.

That Acres should reach this view is difficult to understand. Figure A.1 shows the IH2 lake rainfall series which is similar to the series from the individual gauges and to the series derived by de Baulny and Baker (1970) and used by Acres. The de Baulny and Baker series gives mean annual rainfalls for the periods 1925-60 and 1965-78 of 1634 mm and 1734 mm respectively while the IH2 series based on equal weights applied to the standardised eight-gauge series gave 1671 mm and 1793 mm for the same periods, and 1758 mm for the period 1965 to 1989. Similar results are also obtained using the annual lake rainfall model and the monthly net rainfall model developed in this study. The additional 122 mm of rainfall in the period 1965-78 is sufficient to increase net basin supply by 8,100 MCM/year, or about 250 m^3s^{-1}, which alone explains about half of the observed increase in outflow. Much of the remaining difference is explained by the higher tributary inflows that followed from a regional increase in rainfall. The water balance studies described in Sections 4 and 5 of this report clearly show that a satisfactory water balance can be achieved for the whole century if proper account is taken of this increase in tributary inflows and the differences between rainfall over the lake and that measured at the lakeshore.

That rainfall has increased in the lake basin since 1961-64 is not in doubt. Farmer (1981) attributes this increase primarily to an increase in rainfall during the October and November wet season and this observation seems to be confirmed by the results reported in Section 5.2 of this report. Climatologists talk in terms of anomalies, hydrologists and statisticians in terms of homogeneity of records. Acres appear to take a narrow definition of homogeneity implying that the time series of rainfall should have a stationary mean (and presumably variance) over time-scales of a few decades or less. By increasing the lake outflows substantially in the period before 1960 it is possible to equalise the mean outflow with that observed after 1965. While this might give the impression of homogeneity, it cannot be used as an argument to justify the adjustment of the data, especially when there has been a real increase in rainfall. We believe that the descriptions and hypotheses should fit the data, not that the data should be adjusted to fit the hypotheses.

A.3.5 Implications on the water balance

It is unfortunate that Acres did not extend their analysis of a possible error in the pre-Owen Falls outflows to a review of the lake water balance. They relied heavily on the findings of the WMO study (Kite, 1981) that the full rise in lake levels in the early 1960s could not be reproduced by a water balance model and that this was possibly because portions of the available rainfall data were not consistent. They placed little emphasis on the two IH studies and other studies (cited in this report) which have shown that, by using more plausible

IH2 lake rainfall series extended to 1990

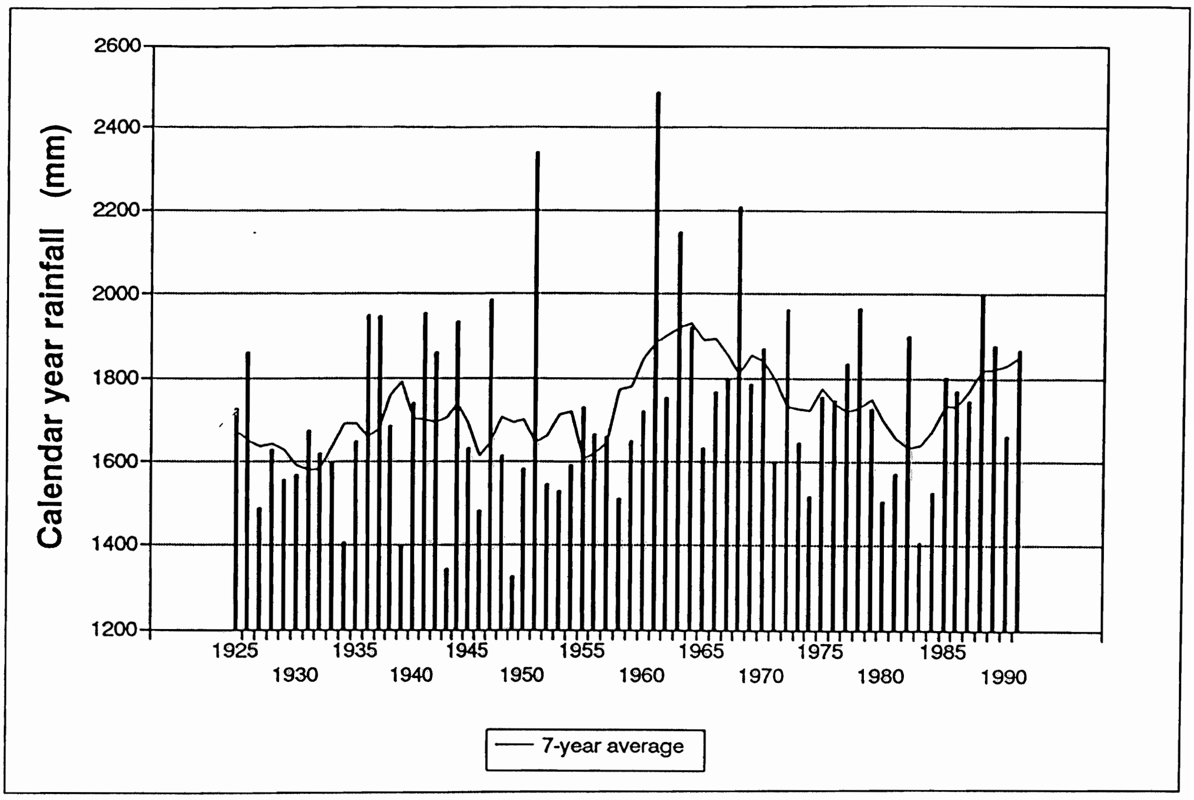


Figure A.1

Comparative curves of cumulative net basin supply

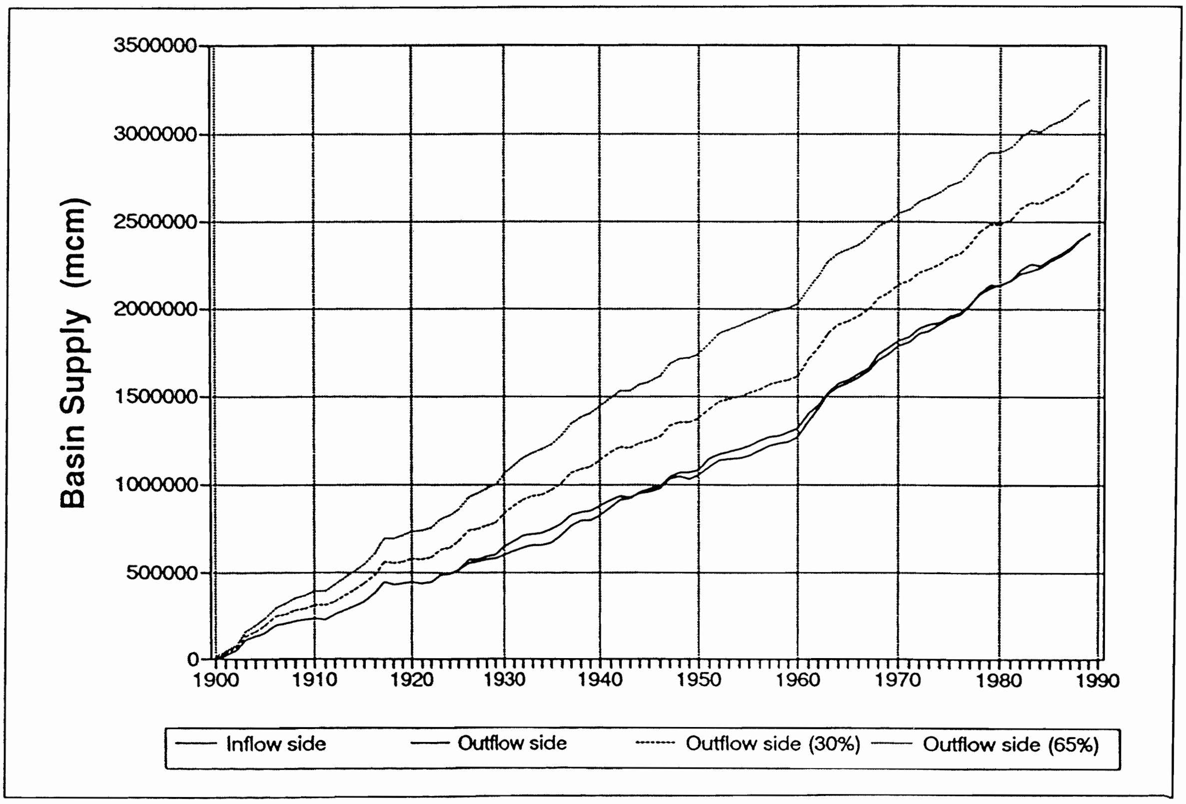


Figure A.2

modelling assumptions, the lake response can be explained by water balance principles alone. In fact Acres cite as evidence a supposed irregular pattern of rainfall adjustments that was needed by IH to achieve a satisfactory lake water balance. This belief derives from the IH1 study, but the later IH2 study placed great emphasis on developing a consistent way in which a revised lake rainfall series could be derived and there were no irregular adjustments of rainfall.

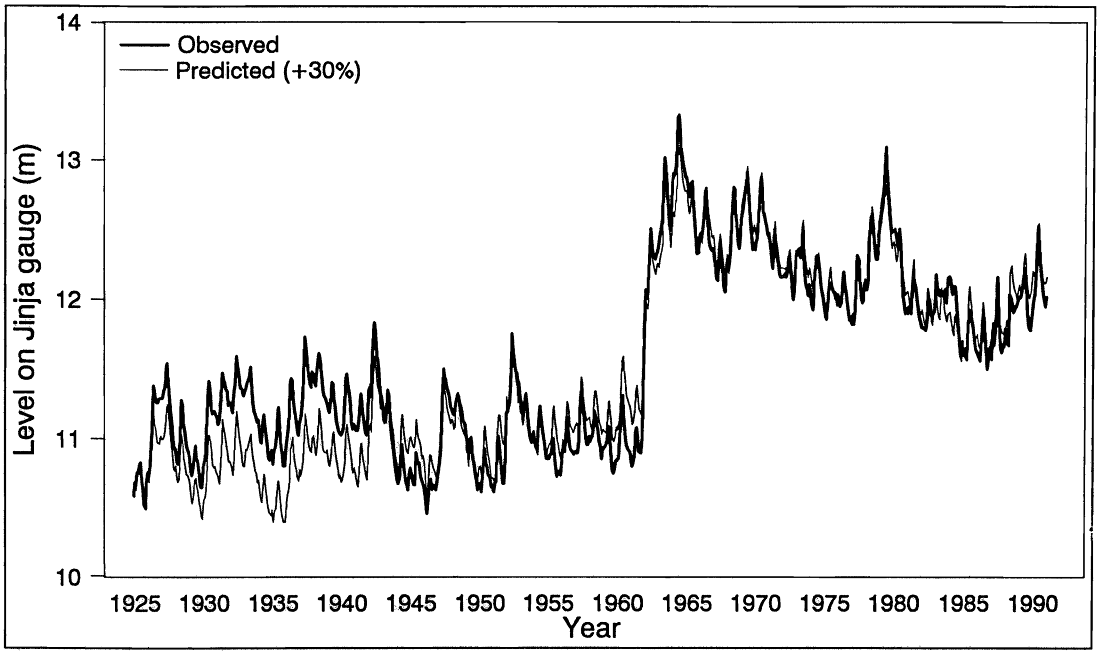
Instead of a lake water balance, Acres presentation relies on the visual comparison of cumulative flow and rainfall curves with arguably misleading results. Comparisons of the same data on a time series basis leads to very different conclusions (see Sections 2.4 and 3.3). It is self-evident that the net basin supply, derived from observed outflows and changes in lake level, has been higher since 1964 than it was before 1961. It is also evident that the net basin supply estimated from rainfall, evaporation and tributary inflows has also been higher (see Sections 4 and 5). Acres' statement that the slope of the lake rainfall mass curve remains constant over the period of record except for a step in the early 1960s is incorrect, even when it is based on the de Baulny and Baker rainfall series. Irrespective of the rainfall series used, lake rainfall in the period from 1965 is at least 100 mm higher per year than it was in the period 1925-60. This is equivalent to at least 7,000 MCM per year in the net basin supply, not allowing for the simultaneous increases in tributary inflows or any amplifying effect due to changes in evaporation.

Figure A.2 shows the impact of the Acres conclusions on the cumulative net basin supply series, and compares the inflow series derived from rainfall, evaporation and tributary inflows with the outflow series derived from outflows and changes in lake storage. Curves are shown for the observed data and for cases where the outflows before the construction of Owen Falls have been increased arbitrarily by 30% and 65% respectively. The curves based on the range of increase in outflows presented by Acres lie substantially above the curves for net basin supply based on rainfall and inflows. The implication of the Acres work is that if the lake outflows were substantially underestimated in the years up to the mid 1950s, the rainfall must have been significantly underestimated in the same period. There is little evidence of this, irrespective of the method used to derive lake rainfall from the eight rainfall series and from other rainfall series for the whole lake catchment and East Africa (see Section 3.2).

It is also interesting to repeat the monthly water balance simulations of Section 5.2 assuming that the Acres hypothesis is correct. Figure A.3 shows the predicted levels using the revised water balance model and assuming that outflows were underestimated by 30% or 65% in the period up to 1954. The effect on levels is roughly as expected, with a reduction in predicted levels of about 0.3 m for the 30% change and about 0.6 m for the 65% change in the period up to 1954. For the 30% change, the agreement between predicted and observed levels is slightly worse than for the case of no adjustment to the outflows (Figure 5.16) while, for the 65% change, the agreement is significantly worse.

A more stringent comparison is shown in Figure A.4 and Table A.1 for the case of a 30% increase in outflows. To facilitate comparison with Tables 5.1-5.3 and Figures 5.4 and 5.17 of this report, these results have been computed using the IH2 models for the lake rainfall and tributary inflows. To distinguish the resulting lake rainfall series from series Rain A and B developed in Section 5.1, the series based on the assumed increase in outflows has been called Rain C here. The main effect of the change in outflows is to increase the errors accumulated in the period 1925-34, while producing a slight improvement in the period 1935-54. The accuracy of the water balance would only be improved if the period 1925-34 were to be omitted from the analysis. These results are therefore somewhat inconclusive due to the

Water levels predicted using the revised monthly water balance model and assuming ouflows are increased by 30% and 65% up to 1954



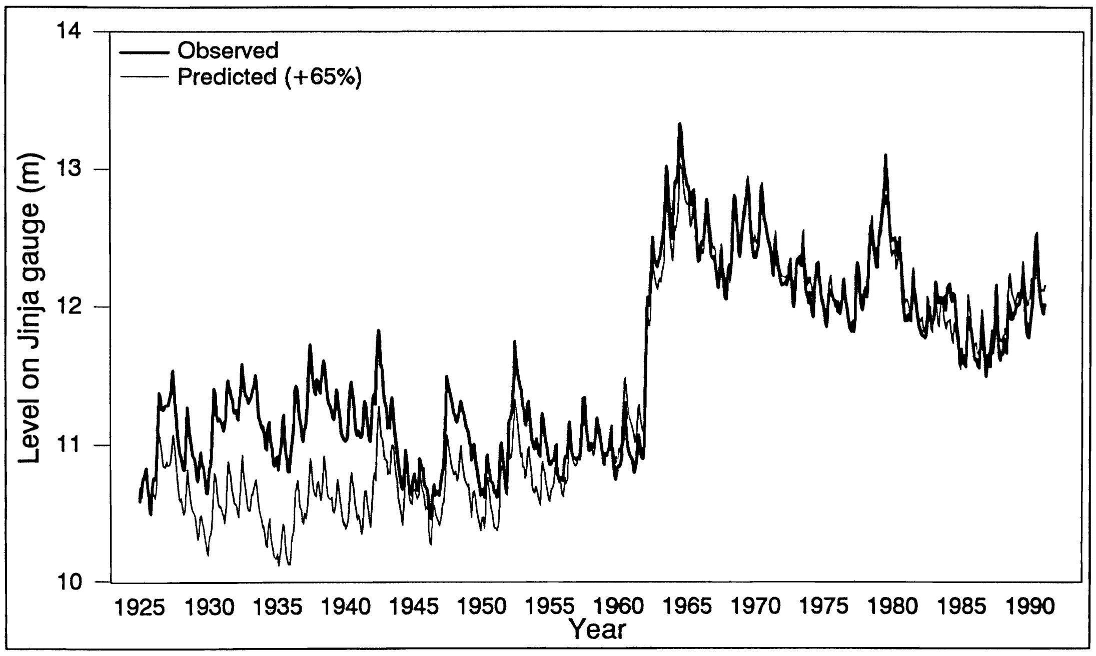


Figure A.3

Cumulative errors in net basin supply
assuming outflows are increased by 30% and 65%

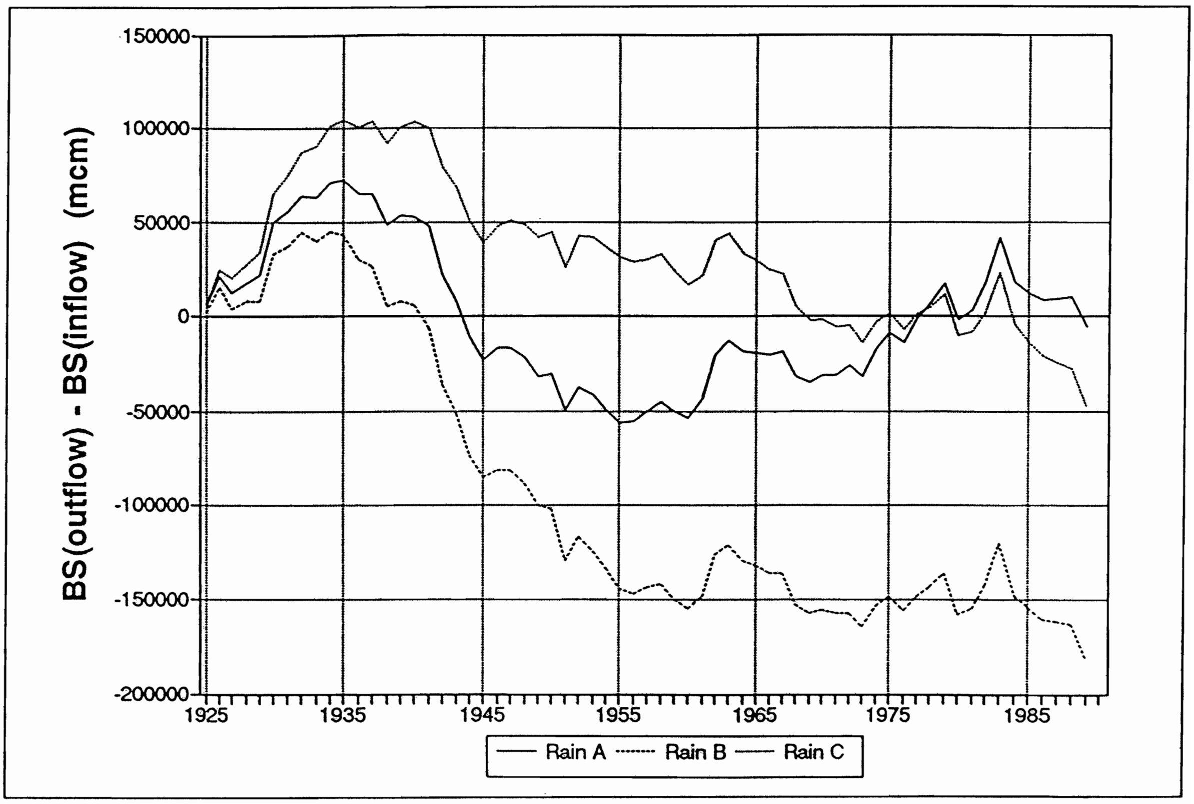


Figure A.4

Lake balance errors expressed in terms of the component variables

Period		1900-24 mean	1925-34 mean	1935-55 mean	1956-60 mean	1961-64 mean	1965-78 mean	1979-89 mean	1965-89 mean	1956-78 mean
Basin supply (inflow)	mcm		19941	30608	23020	68260	40170	35616	38166	41327
Basin supply (outflow)	mcm	25688	30087	27286	20011	72517	38114	30859	34922	40162
Error in water balance BS(inflow) - BS(outflow)	mcm		-10146	3322	3009	-4257	2056	4757	3244	1165
Error as percentage of:										
Outflow	%		38	-12	-11	22	-5	-12	-9	-3
Lake rainfall (Rain C)	%		-9	3	3	-3	2	4	3	1
Tributary inflow	%		-67	17	18	-14	9	20	14	5
Lake evaporation	%		10	-3	-3	4	-2	-4	-3	-1

Notes:
A positive percentage error indicates a possible overestimate of the relevant variable.
In this case outflows have been increased by 30% up to 1955.
Other variables are assumed to be accurate.

Table A.1

uncertainties inherent in the water balance; for example, in the period up to 1954, the change in levels caused by a 30% error in outflows is similar to that resulting from only a 5% error in the rainfall or evaporation components of the water balance. As noted in Section 5.1, a small error in rainfall is much more likely than a large (and previously unreported) error in outflows.

A.3.6 Operational analysis

A detailed assessment of the operational aspects of the Acres study falls outside the scope of the present study. However, some comments can be made based on the results of the IH2 stochastic modelling studies and the additional studies described in Section 6.2 of this report.

For their long term yield assessments, Acres selected the 1961 to 1989 outflows (or net basin supply) as representing the long term average flows available for power generation. While they state that this length of record is normally sufficient for planning purposes, it appears that the reference hydrology was extended to a 40 year period by adjusting the outflows in the 1949 to 1961 period to conform with the mean of the original 29 year reference period. This is a curious starting position for what were rather elaborate studies of alternative hydropower schemes that included the active operation of the lake as a reservoir. Given only the indisputable evidence of the variations in the rainfall regime, it is unjustifiable to select only the wetter period of the record as a basis for operational and planning studies. In any event the selection of a record as short as this is unrealistic when there are apparent long term changes in the inflows, and when the effect of the large lake storage can persist over a decade or more. If Acres had confidence in their adjustment procedure for the period from 1949 to 1961, it is unclear why they did not adjust the whole of the early record so as to use the whole of the available information in their reservoir trials.

Some account is taken of the earlier period of lower outflows and the operational analysis initially accorded a probability of 1% to the return to this low flow regime. This appears to be no more than the relative frequency accorded to the lowest flow in a 90 year record which would be valid if the flows could be considered to be independent. But there are dependencies in the data, particularly in the short term, that combine to produce some longer term dependencies in the net basin supply. In addition, the IH2 and present analyses show that predicted lake levels (and therefore outflows under the Agreed Curve operation), over a time horizon of the order of 10-15 years are dependent on the assumed starting lake level. This is the kind of timescale over which economic analyses are most sensitive.

Little of the statistical analysis is presented in the Acres report and it is therefore difficult to make direct comparisons with the projections developed in the IH2 and present study. However it is possible to assess the probability of exceedance of the outflow on which the firm energy would be based assuming that outflows continue to be determined by the Agreed Curve. Acres seem to define the Firm Energy flow as the monthly flow with a 1 in 10 year return period, which is effectively the 1 in 10 year lowest monthly flow in the sequence used. Acres do not present the sequence actually used in their reservoir trials and the detail of the flow adjustments made for the 1949 to 1960 data is not known. Because of the marked change in lake levels and outflows that took place at the end of 1961 the value of the critical monthly low flow depends strongly on the start month of the sequence and the adjustments made. Nevertheless from the results of the Acres study we can estimate that the Firm Energy flow as defined is in the range 550 to 650 m^3s^{-1}. The results of the IH2 study suggest a probability of non-exceedance on an annual basis of roughly 20% and 37% respectively for these monthly flows. These figures compare directly with the 10% risk assumed by Acres.

Taking a broader view, Acres are correct in assuming that high flow conditions will persist for some years simply because the lake is currently at a relatively high level. The exploratory stochastic studies described in Section 6.2 suggest that the most likely future outcome based on data for this century is a slow drop in levels over the next 10 years or so to reach a mean level of about 11.5 m, corresponding to an outflow of about 850 m^3s^{-1}. Since the Owen Falls dam was designed during a period when outflows were typically varying in the range 500-900 m^3s^{-1}, there is therefore some benefit in considering the economics of increasing the installed capacity at Owen Falls to take advantage of this increased mean outflow.

The Acres' assumption of a very low probability of flows returning sooner or later to a much lower level depends critically on their hypothesis that the Agreed Curve is wrong and that the pre-1954 flows were seriously underestimated. Indeed, the sensitivity studies and stochastic simulations described in Sections 4 and 6.2 of this report show that, viewed over timescales of a few years or more, lake levels can drop as rapidly as they rise and changes of the order 1-2 m within less than a decade have occurred several times this century and also following the peak of 1878. These studies also show that Acres view of a constant net basin supply in recent years is overly simplified and can give misleading views of the future lake response.

The results of the present study suggest that a more detailed stochastic assessment of future lake levels would have to consider several factors, including the serial correlation present in the lake rainfall series, the statistical relationships between lake rainfall and catchment rainfall, the possibilities of future distinct shifts in climate (as occurred in the early 1960s), the impact of changes in lake temperature and the possible future impacts of land use change and, in particular, irrigation and hydropower schemes in the lake catchment.

A.4 CONCLUSIONS

We believe that it is unreasonable to propose any hypothesis regarding errors in data or rejection of data or selection of a subset of the data as representative of the long term condition, unless the proposed change adds to our ability to describe the hydrology of the lake over the period for which data are available. The simpler the solution to the water balance, the more likely it is to be accepted, and estimates for the lake rainfall, tributary inflows and, indeed, outflows should be derived in a consistent way throughout the historical period.

We have demonstrated by annual and monthly water balances using carefully derived data sets that a realistic balance exists and that adjustment of the outflows in the early period would disrupt that balance, if the adjustments are on the scale suggested by Acres. There is no doubt that the lake rainfall and tributary inflows increased substantially in the period 1961-64, and that this increase was responsible for the relatively large rise in lake levels in those years. But it is also beyond doubt that the average annual lake rainfall has been higher in the subsequent period than it was in the period 1925-60. This largely explains the higher net basin supply in recent decades and hence the ability to sustain higher outflows without rapid drops in lake level.

There is little, if any, evidence that positively supports the hypothesis that outflows derived from lake levels using the Agreed Curve are seriously underestimated. We showed in Sections 5.1 and A.3.5 that the lake water balance model could not be used conclusively to refute this hypothesis, but that the balance of probability is against it. More direct evidence from other stations on the Nile, from reviews of climatological variations, and from the simple fact that rainfall in the lake region has increased sufficiently to cause the observed changes in outflows makes it difficult to sustain the Acres hypothesis.

Without better evidence, it is dangerous to assume that the net basin supply of recent decades is a reliable measure of the long term value; indeed at the simplest level, there are more years of low outflows than of the higher outflows in the record since it began in 1896. Also, anecdotal evidence (see Section 3.1) suggests that, although lake levels may have been as high in 1878 as 1964, the lake level dropped rapidly in the next few years. It is evident that the assumption that the later high outflow period of record represents the long term average outflow for energy generation seriously overestimates the firm energy flow unless the Acres hypothesis is correct. For example, the rough comparisons made in Section A.3.6 suggest that outflows could be less than the firm energy flow approximately four times as often as expected by Acres if their hypothesis is not correct.

Appendix B Data Summary

List of tables

LAKE VICTORIA: End of month lake levels (metres on Jinja gauge)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1896	11.57	11.50	11.51	11.53	11.53	11.50	11.41	11.40	11.28	11.22	11.40	11.36	11.43
1897	11.41	11.41	11.42	11.54	11.55	11.58	11.56	-	-	-	-	-	-
1898	-	-	-	-	-	-	-	11.48	11.47	11.45	11.48	11.44	-
1899	11.40	11.40	11.36	11.38	11.52	11.41	11.31	11.07	10.94	10.86	10.83	10.90	11.20
1900	10.89	10.90	10.91	10.90	10.92	10.95	10.97	10.91	10.74	10.59	10.59	10.72	10.83
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	10.91
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	10.67
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	11.22
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	11.35
1905	11.32	11.26	11.37	11.46	11.51	11.38	11.23	11.15	11.07	11.04	11.13	11.30	11.27
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	11.66
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	11.40
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	11.13
1909	11.10	11.03	11.02	11.18	11.32	11.17	11.03	10.89	10.93	10.89	10.83	10.93	11.03
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	10.90
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	10.69
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	10.64
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	10.81
1914	10.67	10.68	10.79	10.82	10.91	10.90	10.84	10.80	10.79	10.75	10.86	10.86	10.81
1915	10.80	10.82	10.94	11.04	11.17	11.14	11.02	10.89	10.88	10.84	10.89	11.00	10.95
1916	11.00	11.08	11.11	11.35	11.51	11.45	11.31	11.27	11.33	11.30	11.30	11.34	11.28
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	11.74
1918	11.79	11.70	11.67	11.77	11.78	11.67	11.46	11.32	11.29	11.22	11.21	11.18	11.51
1919	11.09	11.12	11.15	11.32	11.34	11.21	11.15	11.04	11.03	10.96	10.94	10.91	11.11
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	10.90
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	10.70
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	10.45
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	10.61
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	10.74
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	10.69
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	11.15
1927	11.29	11.34	11.37	11.51	11.54	11.41	11.27	11.17	11.09	11.00	10.93	10.93	11.24
1928	10.87	10.82	10.82	11.02	11.28	11.24	11.12	11.04	10.98	10.93	10.91	10.89	10.99
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	10.78
1930	10.83	10.85	11.03	11.29	11.41	11.36	11.23	11.18	11.20	11.20	11.18	11.15	11.16
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	11.30
1932	11.21	11.19	11.33	11.39	11.59	11.52	11.46	11.36	11.37	11.35	11.31	11.33	11.37
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	11.30
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	10.99
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	10.96
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	11.19
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	11.44
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	11.42
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	11.19
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	11.21
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	11.16
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	11.49
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	11.08
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	10.76
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	10.75
1946	10.59	10.51	10.46	10.60	10.67	10.71	10.63	10.67	10.64	10.63	10.66	10.74	10.63
1947	10.80	10.84	10.95	11.27	11.50	11.45	11.43	11.37	11.34	11.30	11.23	11.22	11.23
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	11.21
1949	11.03	10.98	10.89	10.98	11.01	10.92	10.86	10.82	10.74	10.70	10.63	10.68	10.85
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	10.74
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	10.83
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	11.43
1953	11.25	11.16	11.15	11.29	11.32	11.25	11.11	11.04	11.01	10.97	10.99	11.05	11.13
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	11.01
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	10.84
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	10.97
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	11.09
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	11.03
1959	10.93	10.95	10.97	11.05	11.09	11.00	10.85	10.78	10.75	10.78	10.85	10.84	10.90
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	11.02
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	11.07
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	12.29
1963	12.47	12.51	12.58	12.80	13.02	12.95	12.82	12.70	12.59	12.50	12.70	12.91	12.71
1964	12.89	12.92	12.98	13.30	13.33	13.24	13.09	13.04	12.96	12.93	12.88	12.88	13.04
1965	12.82	12.75	12.74	12.84	12.85	12.67	12.55	12.42	12.33	12.34	12.43	12.48	12.60
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	12.50
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	12.21
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	12.52
1969	12.62	12.69	12.78	12.82	12.92	12.80	12.66	12.51	12.43	12.36	12.39	12.36	12.61
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	12.59
1971	12.40	12.31	12.23	12.42	12.51	12.38	12.30	12.25	12.20	12.16	12.16	12.17	12.29
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	12.19
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	12.23
1974	11.99	11.93	11.96	12.21	12.24	12.30	12.32	12.19	12.12	12.05	12.01	11.97	12.11
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	12.03
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	11.98
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	12.07
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	12.39
1979	12.59	12.71	12.76	12.94	13.10	12.97	12.82	12.70	12.56	12.48	12.49	12.50	12.72
1980	12.51	12.45	12.40	12.37	12.51	12.42	12.30	12.04	11.99	11.90	11.91	11.90	12.22
1981	11.95	11.92	11.90	12.05	12.18	12.12	12.10	12.00	11.92	11.86	11.83	11.80	11.97
1982	11.80	11.79	11.78	11.80	11.88	11.97	12.00	11.92	11.88	11.90	11.92	12.18	11.90
1983	12.13	12.07	12.03	12.07	12.04	12.03	12.04	12.08	11.98	12.13	12.16	12.17	12.08
1984	12.14	12.04	12.05	12.10	12.09	11.95	11.83	11.78	11.62	11.58	11.70	11.60	11.87
1985	11.60	11.59	11.57	11.82	11.93	11.90	11.87	11.83	11.74	11.66	11.62	11.63	11.73
1986	11.59	11.57	11.56	11.80	11.88	11.83	11.66	11.57	11.50	11.57	11.65	11.67	11.65
1987	11.57	11.83	11.67	11.78	12.08	12.16	11.87	11.66	11.62	11.66	11.66	11.73	11.77
1988	11.77	11.68	11.67	12.04	12.01	11.98	11.91	11.92	11.96	11.95	11.99	12.02	11.91
1989	12.01	12.02	12.08	12.16	12.23	12.11	12.01	11.84	11.79	11.78	11.82	11.91	11.98
1990	12.00	12.04	12.25	12.46	12.53	12.38	12.21	12.12	12.03	11.99	11.95	12.02	12.17
1991	12.06	12.07	12.15	12.21	12.41	12.38	12.24	12.14	12.06	12.16	12.12	12.09	12.17
1992	12.01	11.94	11.87	11.96	-	-	-	-	-	-	-	-	-

LAKE VICTORIA: Lake rainfall (mm)

(Estimated using net rainfall model + IH2 evaporation estimates)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	218	111	277	173	170	84	53	87	98	132	249	146	1798
1926	109	221	236	391	221	56	70	69	123	142	190	107	1934
1927	148	168	233	266	173	72	26	55	97	75	126	186	1623
1928	80	111	182	331	247	56	50	66	109	157	120	132	1640
1929	57	81	200	273	146	77	90	64	102	117	102	280	1589
1930	162	165	274	306	205	78	46	51	121	166	112	109	1794
1931	132	97	298	312	260	59	96	60	97	85	145	119	1760
1932	115	108	296	303	273	42	36	76	104	51	122	145	1670
1933	263	149	202	186	185	65	51	109	100	128	82	166	1686
1934	60	100	147	252	219	33	45	93	89	137	126	183	1483
1935	59	222	167	260	203	92	15	33	110	124	138	209	1631
1936	271	173	238	328	147	179	32	49	109	82	114	225	1946
1937	100	191	243	280	262	54	34	45	103	145	224	159	1841
1938	81	72	229	319	219	60	14	45	105	143	145	155	1589
1939	40	144	220	240	206	84	38	83	102	91	171	96	1513
1940	169	210	227	295	206	48	80	62	109	71	178	101	1755
1941	115	81	209	278	227	123	25	98	89	111	284	319	1958
1942	208	92	336	315	264	28	13	114	89	83	149	130	1821
1943	68	178	151	302	192	125	17	69	102	67	97	96	1465
1944	97	109	311	317	243	33	57	86	120	157	226	181	1938
1945	132	135	145	184	304	62	61	121	104	67	164	114	1593
1946	27	35	143	305	238	120	67	103	112	112	162	177	1600
1947	253	161	234	369	287	74	73	53	113	110	115	171	2014
1948	154	93	194	280	215	55	55	78	115	142	121	170	1670
1949	30	97	96	318	140	71	78	80	97	112	114	239	1470
1950	159	68	282	313	219	58	50	88	97	102	95	147	1676
1951	126	161	240	365	226	120	42	91	100	156	215	396	2236
1952	61	167	264	329	234	54	51	58	109	52	175	50	1603
1953	156	76	190	313	168	57	39	45	115	152	205	143	1659
1954	78	109	124	340	214	53	99	61	100	81	105	196	1559
1955	183	152	200	267	223	20	72	69	105	70	106	206	1672
1956	201	93	194	344	185	83	37	93	102	126	148	180	1787
1957	169	113	198	305	262	64	45	54	85	114	164	152	1727
1958	101	115	216	272	211	129	48	52	97	113	89	180	1622
1959	134	138	208	274	162	46	44	77	106	176	225	114	1702
1960	199	168	326	379	170	47	40	35	114	135	109	105	1827
1961	70	176	236	261	196	42	67	106	126	338	474	279	2370
1962	184	88	218	343	256	66	57	86	110	216	171	124	1919
1963	233	193	226	404	261	24	19	54	90	81	263	273	2121
1964	124	247	230	397	196	91	78	72	102	135	160	178	2011
1965	59	109	206	265	178	30	58	34	112	218	220	172	1663
1966	114	220	288	355	145	99	30	105	101	126	178	126	1889
1967	61	74	178	260	276	78	56	67	113	177	274	137	1752
1968	40	220	272	359	210	116	28	41	107	238	249	234	2114
1969	222	227	231	201	212	28	37	48	99	139	223	103	1770
1970	201	132	321	335	206	23	36	58	94	125	136	200	1865
1971	110	89	166	300	230	17	95	71	105	139	155	161	1639
1972	159	181	118	249	224	157	34	76	104	207	294	172	1975
1973	160	189	151	325	209	65	2	70	107	130	211	130	1749
1974	99	110	205	328	151	129	153	46	101	82	123	132	1657
1975	91	145	325	241	218	83	74	77	105	160	103	207	1826
1976	130	160	188	295	211	80	67	101	107	79	196	170	1781
1977	175	100	252	310	206	64	45	81	96	202	267	141	1938
1978	137	225	294	305	200	77	38	71	100	166	185	244	2041
1979	188	245	218	235	198	77	36	62	96	80	197	176	1807
1980	102	92	225	260	229	25	39	72	102	93	189	160	1588
1981	107	87	344	230	215	25	56	76	106	111	130	168	1653
1982	111	99	191	246	239	95	44	61	108	259	272	155	1881
1983	49	59	137	276	222	83	60	92	96	205	149	154	1583
1984	88	99	129	277	165	43	94	71	94	130	246	151	1586
1985	167	122	273	378	215	64	53	36	104	100	165	172	1848
1986	69	154	220	306	211	52	28	42	96	198	167	263	1805
1987	149	181	212	284	201	120	18	46	120	150	196	91	1769
1988	255	133	222	411	171	48	60	93	112	119	195	191	2009
1989	117	136	255	243	203	25	43	59	109	198	195	265	1847
1990	120	192	294	267	173	0	12	64	98	186	147	206	1757

LAKE VICTORIA: Revised outflows (MCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1900	1578	1481	1594	1542	1599	1573	1653	1631	1459	1337	1216	1326	17987
1901	1385	1270	1535	1752	2027	1884	1781	1642	1475	1438	1345	1347	18880
1902	1299	1178	1304	1293	1412	1356	1358	1331	1236	1240	1257	1433	15698
1903	1545	1435	1610	1646	1923	2078	2205	2147	2028	2102	2053	2115	22886
1904	2083	1937	2109	2172	2385	2284	2231	2109	1949	1935	1872	2021	25086
1905	2071	1842	2071	2128	2291	2166	2058	1917	1763	1758	1735	1947	23744
1906	2033	1859	2284	2555	2829	2737	2735	2628	2495	2503	2350	2385	29393
1907	2329	2045	2166	2159	2460	2411	2342	2179	1992	1984	1902	1965	25932
1908	1935	1765	1822	1729	1887	1896	1911	1863	1746	1746	1718	1863	21880
1909	1857	1598	1724	1752	1990	1920	1810	1653	1547	1599	1496	1567	20511
1910	1610	1425	1545	1568	1781	1712	1637	1583	1511	1497	1413	1492	18774
1911	1492	1265	1358	1433	1594	1522	1460	1342	1257	1213	1107	1149	16191
1912	1144	1085	1197	1319	1529	1459	1412	1326	1236	1251	1195	1235	15388
1913	1246	1169	1374	1428	1658	1735	1741	1610	1428	1395	1335	1406	17524
1914	1385	1217	1412	1439	1551	1542	1556	1503	1428	1449	1439	1545	17465
1915	1513	1348	1567	1630	1816	1814	1787	1647	1522	1545	1501	1637	19326
1916	1695	1628	1804	1902	2218	2210	2153	2039	1986	2071	1986	2077	23769
1917	2121	1980	2244	2362	2716	2719	2760	2684	2628	2772	2689	2741	30416
1918	2691	2363	2541	2501	2653	2507	2391	2166	1992	1996	1884	1923	27607
1919	1851	1640	1851	1908	2090	1955	1905	1804	1679	1690	1589	1615	21577
1920	1599	1446	1535	1646	1833	1757	1701	1567	1433	1428	1387	1476	18808
1921	1508	1362	1508	1454	1513	1444	1428	1395	1278	1235	1122	1106	16353
1922	1074	1019	1165	1153	1288	1231	1133	1085	1034	988	956	994	13121
1923	924	835	988	1081	1374	1454	1492	1444	1319	1304	1262	1379	14857
1924	1417	1341	1460	1454	1620	1604	1508	1374	1278	1288	1242	1262	16847
1925	1310	1227	1395	1392	1460	1449	1444	1326	1195	1176	1216	1395	15983
1926	1433	1294	1503	1615	1959	2071	2071	2008	1938	2021	1974	2039	21925
1927	2039	1870	2121	2159	2342	2204	2102	1953	1786	1746	1604	1620	23547
1928	1588	1431	1503	1558	1869	1938	1905	1787	1652	1647	1558	1588	20022
1929	1524	1304	1438	1459	1599	1547	1545	1497	1361	1337	1278	1390	17280
1930	1487	1377	1631	1820	2115	2090	2046	1935	1855	1929	1855	1887	22024
1931	1845	1651	1893	1992	2218	2166	2192	2147	2041	2039	1926	2002	24110
1932	1971	1804	2002	2059	2297	2302	2297	2192	2065	2128	2022	2077	25217
1933	2102	1933	2186	2147	2277	2197	2121	1984	1867	1893	1791	1845	24343
1934	1804	1547	1669	1685	1857	1780	1746	1685	1558	1545	1496	1583	19954
1935	1556	1406	1620	1620	1810	1867	1869	1707	1553	1535	1444	1540	19525
1936	1637	1613	1828	1961	2192	2134	2115	1990	1843	1828	1701	1781	22621
1937	1839	1699	1990	2159	2497	2465	2441	2317	2134	2153	2140	2277	26111
1938	2231	1962	2231	2284	2429	2344	2329	2218	2059	2064	1974	2014	26140
1939	1971	1742	1959	2022	2173	2034	2002	1905	1763	1775	1690	1586	22622
1940	1543	1442	1742	1884	2071	2058	1911	2033	1804	1718	1651	1887	21742
1941	1781	1593	1755	1756	1953	1936	1899	1849	1712	1670	1707	1979	21591
1942	2091	1917	2211	2360	2677	2611	2552	2414	2226	2182	2006	2018	27266
1943	1951	1663	1828	1892	2056	1961	1887	1782	1673	1674	1502	1594	21462
1944	1401	1275	1385	1322	1602	1559	1459	1360	1291	1325	1268	1444	16690
1945	1431	1233	1406	1299	1610	1538	1570	1428	1430	1419	1396	1386	17144
1946	1331	1150	1210	1202	1428	1319	1342	1321	1302	1302	1298	1465	15668
1947	1412	1372	1635	1688	1869	2275	2222	2160	2134	2077	1943	1959	22746
1948	1949	1760	1941	1866	2054	2130	2035	1963	1869	1909	1831	1881	23188
1949	1769	1536	1626	1573	1683	1612	1567	1563	1516	1524	1293	1361	18625
1950	1409	1242	1408	1517	1609	1551	1556	1511	1387	1365	1340	1360	17256
1951	1283	1188	1346	1477	1728	1681	1599	1489	1333	1332	1382	1659	17496
1952	1883	1481	1617	1563	1692	1615	1589	1579	1617	1706	1575	1573	19489
1953	1536	1431	1662	1705	1530	1534	1660	1557	1611	1555	1414	1333	18528
1954	1806	1695	1728	1642	1816	1859	1790	1839	1682	1664	1521	1621	20663
1955	1541	1510	1648	1621	1565	1527	1587	1475	1424	1534	1378	1422	18232
1956	1486	1511	1579	1633	1699	1840	1829	1565	1582	1812	1498	1604	19636
1957	1506	1367	1549	1656	1923	1974	1932	1830	1655	1585	1519	1616	20112
1958	1634	1484	1635	1599	1835	1791	1789	1718	1607	1594	1462	1523	19671
1959	1559	1410	1587	1567	1724	1638	1609	1499	1404	1441	1443	1553	18434
1960	1537	1461	1687	1885	1982	1939	1838	1672	1585	1614	1570	1578	20348
1961	1523	1365	1517	1617	1804	1709	1653	1590	1547	1616	1946	2690	20577
1962	3014	2686	2994	3065	3525	3455	3459	3350	3217	3365	3204	3382	38716
1963	3479	3157	3626	3563	3895	4102	4155	4013	3670	3633	3506	3989	44788
1964	4253	3787	4145	4230	4549	4400	4613	4285	4118	4205	3882	4009	50476
1965	4470	4124	4596	4285	4403	4313	3701	3549	3294	3312	3311	3520	46878
1966	3523	3175	3623	3657	4233	4252	3647	2329	3333	3367	3301	3380	41820
1967	3301	2886	3103	3042	3417	3285	3299	3156	2923	3007	2993	3420	37832
1968	3269	3006	3463	3567	4112	4074	3997	3798	3491	3456	3363	3709	43305
1969	3791	3541	4026	4008	4355	4141	4034	3796	3506	3466	3324	4018	46006
1970	2905	3199	3652	3839	4246	4097	4010	3840	3665	3718	3506	3605	44282
1971	3578	3098	3284	3265	3615	3463	3394	3278	3214	3157	3027	3137	39510
1972	3180	2957	3168	3060	3301	3233	3247	3094	2940	2960	3041	3359	37540
1973	3414	2983	3560	3260	3540	3404	3283	3113	2933	3006	2928	3043	38467
1974	2979	2569	2823	2861	3114	3037	3041	3410	3242	2702	2579	2689	35046
1975	3032	2308	2483	2407	2176	2518	2843	3053	3475	3460	2825	2746	33326
1976	3075	2801	2934	2998	3010	2978	2984	3073	2869	2758	2630	2725	34835
1977	2750	2493	2707	2877	3155	3082	3348	3087	3157	3065	2856	3422	35999
1978	3493	2859	2592	3228	3568	3407	3440	3214	3341	3367	3218	3656	39383
1979	3389	3320	3825	3537	4019	3794	3787	3756	3686	3614	3777	3848	44352
1980	4020	3830	4232	4056	3840	3720	4080	4220	3650	3590	3410	3610	46258
1981	2750	2240	2680	2560	2820	3140	3270	3100	2990	2740	2170	1550	32010
1982	2360	2020	2700	2690	3320	3200	2650	2640	2640	3040	2790	3040	33090
1983	3320	2960	3300	2220	2620	2650	2810	2860	2200	2360	2080	2170	31550
1984	2300	2680	2460	2200	2320	2230	3100	3380	2420	3380	2360	2410	31240
1985	2330	2200	2820	2840	2820	2560	2900	2890	2770	2810	3220	2460	32620
1986	2160	2440	2960	2710	2500	2650	2620	2360	2350	2440	2280	2380	29850
1987	2380	2040	2280	2200	2260	2400	2900	2760	2830	2930	2720	2400	30100
1988	2622	2424	2528	2665	2741	2616	2866	2829	2768	2879	2804	2942	32683
1989	2801	2947	3527	3401	3457	3343	3241	3191	2914	3006	2678	1990	36496
1990	2225	2234	2763	3067	3200	3034	3056	3102	3051	3197	2906	2901	34736
1991	2978	2679	2954	2886	3255	3204	3374	3396	3231	3049	3012	3068	37086
1992	2999	1930	1952	2823	-	-	-	-	-	-	-	-	-

LAKE VICTORIA: Estimated total tributary inflows (MCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	955	744	1116	1487	1627	1530	1526	1601	1320	960	1345	1733	15943
1926	1162	787	850	2241	2490	1646	1511	1926	2449	2285	1911	1867	21123
1927	1394	924	986	1829	1781	1108	858	789	674	557	500	546	11945
1928	548	451	491	1570	2282	1713	1109	996	937	765	652	597	12112
1929	493	366	399	937	1542	1142	1328	1269	909	666	547	591	10190
1930	640	461	1608	4565	3604	2451	1795	1405	1447	1434	1256	1163	21830
1931	934	658	1063	2377	2324	1579	1428	1907	1966	1517	1169	1130	18050
1932	966	711	1248	2206	2245	1651	1561	1915	2097	1784	1377	1320	19082
1933	1085	810	859	883	907	711	757	1193	1313	1012	725	648	10903
1934	511	354	381	1074	1505	1271	1424	1632	1364	931	782	766	11995
1935	628	786	833	964	2099	2358	1815	1219	1041	953	813	735	14244
1936	655	854	1425	3075	2493	2229	2002	1772	1685	1335	1113	1093	19730
1937	931	737	1020	3240	3536	2710	2588	2609	2192	1658	1736	1958	24916
1938	1454	1054	1190	1484	1788	1726	2048	2408	2172	1623	1309	1237	19492
1939	1040	811	815	2181	1744	1145	1418	1341	984	768	684	674	13605
1940	646	613	1571	3040	2477	1576	1475	1520	1242	984	1071	1215	17429
1941	903	636	711	2282	2654	1974	1488	1403	1244	974	1517	2224	18012
1942	1622	1001	2057	4189	3955	3042	2448	2200	1931	1502	1230	1195	26371
1943	1020	773	827	1599	1998	1634	1335	1216	1084	827	666	654	13632
1944	585	487	607	1219	1777	1359	1369	1357	1309	1142	962	899	13073
1945	649	472	491	470	1662	2106	1812	1760	1863	1526	1116	1047	14973
1946	848	603	624	1560	1970	1894	1683	2101	2174	1575	1180	1086	17297
1947	932	669	683	3318	3881	2821	2712	2304	2071	1781	1389	1348	23908
1948	1133	847	879	2029	2224	1885	1845	1726	1579	1426	1256	1169	17997
1949	944	671	701	1696	2028	1533	1394	1368	1487	1302	970	918	15012
1950	750	521	633	1364	1293	1130	1556	1651	1403	1073	841	797	13012
1951	662	492	651	4038	3726	2113	1638	1515	1286	1034	1378	2809	21341
1952	2568	1464	1414	3164	4010	2651	2097	2012	1698	1399	1199	1169	24845
1953	1001	774	855	1890	1971	1727	1421	1152	1062	892	795	817	14355
1954	668	519	588	1689	2693	2115	1638	1443	1341	1128	866	802	15489
1955	671	538	604	1524	1555	885	1181	1737	2023	1710	1290	1286	15006
1956	1513	962	805	1848	2561	1684	1674	2201	2170	1688	1156	1065	19326
1957	840	677	816	1842	2890	2898	1881	1944	1468	951	910	1003	18121
1958	768	802	862	998	1867	1295	1593	1646	1663	1335	838	962	14629
1959	787	618	1016	1558	1841	967	941	1091	1259	1146	1062	1025	13310
1960	823	671	1210	2641	2149	1644	1488	1573	1953	1336	1084	954	17526
1961	737	611	690	1070	1276	922	1031	1938	1772	1903	4517	5390	21856
1962	3886	1712	2155	3700	6064	3541	3172	3192	3030	2203	1756	1727	36136
1963	1865	1482	1827	3928	7552	3473	2686	2813	2048	1563	1605	3822	34664
1964	2231	1546	2161	5598	3677	2608	2746	3134	2655	2617	1618	1741	32332
1965	1557	1099	1175	2099	2502	1423	1343	1180	987	1047	1503	1513	17428
1966	1130	1137	1748	4231	2881	1763	1674	1445	1852	1267	1288	1021	21435
1967	923	771	890	1783	3400	2066	2439	2068	1662	1500	1893	2054	21448
1968	1372	1455	2687	4880	5490	3407	2721	2969	1930	1458	1571	2661	32600
1969	1553	1612	2127	2439	2990	1888	1570	1705	1523	1293	1171	1212	21083
1970	1493	1402	2690	4127	3542	2666	1997	2731	2219	1915	1406	1384	27572
1971	947	704	706	2024	2850	2044	1902	2472	2433	1743	1186	1128	20139
1972	953	992	983	927	1988	2036	1920	1618	1270	1445	3207	2611	19950
1973	2168	1497	1106	1279	1956	2048	1312	1721	2105	1578	1968	1244	19982
1974	896	685	872	4166	2470	1708	3006	1719	1942	1503	1069	910	20946
1975	781	591	1076	1588	1652	1621	1540	2473	2964	2334	1234	1114	18968
1976	813	726	735	1089	1721	1681	1668	1405	1680	1029	975	887	14409
1977	1102	1053	1016	3816	6081	2452	2527	2291	1717	1291	3716	2085	29147
1978	1455	1551	6112	4789	4591	2634	2721	2916	2507	1977	1870	2452	35575
1979	1400	2356	2184	3206	2701	2409	2028	2228	1749	1510	1295	1188	24254
1980	1006	910	1044	1225	2167	1631	1624	1221	1216	878	836	877	14634
1981	1007	978	1400	3077	2875	2146	1787	2119	1711	1463	1833	2258	22653
1982	1032	940	979	3691	2748	1754	1736	2260	2091	1339	2256	3284	24110
1983	2224	1769	1479	2200	2132	1527	1590	1972	2530	2455	1984	1607	23469
1984	1277	1070	1031	1503	1465	1282	1150	1141	962	807	974	990	13654
1985	970	908	1379	3666	3327	2363	2309	1983	1500	1138	1040	1084	21668
1986	1009	983	1050	2985	3007	1992	2060	1714	1433	1177	909	951	19270
1987	1011	926	1114	1583	2394	2228	1734	1428	1396	1093	1350	1782	18038
1988	1671	1295	1301	4372	4030	2573	2957	3102	3180	2736	2162	2118	31497
1989	1807	1450	1947	3108	2946	2451	2379	2449	2291	2076	1861	1842	26605
1990	1622	1382	2627	4777	3578	2173	1702	1617	1543	1230	1116	1178	24544

JINJA RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1900	-	-	-	-	-	-	-	-	-	-	-	-	-
1901	-	-	-	-	-	-	-	-	-	-	-	-	-
1902	84	113	31	307	191	26	85	209	20	96	131	113	1406
1903	160	53	126	165	165	167	45	46	106	140	47	64	1284
1904	53	52	160	166	85	68	24	138	80	97	162	144	1229
1905	68	20	108	110	114	13	96	76	85	151	254	84	1179
1906	6	152	279	222	99	97	26	160	81	132	29	33	1316
1907	54	81	7	236	202	43	92	110	23	89	87	111	1135
1908	20	138	14	166	155	72	32	67	107	101	109	74	1055
1909	135	25	109	305	41	41	78	219	220	97	27	284	1581
1910	59	13	132	224	241	132	133	48	54	86	205	72	1399
1911	64	37	268	160	168	43	21	108	53	158	282	40	1402
1912	46	119	157	197	102	84	80	129	29	139	111	129	1322
1913	17	143	91	228	223	22	78	41	90	96	62	68	1159
1914	130	93	192	185	141	83	113	133	121	83	208	41	1523
1915	72	225	151	233	188	79	12	66	143	158	109	118	1554
1916	39	176	88	277	132	110	59	90	176	62	47	165	1421
1917	149	160	59	256	181	88	21	242	79	175	46	21	1477
1918	48	7	33	104	67	49	59	60	95	122	87	66	797
1919	22	199	224	128	122	19	90	92	133	45	232	17	1323
1920	43	19	229	136	92	65	52	92	52	62	85	106	1033
1921	39	77	48	131	106	36	91	177	62	79	106	98	1050
1922	30	60	152	174	224	24	23	238	78	108	68	76	1255
1923	0	173	178	178	264	25	77	84	192	143	89	162	1565
1924	25	99	180	217	201	44	112	224	60	198	60	60	1480
1925	99	70	211	220	73	99	96	87	129	183	174	109	1550
1926	29	179	154	284	123	53	24	108	145	126	166	34	1425
1927	152	231	106	192	83	66	47	66	88	96	53	107	1287
1928	14	19	102	225	113	41	39	126	95	158	66	26	1024
1929	9	31	76	109	62	130	117	99	121	138	56	306	1254
1930	172	51	86	163	106	110	34	92	93	152	48	10	1117
1931	37	49	309	240	259	49	95	62	73	45	64	46	1328
1932	30	15	247	122	123	52	46	78	67	17	93	23	913
1933	77	43	160	180	168	95	39	112	29	92	26	69	1090
1934	8	59	144	124	146	39	65	138	40	133	91	115	1102
1935	0	123	114	203	184	114	15	42	86	130	80	146	1237
1936	212	90	138	201	68	180	20	62	114	54	40	136	1315
1937	25	65	96	166	177	14	34	55	78	124	272	97	1203
1938	27	14	119	294	144	35	20	115	109	164	55	91	1187
1939	1	108	131	194	184	49	97	136	142	98	149	9	1298
1940	90	119	85	177	97	39	65	62	138	65	165	22	1124
1941	43	72	90	173	199	155	79	141	10	81	268	316	1627
1942	57	26	202	303	231	64	3	195	35	40	90	90	1336
1943	12	87	77	227	97	90	15	119	44	77	4	67	916
1944	32	22	206	288	201	41	64	113	75	139	163	112	1456
1945	29	31	75	76	282	60	54	216	77	42	153	19	1114
1946	15	0	39	259	314	60	79	78	111	114	89	106	1264
1947	117	74	115	322	314	43	126	91	154	23	14	69	1462
1948	96	85	126	218	184	124	93	111	222	95	166	63	1583
1949	2	43	36	136	112	35	87	87	77	91	117	157	980
1950	132	18	118	194	128	29	52	55	59	101	47	41	974
1951	73	98	171	276	177	58	37	158	93	112	80	277	1610
1952	15	146	181	143	88	92	83	63	46	11	118	0	986
1953	88	17	51	254	59	53	26	45	35	102	181	49	960
1954	17	26	33	186	100	104	69	49	80	107	38	140	949
1955	86	65	70	167	136	38	26	121	79	65	51	160	1064
1956	96	24	124	257	138	84	64	141	114	101	93	104	1340
1957	116	34	75	175	220	44	66	66	11	81	104	62	1054
1958	66	91	93	199	58	57	38	45	64	92	91	101	995
1959	88	92	75	182	67	72	64	110	69	217	196	32	1264
1960	107	43	218	209	58	2	108	41	181	149	78	37	1231
1961	18	64	181	143	100	33	67	114	94	369	431	120	1734
1962	59	20	128	199	201	67	82	86	128	279	151	51	1451
1963	137	114	169	233	258	25	39	78	46	121	218	209	1647
1964	23	240	122	247	93	149	109	29	120	113	169	121	1535
1965	4	31	55	117	75	13	55	27	122	197	153	151	1000
1966	44	224	184	203	117	134	42	93	104	105	210	20	1480
1967	8	34	127	116	265	76	58	46	87	159	294	110	1380
1968	10	77	161	237	96	88	28	70	94	161	121	209	1352
1969	96	156	110	205	149	48	55	54	136	110	186	24	1329
1970	128	40	276	193	211	33	25	108	42	108	105	23	1292
1971	45	60	133	191	111	35	138	99	121	75	70	58	1136
1972	38	151	42	206	133	241	46	122	138	169	288	42	1616
1973	37	58	50	161	91	56	3	90	149	117	148	32	992
1974	72	43	137	179	117	67	132	58	131	85	48	59	1128
1975	33	33	244	241	226	59	59	92	163	115	48	128	1441
1976	126	131	150	177	115	76	152	102	83	37	173	58	1380
1977	86	35	227	226	122	39	109	156	30	184	218	95	1527
1978	27	171	159	183	197	94	60	91	83	88	111	152	1416
1979	96	177	119	158	142	104	71	126	9	97	154	107	1360
1980	71	10	160	199	120	32	54	55	132	84	157	164	1238
1981	27	104	183	125	204	44	74	119	104	53	144	100	1281
1982	27	62	115	147	217	35	9	45	89	159	228	84	1217
1983	33	20	61	208	166	64	58	123	91	168	94	38	1124
1984	73	19	37	118	77	21	73	128	60	75	179	56	916
1985	130	50	-	-	-	-	-	-	-	-	-	-	-
1986	2	12	97	264	165	55	49	36	44	131	131	-	-
1987	58	148	194	207	168	83	7	100	232	144	111	33	1485
1988	89	48	139	242	63	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	85	-	118	136	178	148	-
1990	44	122	200	179	68	2	11	57	142	134	63	119	1141
1991	40	132	122	176	198	63	130	33	122	101	70	65	1252
1992	-	-	-	-	-	-	-	-	-	-	-	-	-

ENTEBBE RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1896	-	-	-	219	113	81	8	104	60	117	306	119	-
1897	44	92	101	349	268	115	73	149	120	-	-	-	-
1898	-	-	-	173	154	109	16	114	143	115	194	41	-
1899	16	88	88	232	217	77	84	35	16	-	-	-	-
1900	57	107	155	344	68	148	11	74	87	39	152	318	1560
1901	99	125	112	206	202	128	102	5	17	49	58	95	1198
1902	74	177	73	129	105	28	57	101	143	114	197	96	1294
1903	166	18	180	221	175	261	107	30	113	92	95	139	1597
1904	42	91	250	172	242	137	45	106	59	66	204	186	1600
1905	55	18	239	138	209	169	144	44	108	165	194	187	1670
1906	72	126	132	371	122	129	42	153	64	123	57	117	1508
1907	87	62	21	401	254	159	145	14	62	69	87	119	1480
1908	30	87	59	300	263	92	128	74	24	89	61	108	1315
1909	48	37	142	307	151	68	73	85	63	114	99	221	1408
1910	203	22	186	225	401	119	52	58	27	38	86	163	1580
1911	68	7	152	314	276	34	75	168	49	53	102	47	1345
1912	90	91	219	192	305	249	66	172	53	24	209	253	1923
1913	16	186	242	323	270	25	82	36	43	112	23	76	1434
1914	51	81	168	236	196	134	72	79	116	87	217	80	1517
1915	65	86	251	261	199	174	73	43	133	137	113	239	1774
1916	19	151	143	150	101	248	80	115	113	77	89	93	1379
1917	73	211	56	338	251	72	1	38	135	141	69	27	1412
1918	53	27	91	276	230	131	48	45	82	78	148	61	1270
1919	37	179	228	123	268	152	196	69	79	90	75	39	1535
1920	61	35	105	189	363	205	84	39	42	39	90	146	1398
1921	55	47	119	225	172	163	44	55	78	103	131	127	1319
1922	58	106	205	188	315	83	75	79	34	84	135	111	1473
1923	6	113	249	251	630	101	140	84	98	199	264	125	2260
1924	38	142	102	376	366	50	25	94	107	81	132	40	1553
1925	130	85	228	233	91	56	24	97	26	139	124	131	1364
1926	132	169	175	446	168	113	172	98	97	184	118	41	1913
1927	37	175	59	169	132	201	102	62	81	52	160	136	1366
1928	30	57	162	423	240	82	77	39	60	186	121	86	1563
1929	34	20	183	174	108	45	78	33	88	159	29	103	1054
1930	84	95	169	205	279	151	73	15	78	66	94	55	1364
1931	109	82	123	321	336	99	202	65	81	139	143	34	1734
1932	103	68	347	284	409	87	59	81	57	37	151	118	1801
1933	131	97	166	185	236	70	112	105	89	87	39	151	1468
1934	8	53	129	249	283	83	63	72	27	100	70	154	1291
1935	18	135	114	248	260	119	32	45	119	101	231	167	1589
1936	117	113	214	417	155	336	91	38	46	93	135	95	1850
1937	18	109	196	222	329	147	106	53	112	102	216	104	1714
1938	36	32	144	231	183	87	17	36	52	101	62	101	1082
1939	27	70	92	91	208	66	19	89	62	47	171	57	999
1940	86	147	196	306	248	78	116	87	78	80	148	32	1602
1941	55	42	153	329	320	93	39	105	2	151	181	230	1700
1942	134	110	229	243	458	84	67	170	71	59	135	69	1829
1943	35	86	207	253	218	291	43	123	75	52	74	65	1522
1944	92	26	220	394	319	49	85	28	120	82	201	221	1837
1945	68	135	209	122	324	69	108	76	57	45	167	69	1449
1946	32	5	101	376	301	196	99	37	101	72	92	122	1534
1947	237	118	165	207	453	87	55	27	66	103	117	82	1717
1948	18	65	122	318	234	33	42	111	65	123	141	141	1413
1949	69	90	65	236	135	93	64	85	25	105	53	110	1130
1950	135	29	141	395	420	113	91	220	88	28	54	65	1779
1951	41	118	156	310	403	184	70	91	98	42	271	353	2137
1952	20	159	283	163	254	109	119	63	148	36	209	4	1567
1953	36	25	118	235	122	44	89	23	282	127	172	100	1373
1954	30	55	99	201	156	52	98	59	35	45	44	145	1019
1955	117	50	172	337	394	69	74	62	46	27	54	119	1521
1956	165	69	86	457	167	111	3	245	26	43	195	188	1755
1957	101	49	195	322	240	140	79	58	8	115	227	116	1650
1958	108	48	127	246	463	264	42	28	72	22	48	207	1675
1959	40	56	116	235	148	89	103	111	198	132	196	15	1439
1960	121	199	309	426	86	78	49	47	44	78	62	72	1571
1961	46	86	189	253	169	74	77	103	140	265	385	210	1997
1962	83	70	219	203	298	49	42	167	70	242	81	74	1598
1963	174	177	142	410	290	32	22	44	55	53	299	180	1878
1964	42	184	165	329	457	92	48	47	43	135	174	109	1825
1965	12	76	110	154	184	67	164	59	130	206	150	97	1409
1966	56	95	274	245	101	202	18	74	30	113	183	53	1444
1967	46	39	129	162	398	207	155	181	64	145	230	73	1829
1968	8	100	175	298	247	155	39	34	138	149	197	149	1689
1969	103	177	237	168	239	63	71	26	23	187	219	42	1555
1970	119	84	347	326	167	57	52	58	38	67	112	152	1579
1971	118	25	96	164	319	82	64	89	88	104	171	113	1433
1972	185	70	44	175	197	175	46	17	119	118	305	118	1569
1973	128	167	127	294	201	128	33	88	75	140	162	41	1584
1974	68	73	98	241	138	134	240	61	37	97	49	68	1304
1975	87	137	196	171	196	203	148	82	91	152	113	104	1680
1976	54	98	138	217	257	184	13	120	85	26	237	197	1626
1977	102	61	238	176	202	113	12	42	51	147	144	68	1356
1978	60	181	349	298	312	92	61	30	28	164	165	135	1875
1979	99	107	220	-	165	124	66	32	24	45	193	115	-
1980	63	24	152	209	217	74	69	214	29	59	204	143	1457
1981	63	12	114	89	281	57	86	49	146	258	48	110	1313
1982	13	5	228	160	327	108	105	33	116	154	178	50	1477
1983	18	33	121	227	304	71	67	64	7	117	89	129	1247
1984	68	55	131	319	188	65	73	34	30	77	191	107	1338
1985	0	-	-	-	-	71	74	44	141	67	164	133	-
1986	1	61	189	112	245	117	21	60	60	63	194	191	1314
1987	129	27	81	237	270	114	67	49	162	-	154	25	-
1988	134	67	118	366	212	93	33	203	115	108	147	159	1755
1989	-	-	-	-	-	-	100	11	84	204	187	321	-
1990	97	35	314	177	268	24	42	132	49	63	134	-	-
1991	105	84	264	469	315	112	113	-	-	-	-	-	-

KALANGALA RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	-	-	-	-	-	-	-	-	-	-	-	-	-
1926	195	228	323	419	231	188	36	62	97	71	182	135	2167
1927	197	77	208	232	319	131	33	49	107	78	111	101	1643
1928	129	123	234	431	473	143	17	63	149	115	86	161	2124
1929	96	60	242	317	176	89	130	107	102	116	261	242	1938
1930	102	281	223	355	348	210	30	114	49	61	198	218	2189
1931	29	120	337	263	335	65	152	23	38	133	143	68	1706
1932	131	104	226	340	568	258	66	126	100	105	108	128	2260
1933	214	227	320	219	378	144	203	92	85	112	123	169	2286
1934	59	120	168	278	349	160	105	148	59	105	106	131	1788
1935	43	288	112	349	436	260	38	82	24	106	232	182	2152
1936	177	190	342	584	509	609	268	105	168	179	175	246	3552
1937	71	137	301	400	313	264	262	48	198	328	511	436	3269
1938	181	126	394	511	342	456	134	64	117	167	178	163	2833
1939	26	159	131	240	277	161	10	90	100	89	117	115	1515
1940	129	274	233	369	359	135	161	147	109	96	205	137	2354
1941	92	143	121	292	277	327	142	76	161	145	292	482	2550
1942	209	139	520	555	634	184	180	404	93	113	274	50	3355
1943	60	207	184	301	313	332	55	23	34	49	77	94	1729
1944	101	125	207	408	-	-	-	-	-	-	-	-	-
1945	-	-	-	-	-	-	-	-	-	57	206	36	-
1946	61	39	61	190	180	204	133	117	58	48	75	205	1371
1947	241	177	210	570	404	173	142	76	218	94	200	164	2669
1948	191	106	120	345	256	198	183	86	87	196	92	85	1945
1949	71	111	66	329	220	41	173	134	25	44	0	177	1391
1950	83	42	257	361	297	103	182	95	95	116	108	151	1890
1951	96	138	523	389	642	152	146	141	75	128	514	565	3509
1952	107	27	231	204	309	209	175	261	170	169	120	58	2040
1953	111	102	120	339	172	184	0	70	122	91	74	141	1526
1954	-	-	-	-	-	-	-	-	-	-	-	-	-
1955	131	97	272	357	394	216	123	77	176	131	104	252	2330
1956	119	123	248	312	230	111	44	53	224	72	189	370	2095
1957	169	21	209	455	248	123	60	149	88	180	122	320	2144
1958	108	211	297	229	270	292	83	181	69	87	115	250	2192
1959	121	152	241	307	111	195	141	233	198	34	239	85	2057
1960	221	187	297	340	205	132	61	56	83	121	162	133	1998
1961	92	102	216	-	-	102	160	52	72	322	386	194	-
1962	38	47	234	212	502	183	156	87	85	219	43	181	1987
1963	168	166	196	460	450	120	71	39	106	74	270	377	2497
1964	75	214	289	296	341	187	43	130	67	172	98	158	2070
1965	35	112	145	133	204	83	127	160	115	158	220	148	1640
1966	176	148	341	266	185	93	71	51	164	104	357	242	2198
1967	174	22	333	369	436	171	60	123	223	263	271	145	2590
1968	22	133	339	541	539	232	1	109	70	225	443	273	2927
1969	192	260	209	304	319	155	188	163	97	248	260	65	2460
1970	101	223	300	454	340	170	137	121	73	144	189	286	2538
1971	150	42	218	401	400	112	172	28	195	72	176	167	2133
1972	260	39	176	327	431	141	26	52	46	297	297	271	2363
1973	141	124	71	561	269	231	19	105	97	154	213	103	2088
1974	123	68	180	431	265	183	189	4	63	115	107	103	1831
1975	99	360	265	238	271	161	175	100	154	193	70	206	2292
1976	208	229	282	274	341	115	95	50	100	42	142	300	2178
1977	185	39	178	228	397	278	31	29	-	200	260	-	-
1978	-	-	-	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-	-	-	-	-

BUKOBA RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1900	-	-	-	-	-	-	-	-	-	-	-	-	-
1901	-	-	-	-	-	-	-	-	-	-	-	-	-
1902	-	-	-	-	-	-	-	-	-	-	-	-	-
1903	-	-	-	-	-	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-	-	-	-	-	-
1906	128	109	287	306	114	119	66	156	-	-	-	-	-
1907	-	109	74	217	266	16	8	6	89	119	115	79	-
1908	22	140	195	355	555	38	143	46	68	128	164	228	2082
1909	118	140	347	370	256	11	144	88	133	139	168	239	2153
1910	139	78	287	378	266	0	70	82	61	167	277	247	2052
1911	197	28	182	180	126	35	0	125	22	24	178	145	1242
1912	123	110	241	633	230	102	24	150	86	170	227	400	2496
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	-	-	-	-	-	-	-	-	-	-	-	-	-
1917	-	-	-	-	-	-	-	-	-	-	-	-	-
1918	-	-	-	-	-	-	-	-	-	-	-	-	-
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	-	-	-	-	-	-	-	-	-	-	-	-	-
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
1922	30	0	242	44	267	48	25	23	22	30	38	69	838
1923	199	145	195	114	210	158	120	71	19	152	132	176	1691
1924	84	198	167	533	396	5	30	133	124	43	219	97	2029
1925	174	139	285	151	266	126	47	121	123	103	282	78	1895
1926	129	208	365	387	304	144	39	19	145	132	175	79	2126
1927	156	115	317	317	239	37	0	65	91	121	158	228	1844
1928	176	243	256	380	432	126	43	79	115	112	138	144	2244
1929	148	164	262	424	184	107	40	90	84	33	101	264	1901
1930	142	235	376	269	185	24	34	79	102	162	113	127	1848
1931	169	74	358	362	552	42	75	30	50	93	270	61	2136
1932	163	121	183	229	490	98	41	125	59	73	104	155	1841
1933	371	170	207	144	209	45	47	75	48	174	73	233	1796
1934	129	142	128	329	380	71	33	109	56	118	116	269	1880
1935	87	290	240	197	172	102	0	25	82	143	146	284	1768
1936	204	89	198	423	108	163	2	71	118	86	149	230	1841
1937	105	143	308	272	393	108	16	15	121	182	173	271	2107
1938	120	67	317	462	399	135	11	37	57	140	252	199	2196
1939	81	223	318	228	415	151	28	54	119	134	120	120	1991
1940	165	249	314	401	252	53	95	129	258	76	119	127	2238
1941	116	89	177	323	251	157	15	114	80	184	242	287	2035
1942	297	42	342	403	386	19	0	106	17	156	204	80	2052
1943	76	253	160	409	242	47	31	15	56	53	170	126	1638
1944	170	186	283	295	418	79	10	42	215	228	207	214	2347
1945	192	236	120	302	540	24	104	69	115	75	146	76	1999
1946	46	22	123	383	257	125	106	171	167	100	157	151	1808
1947	232	263	172	560	437	118	62	66	178	187	169	234	2678
1948	157	66	193	321	274	53	99	96	140	137	100	243	1879
1949	49	79	127	461	121	57	183	130	100	228	121	246	1902
1950	150	32	368	318	359	78	83	83	108	89	104	263	2035
1951	107	257	170	409	246	113	3	81	51	218	201	572	2428
1952	71	177	162	433	275	4	38	90	134	116	364	48	1912
1953	289	111	338	465	320	59	41	104	150	236	205	129	2447
1954	77	171	97	336	384	51	35	72	88	88	204	170	1773
1955	243	171	285	288	273	44	111	5	97	98	126	218	1959
1956	163	85	250	380	296	53	23	23	84	125	105	217	1804
1957	122	71	233	315	323	42	54	61	47	132	155	119	1674
1958	92	66	187	432	331	139	9	45	91	46	136	140	1714
1959	192	224	211	435	169	106	46	92	71	102	126	180	1954
1960	201	196	287	523	366	99	0	31	222	236	120	130	2411
1961	187	315	313	265	318	99	153	101	205	312	291	192	2751
1962	89	76	248	458	300	56	125	117	136	117	107	153	1982
1963	198	293	226	630	366	61	43	61	81	84	263	332	2638
1964	194	291	238	427	191	49	14	111	49	80	179	147	1970
1965	72	198	292	322	276	70	30	50	129	153	335	180	2107
1966	137	211	225	573	190	86	56	66	163	162	151	252	2272
1967	134	82	233	343	412	90	25	41	206	225	218	79	2088
1968	48	146	329	387	518	152	42	32	110	230	478	236	2708
1969	146	237	184	300	223	31	49	104	108	103	236	120	1841
1970	101	137	209	414	373	33	78	50	52	200	160	320	2127
1971	124	100	258	324	366	4	114	33	87	135	154	168	1867
1972	286	283	184	332	425	152	35	80	45	259	321	199	2601
1973	163	235	297	543	385	91	0	72	44	139	110	167	2246
1974	173	187	226	381	183	257	172	12	57	81	130	111	1970
1975	151	248	261	332	390	125	43	58	42	101	122	325	2198
1976	175	250	265	381	399	89	22	127	122	86	164	150	2230
1977	157	95	358	183	287	54	32	84	145	240	281	158	2074
1978	146	124	332	469	183	102	9	64	51	161	141	362	2144
1979	270	199	230	309	341	94	15	68	142	112	201	118	2099
1980	113	164	289	267	394	16	19	37	93	92	265	217	1966
1981	104	64	408	324	141	11	38	90	81	97	208	326	1892
1982	182	123	257	271	313	100	38	121	73	360	215	193	2246
1983	63	48	86	299	369	121	150	81	86	187	110	248	1848
1984	86	126	200	408	213	119	68	64	59	195	343	220	2101
1985	243	53	228	455	341	113	74	45	136	171	180	276	2315
1986	138	295	204	356	327	66	4	79	78	372	179	237	2335
1987	240	185	221	405	200	58	14	48	122	96	254	48	1891
1988	257	221	249	352	156	89	9	136	133	121	195	185	2103
1989	78	128	265	371	290	70	40	87	57	150	139	244	1919
1990	167	140	268	117	262	32	5	8	44	270	191	285	1789
1991	135	133	283	389	363	66	59	42	91	143	200	49	1953
1992	106	63	163	304	-	-	-	-	-	-	-	-	-

KAGONDO RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	78	151	152	118	221	27	27	9	52	116	192	-	-
1926	104	73	280	316	196	100	8	11	134	104	190	100	1616
1927	60	65	340	281	180	5	0	90	110	92	80	140	1443
1928	95	188	346	311	355	114	19	60	58	115	98	175	1934
1929	63	109	260	273	230	82	92	27	32	78	93	199	1538
1930	58	181	250	322	124	12	25	57	59	50	148	67	1353
1931	154	81	221	401	322	41	70	39	13	55	201	129	1727
1932	118	91	123	204	308	6	34	67	43	59	134	183	1370
1933	245	179	240	154	299	9	31	63	41	177	97	141	1676
1934	132	99	195	394	242	20	45	85	50	94	105	233	1694
1935	66	312	173	182	259	61	0	8	38	166	277	279	1821
1936	157	85	158	342	110	159	0	45	94	51	116	234	1551
1937	100	194	291	308	347	5	6	11	115	280	129	144	1930
1938	111	24	286	355	247	33	0	21	67	185	361	177	1867
1939	86	137	379	249	184	28	14	26	73	112	119	31	1438
1940	128	252	326	399	279	5	41	64	77	133	143	35	1882
1941	107	58	150	247	110	46	28	105	88	88	196	192	1415
1942	273	48	386	369	146	0	0	106	30	103	158	59	1678
1943	42	256	98	292	258	20	0	13	85	32	214	115	1425
1944	121	186	200	203	286	2	7	31	69	135	230	164	1634
1945	174	183	111	255	506	19	102	93	161	73	182	101	1960
1946	41	56	128	284	190	46	32	73	83	90	145	147	1315
1947	127	108	175	511	436	15	37	9	68	158	99	156	1899
1948	157	39	245	329	187	27	15	35	70	138	107	170	1519
1949	40	76	52	400	66	32	50	66	186	88	147	191	1394
1950	130	72	419	236	363	12	21	215	72	76	54	195	1865
1951	119	247	176	181	242	34	2	68	52	142	247	296	1806
1952	40	109	256	270	161	8	14	35	78	78	177	73	1299
1953	251	30	198	396	182	10	0	52	56	115	190	83	1563
1954	23	155	99	458	380	5	37	56	92	184	209	232	1930
1955	476	139	235	267	186	46	104	28	265	137	127	291	2301
1956	244	86	131	320	160	60	3	24	101	47	114	168	1458
1957	59	44	213	304	125	45	9	67	47	77	170	177	1337
1958	70	48	113	290	217	54	20	12	90	71	157	121	1263
1959	108	227	154	499	212	76	41	50	81	93	177	229	1947
1960	113	240	401	501	122	37	0	2	161	174	103	121	1975
1961	140	352	364	290	358	43	84	69	227	273	423	116	2739
1962	48	123	175	254	312	32	28	162	16	52	92	50	1344
1963	78	141	281	434	351	71	0	38	99	84	260	292	2129
1964	145	189	313	537	97	0	7	45	34	124	151	211	1853
1965	16	118	152	230	498	2	87	27	167	161	403	153	2014
1966	246	93	279	309	26	52	0	16	131	103	90	197	1542
1967	75	160	210	242	288	36	11	51	209	151	228	46	1707
1968	50	219	345	412	341	158	1	0	8	236	374	282	2426
1969	201	286	201	452	352	20	40	2	97	101	211	137	2100
1970	217	145	257	374	261	6	21	96	99	124	243	232	2075
1971	96	105	153	407	184	31	83	26	82	97	162	54	1480
1972	159	82	164	268	290	43	32	13	141	198	354	218	1962
1973	146	183	185	543	234	35	0	11	74	85	94	123	1713
1974	108	185	187	268	120	146	68	36	27	31	78	72	1326
1975	102	150	206	460	266	18	57	55	51	77	131	140	1713
1976	147	196	144	402	251	47	11	55	78	96	85	187	1699
1977	132	43	240	144	207	68	2	40	134	123	228	90	1451
1978	41	77	169	382	116	12	0	16	12	64	291	279	1459
1979	146	157	216	211	245	22	0	20	86	94	158	187	1542
1980	40	56	189	98	236	-	9	28	48	44	167	93	-
1981	39	33	221	18	51	49	24	104	47	73	12	132	803
1982	141	89	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	2	4	4	7	8	20	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-

MWANZA RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1900	-	-	-	-	-	-	-	-	-	-	-	-	-
1901	-	-	-	-	-	-	-	-	-	-	-	-	-
1902	18	12	17	43	76	71	2	45	55	94	118	18	569
1903	40	37	146	408	141	90	4	3	33	41	90	88	1121
1904	34	191	172	76	43	0	0	59	1	26	99	237	938
1905	58	19	187	142	18	0	0	1	71	70	192	218	976
1906	52	164	253	305	7	26	0	8	70	84	112	75	1156
1907	45	7	148	257	182	50	0	23	45	53	118	130	1058
1908	211	65	54	190	415	13	2	35	12	90	186	174	1447
1909	65	42	166	261	17	0	0	13	119	2	88	156	929
1910	96	46	103	180	92	0	38	34	0	34	121	107	851
1911	61	38	140	159	20	12	0	4	7	63	114	30	648
1912	-	-	-	-	-	-	-	-	-	-	-	-	-
1913	-	-	-	-	-	-	-	-	-	-	-	-	-
1914	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	-	-	-	-	-	-	-	-	-	-	-	-	-
1916	-	-	-	-	-	-	-	-	-	-	-	-	-
1917	-	-	-	-	-	-	-	-	-	-	-	-	-
1918	-	-	-	-	-	-	-	-	-	-	-	-	-
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	-	-	-	-	-	-	-	-	-	-	-	-	-
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
1922	57	136	116	203	83	0	0	75	25	92	115	110	1012
1923	24	147	72	451	110	0	4	0	47	55	97	154	1161
1924	60	197	113	210	49	0	0	29	3	56	58	103	878
1925	208	51	258	33	89	53	0	22	0	29	248	89	1080
1926	30	209	142	309	36	2	35	2	132	40	187	173	1297
1927	116	22	134	142	108	18	0	0	4	6	96	196	842
1928	57	70	67	191	139	2	30	32	42	43	83	116	872
1929	26	56	196	213	50	34	100	2	28	92	47	257	1101
1930	70	207	278	250	55	6	14	0	144	70	93	77	1264
1931	110	74	272	159	81	43	3	50	32	38	59	130	1051
1932	85	71	300	302	85	6	0	0	78	50	104	122	1203
1933	217	240	115	107	57	94	1	68	59	91	62	128	1239
1934	110	95	59	137	112	5	49	5	14	61	74	144	865
1935	89	161	69	201	107	18	0	5	63	45	55	155	968
1936	187	168	243	186	47	50	2	0	96	18	50	225	1272
1937	88	235	147	168	156	0	0	2	63	75	208	82	1224
1938	79	75	102	113	126	15	0	3	80	85	103	74	855
1939	26	118	83	170	49	0	17	31	12	4	166	59	735
1940	122	206	88	112	195	1	40	27	1	26	85	82	985
1941	134	34	266	174	110	2	0	55	29	4	396	276	1480
1942	160	60	231	242	68	0	0	20	0	21	174	104	1080
1943	127	141	50	94	115	38	0	29	59	9	45	30	737
1944	67	105	292	147	66	6	0	0	104	64	246	138	1235
1945	93	56	41	89	180	18	0	69	93	39	170	158	1006
1946	37	1	89	167	82	8	5	37	6	117	219	164	932
1947	113	110	257	284	106	25	53	0	54	35	53	107	1197
1948	57	47	128	162	97	9	5	37	14	72	12	79	719
1949	29	40	5	201	25	13	1	29	23	25	57	314	762
1950	55	72	171	200	66	3	11	27	12	96	83	137	933
1951	181	77	261	173	65	89	16	5	22	43	172	384	1488
1952	91	115	210	217	153	0	0	4	77	29	41	4	941
1953	60	55	161	104	72	55	0	30	23	51	101	152	864
1954	144	128	28	195	149	5	13	3	42	5	65	190	967
1955	53	159	84	203	82	0	18	12	27	5	62	166	871
1956	98	76	124	179	45	0	0	5	55	190	116	70	958
1957	95	41	100	168	152	15	7	0	4	57	76	140	855
1958	98	94	243	138	50	20	26	16	8	138	31	72	934
1959	87	24	135	136	64	0	0	0	0	144	301	97	988
1960	138	81	156	99	34	0	1	0	13	12	45	42	621
1961	27	128	145	234	42	8	0	50	56	275	422	313	1700
1962	168	71	103	258	134	60	0	22	13	150	149	62	1190
1963	129	105	194	248	112	3	0	0	0	7	166	300	1264
1964	161	110	140	363	7	62	111	127	16	59	88	218	1462
1965	60	63	80	182	21	25	0	0	14	179	194	120	938
1966	84	140	283	214	5	11	0	20	0	32	141	129	1059
1967	40	46	83	238	179	1	5	52	32	46	166	137	1025
1968	92	263	313	240	54	17	0	0	7	206	135	163	1490
1969	232	206	162	31	145	0	0	0	9	63	173	111	1132
1970	170	129	293	201	43	0	8	19	54	24	67	144	1152
1971	47	87	34	221	60	0	16	21	19	63	126	88	782
1972	73	123	22	74	136	63	0	21	24	104	203	156	999
1973	106	253	40	80	55	16	0	0	65	120	344	158	1237
1974	53	44	173	197	11	7	23	33	3	31	76	148	799
1975	65	108	385	89	39	20	66	0	82	135	33	178	1200
1976	49	131	114	87	132	9	71	47	14	105	171	182	1112
1977	167	96	105	301	82	36	12	5	27	55	264	127	1277
1978	116	204	150	88	35	1	4	47	61	72	150	198	1126
1979	80	195	98	92	63	21	0	0	0	10	163	151	873
1980	55	83	113	190	126	0	0	0	49	38	130	64	848
1981	149	74	254	185	183	1	6	23	30	29	51	82	1067
1982	125	79	68	178	155	41	5	17	19	148	181	150	1166
1983	50	10	115	100	71	9	11	89	17	169	117	101	859
1984	42	92	27	161	5	0	38	13	9	31	173	105	696
1985	71	144	191	224	57	0	0	0	8	39	149	69	952
1986	43	89	108	215	58	0	0	0	0	104	117	229	963
1987	52	192	147	180	54	116	0	0	20	84	184	127	1156
1988	216	162	207	308	52	4	51	38	47	98	168	124	1475
1989	118	67	182	95	111	0	0	48	22	82	167	226	1118
1990	82	290	246	247	66	0	0	0	14	142	128	203	1418
1991	87	107	150	185	66	25	0	3	1	260	54	156	1094
1992	37	95	102	97	-	-	-	-	-	-	-	-	-

MUSOMA RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1920	-	-	-	-	-	-	-	-	-	-	-	-	-
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
1922	51	48	192	110	96	2	5	35	28	34	20	20	641
1923	7	191	37	195	181	10	2	0	14	23	234	119	1013
1924	-	-	-	-	-	-	-	-	-	-	-	-	-
1925	106	77	124	39	46	55	28	61	5	52	155	102	850
1926	88	104	54	201	153	0	35	17	17	73	159	14	915
1927	53	108	212	196	93	20	0	6	1	18	16	56	779
1928	25	34	22	151	137	11	10	23	10	108	23	21	575
1929	19	4	85	82	79	10	33	48	1	16	50	255	682
1930	-	-	-	-	-	-	-	-	-	-	-	-	-
1931	61	28	147	173	49	11	45	23	10	13	29	56	645
1932	37	36	117	152	149	3	23	0	74	5	30	89	715
1933	62	46	98	41	106	23	4	47	4	31	22	69	553
1934	3	10	26	131	101	3	2	10	3	36	56	39	420
1935	11	137	55	92	74	12	0	0	105	38	43	88	655
1936	189	158	169	208	115	31	13	12	54	44	48	133	1174
1937	75	242	160	267	133	18	2	17	11	12	66	8	1011
1938	37	28	134	158	80	15	3	7	31	44	64	24	625
1939	11	36	231	154	48	21	0	21	1	11	62	41	637
1940	63	59	146	225	86	54	31	3	1	11	75	29	783
1941	88	8	30	135	80	62	0	46	2	10	130	112	703
1942	106	6	317	140	26	18	0	41	17	63	51	66	851
1943	37	131	25	263	110	51	0	5	5	40	28	16	711
1944	26	53	140	254	96	6	13	51	58	102	142	59	1000
1945	50	60	41	99	244	18	19	32	66	14	73	46	762
1946	16	8	54	139	170	30	9	21	14	10	60	119	650
1947	106	30	157	211	84	41	38	8	13	25	71	86	870
1948	120	50	102	179	173	48	1	18	24	46	55	150	966
1949	8	27	2	131	43	41	11	9	54	3	26	113	468
1950	47	53	260	187	80	34	0	24	6	18	46	18	773
1951	62	67	139	171	114	49	3	8	34	105	63	134	949
1952	54	43	154	231	161	33	3	21	21	5	46	10	782
1953	38	2	46	153	72	5	29	6	10	66	106	80	613
1954	31	18	43	457	121	44	145	11	35	18	44	47	1014
1955	119	109	123	117	143	1	37	17	37	56	65	71	895
1956	70	59	73	186	107	7	103	23	13	17	73	43	774
1957	110	128	128	168	244	50	0	15	19	14	78	77	1031
1958	27	87	169	111	66	39	20	7	14	66	9	213	828
1959	67	71	154	164	136	9	1	12	14	112	114	16	870
1960	128	159	329	314	46	16	3	0	41	19	74	7	1136
1961	19	119	58	104	152	19	5	53	121	103	500	179	1432
1962	179	71	79	262	125	37	0	11	37	33	168	40	1042
1963	79	60	123	143	207	4	3	5	2	15	183	121	945
1964	24	120	191	239	93	12	26	5	58	127	35	39	969
1965	24	43	165	173	31	12	13	18	11	34	70	112	706
1966	90	94	156	227	45	30	1	166	20	48	83	16	976
1967	21	15	49	168	120	9	50	15	30	75	116	64	732
1968	1	251	82	207	50	6	16	1	34	54	132	95	929
1969	150	88	196	76	171	22	0	4	10	19	120	12	868
1970	49	90	204	233	120	1	31	5	23	49	73	114	992
1971	90	43	60	156	67	3	98	33	74	33	79	90	826
1972	15	60	25	112	84	28	1	3	6	63	130	149	676
1973	46	41	43	240	83	49	0	42	54	13	139	81	831
1974	22	62	92	246	86	74	52	2	49	10	75	61	831
1975	14	41	190	73	98	6	35	13	31	81	17	75	674
1976	20	22	52	150	90	35	10	26	10	26	37	30	508
1977	79	13	71	258	47	39	4	31	19	115	228	29	933
1978	34	189	149	176	59	41	1	17	23	103	152	140	1084
1979	102	239	68	156	113	25	2	9	28	46	52	84	924
1980	63	14	101	99	224	12	0	35	7	27	50	8	640
1981	44	29	399	211	118	9	26	5	38	13	27	28	947
1982	45	42	72	244	188	44	5	21	39	91	229	65	1085
1983	46	8	68	186	125	84	14	45	42	75	55	35	783
1984	46	34	19	129	106	18	34	14	4	99	85	54	642
1985	96	81	174	307	108	10	9	5	5	29	83	59	966
1986	42	122	136	238	129	6	1	0	3	87	44	269	1077
1987	34	124	112	155	180	71	13	12	17	12	100	18	848
1988	72	49	107	323	192	7	46	9	55	43	89	144	1136
1989	33	62	125	95	83	7	5	27	106	113	164	167	987
1990	31	103	157	303	42	0	0	1	18	125	58	60	898
1991	131	123	88	154	96	98	19	1	5	221	73	67	1076
1992	11	39	88	146	-	-	-	-	-	-	-	-	-

KISUMU RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1900	-	-	-	-	-	-	-	-	-	-	-	-	-
1901	-	-	-	-	-	-	-	-	-	-	-	-	-
1902	-	-	-	-	-	-	-	-	-	-	-	-	-
1903	152	138	166	212	231	244	28	21	101	161	19	118	1591
1904	33	38	101	128	153	18	45	124	45	93	152	261	1191
1905	135	77	249	122	57	48	77	57	64	47	184	363	1480
1906	8	437	393	171	109	163	42	152	67	76	53	221	1892
1907	50	49	74	286	133	77	63	24	16	23	71	22	888
1908	65	114	137	313	194	122	149	113	28	51	90	77	1453
1909	55	51	113	146	91	63	28	61	61	26	66	175	936
1910	27	17	75	125	79	63	145	50	61	100	11	149	902
1911	0	6	173	185	183	78	25	61	25	81	177	0	994
1912	26	129	151	276	124	85	92	128	33	19	154	61	1278
1913	14	38	293	208	125	92	80	49	19	80	64	67	1129
1914	111	92	155	78	110	91	69	200	171	47	166	91	1381
1915	58	7	161	179	143	219	0	20	93	96	71	96	1143
1916	172	107	149	381	173	125	0	84	95	45	27	101	1459
1917	118	151	51	245	211	188	16	96	51	72	9	0	1208
1918	72	62	72	126	93	30	40	26	18	62	70	76	747
1919	0	96	82	200	164	106	62	57	107	74	114	174	1236
1920	8	41	120	252	156	36	72	20	47	81	145	87	1065
1921	41	99	35	86	166	80	181	74	44	88	78	93	1065
1922	33	121	253	200	116	32	29	133	132	64	16	82	1211
1923	0	99	133	356	196	191	214	8	66	50	45	88	1446
1924	0	76	100	213	89	30	27	78	88	21	112	43	877
1925	96	21	182	48	189	66	99	72	32	45	237	78	1165
1926	24	154	163	256	357	21	69	120	182	38	85	35	1504
1927	56	90	208	200	120	59	19	88	40	21	45	80	1026
1928	29	19	137	194	282	72	80	48	171	48	66	118	1264
1929	16	9	45	254	87	97	95	63	65	53	113	124	1021
1930	46	19	150	307	229	65	64	33	149	127	26	53	1268
1931	28	61	196	206	168	102	71	84	63	27	68	117	1191
1932	35	114	196	326	288	30	47	116	76	32	26	76	1362
1933	113	48	117	135	93	44	82	171	120	62	57	47	1089
1934	3	22	64	174	105	35	45	159	33	125	124	64	953
1935	53	185	70	248	208	120	69	48	58	62	40	90	1251
1936	90	154	102	112	81	98	67	69	74	48	41	193	1129
1937	91	74	187	195	268	39	48	91	23	111	144	98	1369
1938	38	19	199	240	200	63	63	36	111	65	99	148	1281
1939	45	59	110	243	121	167	64	109	50	86	111	30	1195
1940	115	185	173	152	147	76	72	17	22	40	229	52	1280
1941	18	37	183	149	228	151	32	57	51	35	199	301	1441
1942	25	96	300	147	305	30	40	75	34	9	6	94	1161
1943	4	100	53	166	137	112	39	72	151	50	45	13	942
1944	5	38	334	110	213	57	141	220	105	43	132	35	1433
1945	80	50	50	93	212	172	43	183	16	67	35	49	1050
1946	2	0	121	104	151	186	60	203	146	55	112	92	1232
1947	131	114	176	182	257	96	53	84	91	88	45	144	1461
1948	141	30	142	93	135	62	61	37	126	122	29	42	1020
1949	0	85	25	332	82	157	61	83	21	17	88	152	1103
1950	87	7	258	173	77	84	43	56	34	95	18	69	1001
1951	28	87	179	405	176	112	114	139	55	131	238	218	1882
1952	13	99	219	366	312	88	43	59	66	22	28	1	1316
1953	87	44	80	257	94	120	46	24	88	54	208	59	1161
1954	26	35	119	235	178	65	147	126	67	76	15	164	1253
1955	73	107	114	111	130	27	113	145	141	44	59	179	1243
1956	162	31	161	175	114	192	27	59	90	52	72	151	1286
1957	97	131	109	279	284	77	52	83	34	76	102	107	1431
1958	13	75	121	123	97	124	136	130	60	110	7	37	1033
1959	46	119	202	109	106	14	40	80	92	28	148	73	1057
1960	53	67	264	246	159	100	74	58	76	72	56	75	1300
1961	1	74	167	192	173	40	57	143	144	86	449	293	1819
1962	115	10	177	249	358	108	64	53	126	82	125	87	1554
1963	150	125	142	285	221	72	30	91	19	58	169	133	1495
1964	43	220	163	309	113	119	101	60	101	52	74	127	1482
1965	87	22	184	265	228	37	56	20	139	143	151	70	1402
1966	41	258	228	231	99	54	72	141	60	65	54	9	1312
1967	15	31	102	161	197	46	16	18	143	89	335	73	1226
1968	32	185	196	341	96	173	51	72	81	195	156	213	1791
1969	102	194	133	94	148	50	44	58	51	100	139	46	1159
1970	186	70	204	216	115	68	23	61	54	73	69	125	1264
1971	13	11	74	345	289	45	59	97	48	170	92	153	1396
1972	12	123	71	228	194	106	76	155	93	152	226	62	1498
1973	132	102	14	215	234	34	20	77	78	13	104	20	1043
1974	11	28	149	306	71	104	135	69	88	40	131	64	1196
1975	19	53	280	178	169	35	39	160	20	86	64	106	1209
1976	82	67	64	358	71	41	89	113	144	52	140	101	1322
1977	71	83	142	310	287	88	89	109	20	101	182	84	1566
1978	147	177	240	212	196	93	88	123	115	104	143	129	1767
1979	62	234	217	162	142	57	61	89	82	24	163	176	1469
1980	44	45	178	224	126	66	89	39	74	90	75	66	1116
1981	39	31	306	95	169	78	76	113	54	15	71	60	1107
1982	49	68	61	113	81	170	91	80	152	169	318	94	1446
1983	15	46	40	254	120	100	27	88	43	141	191	79	1144
1984	45	51	34	143	126	57	195	119	93	67	229	73	1232
1985	97	87	247	224	227	111	87	57	63	42	47	69	1358
1986	68	88	228	246	146	72	103	39	105	69	95	90	1349
1987	61	136	164	128	121	163	32	28	113	188	119	41	1294
1988	175	10	152	397	83	57	132	27	103	46	162	80	1424
1989	79	127	202	171	186	57	17	83	103	140	81	122	1368
1990	49	180	197	199	69	39	44	137	54	41	74	94	1177
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-

NZOIA CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	87	28	162	59	197	150	200	171	36	73	165	9	1337
1926	34	76	91	164	183	92	194	231	248	115	103	7	1538
1927	62	50	78	175	134	81	108	121	66	9	27	28	939
1928	41	24	41	155	186	136	100	178	101	111	79	10	1162
1929	9	9	42	122	179	104	226	121	55	75	114	117	1173
1930	56	35	237	221	142	176	100	137	145	155	45	43	1492
1931	26	22	139	164	155	72	169	275	130	48	48	56	1304
1932	7	86	157	135	183	95	230	225	189	59	33	39	1438
1933	42	40	24	95	126	64	141	201	146	101	47	50	1077
1934	0	11	59	174	157	146	202	224	62	72	78	48	1233
1935	2	121	49	125	263	217	119	123	136	112	22	51	1340
1936	49	144	135	240	134	229	136	205	137	86	34	75	1604
1937	50	51	118	225	214	158	225	229	39	89	157	18	1573
1938	64	8	71	68	183	131	261	253	102	73	36	15	1265
1939	14	40	41	204	96	101	213	102	82	46	81	16	1036
1940	35	121	200	178	152	105	166	145	26	48	136	24	1336
1941	26	68	117	204	179	126	136	163	87	97	180	75	1458
1942	4	39	178	222	228	181	183	163	127	19	15	21	1380
1943	23	59	26	181	159	155	128	163	105	35	26	22	1082
1944	23	33	88	134	223	124	209	125	158	75	110	29	1331
1945	16	41	22	21	274	180	156	221	167	84	65	30	1277
1946	4	6	58	178	180	198	161	335	142	103	93	39	1497
1947	83	81	105	288	207	165	236	145	154	62	32	76	1634
1948	28	10	72	199	156	162	186	178	146	155	35	11	1338
1949	3	31	8	157	200	133	177	176	186	55	43	65	1234
1950	21	15	115	137	113	181	236	186	125	110	17	18	1274
1951	30	51	139	300	190	111	148	180	88	126	163	166	1692
1952	6	68	99	193	237	106	181	175	107	81	57	0	1310
1953	2	7	18	189	151	178	120	169	37	105	60	36	1072
1954	13	15	59	169	225	144	143	143	142	60	27	74	1214
1955	63	65	28	187	95	96	228	214	193	73	69	84	1395
1956	109	56	55	151	162	128	143	208	122	92	51	40	1317
1957	53	36	93	222	230	155	137	173	67	57	54	59	1336
1958	46	95	77	127	184	178	137	197	111	93	24	111	1380
1959	55	76	119	143	172	96	151	122	106	160	113	20	1333
1960	57	40	199	170	163	80	130	156	154	71	59	41	1320
1961	3	28	73	153	155	112	155	265	197	178	322	153	1794
1962	53	8	127	220	258	129	164	173	139	105	127	42	1545
1963	48	73	113	347	253	81	124	215	49	58	194	170	1725
1964	12	112	93	217	151	119	213	233	184	131	27	78	1570
1965	41	18	107	168	129	69	127	104	76	166	127	48	1180
1966	15	100	127	261	83	90	124	135	111	117	63	16	1242
1967	8	35	67	183	310	144	168	214	88	134	175	18	1544
1968	2	181	162	221	172	140	98	151	50	127	100	60	1464
1969	90	151	129	94	211	117	162	125	100	145	70	16	1410
1970	134	48	175	198	147	97	126	213	131	89	54	34	1446
1971	20	7	24	238	201	154	126	200	118	116	73	64	1341
1972	12	126	64	138	162	153	181	189	110	157	140	29	1461
1973	83	101	19	94	220	156	106	189	168	119	110	23	1388
1974	24	10	170	146	146	143	210	144	124	80	42	14	1253
1975	4	21	71	192	166	106	210	296	183	159	14	34	1456
1976	19	57	9	129	392	81	173	218	39	38	71	19	1245
1977	62	35	71	209	165	162	137	184	97	185	247	38	1592
1978	68	167	153	86	146	167	159	176	120	80	46	77	1445
1979	84	135	106	129	170	132	105	143	91	47	79	47	1268
1980	28	24	57	144	258	133	110	131	89	61	84	15	1134
1981	19	30	239	215	130	73	132	173	144	79	43	46	1323
1982	50	67	58	221	237	116	152	172	84	162	168	63	1550
1983	30	44	42	171	189	132	145	273	188	191	72	37	1514
1984	10	18	20	163	159	153	142	121	69	73	133	69	1130
1985	48	57	181	201	189	133	178	142	73	62	104	15	1383
1986	33	26	94	281	154	122	142	126	136	81	27	41	1263
1987	24	77	125	129	228	138	67	177	65	89	182	26	1327
1988	59	21	114	311	138	127	265	252	258	111	65	15	1736
1989	4	46	139	130	174	129	234	190	135	147	90	123	1541
1990	47	124	154	199	128	56	68	179	75	91	90	26	1237

YALA CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	151	30	209	60	216	103	148	192	57	85	217	76	1544
1926	38	154	158	314	298	83	151	220	203	109	98	36	1862
1927	76	72	141	216	183	132	74	151	66	19	44	63	1237
1928	69	33	132	243	287	137	77	144	155	114	88	66	1545
1929	15	8	65	222	168	128	155	155	117	85	161	173	1452
1930	76	66	233	278	241	142	79	153	232	172	61	53	1786
1931	56	50	274	280	249	126	131	234	152	67	67	124	1810
1932	27	127	196	275	249	101	135	218	182	80	53	105	1748
1933	103	98	95	169	179	78	174	252	203	96	42	56	1545
1934	3	29	70	188	217	122	148	190	100	133	142	94	1436
1935	21	214	104	201	305	216	108	102	133	152	45	110	1711
1936	121	167	191	236	162	185	95	143	119	93	86	132	1730
1937	79	86	175	301	269	122	122	183	83	120	200	89	1829
1938	56	24	172	196	263	156	184	162	189	121	76	79	1678
1939	36	51	106	260	144	204	120	132	66	76	124	50	1369
1940	78	196	283	248	237	90	149	133	55	67	249	51	1836
1941	39	71	149	214	235	231	112	143	86	71	266	241	1858
1942	14	74	307	267	351	88	106	160	141	40	11	75	1634
1943	11	95	57	236	184	177	75	172	130	39	32	31	1239
1944	19	46	234	183	254	92	133	194	167	113	148	50	1633
1945	45	53	45	53	320	215	152	228	159	105	56	58	1489
1946	7	2	93	217	215	243	144	290	185	110	140	85	1731
1947	148	114	151	342	322	161	149	151	183	86	55	143	2005
1948	65	19	111	182	196	167	130	167	129	153	43	25	1387
1949	2	40	16	310	161	164	126	139	189	76	80	112	1415
1950	67	25	207	212	154	177	151	163	117	149	22	49	1493
1951	48	121	167	403	267	116	121	180	104	143	253	269	2192
1952	15	90	144	329	334	112	198	138	139	86	73	1	1659
1953	43	24	56	287	148	152	80	109	80	111	157	62	1309
1954	27	29	74	244	278	102	185	187	126	102	41	147	1542
1955	82	131	88	200	186	81	184	199	206	125	73	194	1749
1956	149	68	148	253	208	138	107	179	155	124	87	126	1742
1957	114	80	148	319	291	128	138	152	87	72	85	159	1773
1958	65	118	143	155	256	166	138	202	90	132	38	99	1602
1959	60	130	172	188	172	74	121	143	149	175	162	69	1615
1960	105	87	301	271	188	128	117	127	193	112	106	61	1796
1961	0	68	154	227	211	108	113	264	266	151	480	277	2319
1962	102	18	184	336	346	169	156	187	199	169	154	87	2107
1963	131	134	180	361	238	132	82	164	94	89	205	150	1960
1964	32	158	172	328	165	141	152	200	208	137	55	98	1846
1965	55	38	149	270	194	66	112	117	115	185	158	94	1553
1966	35	193	209	292	143	100	103	147	105	104	103	27	1561
1967	11	65	102	225	353	187	105	167	154	148	259	57	1833
1968	24	274	202	331	207	198	77	201	125	158	164	115	2076
1969	99	197	158	103	197	120	105	175	118	160	110	38	1580
1970	210	83	270	273	190	138	145	214	180	109	95	84	1991
1971	64	18	45	357	296	147	159	223	135	165	85	121	1815
1972	36	149	81	247	220	177	164	161	111	206	301	69	1922
1973	147	155	11	158	300	133	94	197	234	120	137	34	1720
1974	28	18	197	291	175	193	215	106	153	106	74	51	1607
1975	26	72	378	241	228	47	53	216	27	116	87	143	1634
1976	111	91	87	484	96	55	120	153	195	70	189	137	1788
1977	137	101	193	308	316	185	120	197	67	129	221	78	2052
1978	115	203	215	227	193	170	118	199	175	166	98	110	1989
1979	108	265	213	177	205	178	104	207	141	53	119	98	1868
1980	42	42	84	233	249	135	133	138	127	93	124	37	1437
1981	62	69	306	270	156	126	163	179	161	118	95	64	1769
1982	90	83	53	199	282	137	195	221	172	236	277	113	2058
1983	49	70	85	272	180	133	110	186	204	222	148	89	1748
1984	40	49	34	238	177	111	204	176	95	87	166	93	1470
1985	88	72	195	283	240	121	195	131	133	100	130	40	1728
1986	50	56	160	272	218	85	155	72	173	139	65	94	1539
1987	71	114	229	170	306	125	95	136	101	148	211	36	1742
1988	151	49	175	490	196	146	216	240	270	141	120	42	2236
1989	48	108	198	222	250	92	115	215	165	165	105	166	1849
1990	76	184	210	278	178	99	100	208	118	92	122	90	1755

SONDU CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	161	4	130	29	184	123	137	204	27	50	174	62	1285
1926	83	126	87	278	161	113	172	234	213	113	163	36	1779
1927	28	71	62	175	159	88	155	135	89	20	83	34	1099
1928	28	34	67	221	260	146	88	115	38	138	99	15	1249
1929	5	4	62	170	183	117	189	130	113	60	52	108	1193
1930	144	49	258	285	215	159	93	139	160	91	60	32	1685
1931	18	43	171	213	220	139	176	159	153	56	90	97	1535
1932	19	43	222	148	230	140	124	190	189	63	51	54	1473
1933	71	43	45	62	184	94	164	202	143	57	33	57	1155
1934	11	27	48	115	98	121	167	183	68	50	87	74	1049
1935	4	196	65	175	264	217	111	115	107	131	35	109	1529
1936	111	185	186	186	132	134	70	156	108	75	41	106	1490
1937	61	68	166	301	248	186	177	170	35	103	190	56	1761
1938	54	42	173	145	206	152	182	223	126	97	38	65	1503
1939	37	58	63	220	90	130	153	144	46	40	102	33	1116
1940	93	124	223	211	186	111	153	182	29	51	135	16	1514
1941	54	83	128	264	271	170	100	166	81	111	197	126	1751
1942	19	16	275	233	217	126	66	220	101	38	28	74	1413
1943	11	67	54	130	217	144	135	128	125	36	35	55	1137
1944	14	30	111	194	139	67	147	141	151	117	130	84	1325
1945	44	44	14	42	222	183	190	204	215	61	55	53	1327
1946	10	10	86	235	169	214	112	217	126	63	41	49	1332
1947	156	80	145	313	202	198	156	160	189	59	23	84	1765
1948	21	9	87	204	185	217	193	169	145	80	48	39	1397
1949	14	34	3	210	168	124	132	179	188	42	35	106	1235
1950	59	28	132	179	226	115	156	124	116	97	33	17	1282
1951	53	60	165	397	177	90	59	134	55	135	162	299	1786
1952	22	61	77	365	300	69	167	115	105	110	39	9	1439
1953	43	5	45	160	157	187	73	100	60	104	83	94	1111
1954	28	43	40	216	253	133	124	177	154	97	37	85	1387
1955	27	114	80	153	157	95	163	213	215	82	82	120	1501
1956	166	86	98	204	202	127	125	184	97	98	68	56	1511
1957	80	42	143	306	254	207	105	131	55	46	80	63	1512
1958	74	106	150	165	214	81	102	143	105	112	44	143	1439
1959	64	82	198	179	173	68	62	109	104	90	149	59	1337
1960	87	86	216	253	135	72	71	122	131	130	103	36	1442
1961	5	68	86	181	168	100	48	178	121	135	454	235	1779
1962	98	45	149	274	259	131	136	108	139	150	73	148	1710
1963	151	85	120	269	226	78	119	164	45	52	230	185	1724
1964	36	130	156	355	134	82	140	99	117	117	33	105	1504
1965	80	30	108	248	171	99	102	90	78	142	136	98	1382
1966	45	160	198	303	91	69	136	188	149	98	98	23	1558
1967	14	46	131	201	267	128	118	103	79	92	198	78	1455
1968	40	203	151	356	149	145	140	135	43	118	140	100	1720
1969	136	163	141	79	137	99	74	74	99	58	101	29	1190
1970	219	114	254	256	217	132	113	167	122	112	60	79	1845
1971	77	10	53	241	214	135	129	189	107	73	42	134	1404
1972	96	146	94	107	191	127	53	103	88	173	159	105	1442
1973	186	161	22	130	219	146	80	155	176	105	126	27	1533
1974	33	37	217	260	146	146	247	93	100	69	57	34	1439
1975	30	36	203	282	180	92	171	205	130	123	44	77	1573
1976	42	59	79	180	195	113	141	158	80	51	105	86	1289
1977	188	68	126	256	188	117	125	93	50	101	211	108	1631
1978	110	173	294	238	159	168	83	125	124	112	91	146	1823
1979	92	172	131	216	189	139	72	113	98	34	73	100	1429
1980	73	24	133	166	219	132	76	77	99	88	139	35	1261
1981	33	51	219	259	200	88	182	145	175	76	55	68	1551
1982	45	64	58	254	223	74	97	166	119	178	255	192	1725
1983	50	81	83	218	100	140	107	133	121	194	92	94	1413
1984	93	36	31	219	85	75	114	134	84	106	157	99	1233
1985	69	81	213	285	174	96	144	108	86	55	121	76	1508
1986	43	54	67	188	147	79	83	89	103	92	96	129	1170
1987	84	105	151	164	197	178	85	126	85	58	175	27	1435
1988	191	54	147	320	174	86	122	199	147	99	103	39	1681
1989	56	120	206	276	185	70	110	187	153	188	90	152	1793
1990	80	159	284	279	198	62	90	176	83	135	89	102	1737

SONDU CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	161	4	130	29	184	123	137	204	27	50	174	62	1285
1926	83	126	87	278	161	113	172	234	213	113	163	36	1779
1927	28	71	62	175	159	88	155	135	89	20	83	34	1099
1928	28	34	67	221	260	146	88	115	38	138	99	15	1249
1929	5	4	62	170	183	117	189	130	113	60	52	108	1193
1930	144	49	258	285	215	159	93	139	160	91	60	32	1685
1931	18	43	171	213	220	139	176	159	153	56	90	97	1535
1932	19	43	222	148	230	140	124	190	189	63	51	54	1473
1933	71	43	45	62	184	94	164	202	143	57	33	57	1155
1934	11	27	48	115	98	121	167	183	68	50	87	74	1049
1935	4	196	65	175	264	217	111	115	107	131	35	109	1529
1936	111	185	186	186	132	134	70	156	108	75	41	106	1490
1937	61	68	166	301	248	186	177	170	35	103	190	56	1761
1938	54	42	173	145	206	152	182	223	126	97	38	65	1503
1939	37	58	63	220	90	130	153	144	46	40	102	33	1116
1940	93	124	223	211	186	111	153	182	29	51	135	16	1514
1941	54	83	128	264	271	170	100	166	81	111	197	126	1751
1942	19	16	275	233	217	126	66	220	101	38	28	74	1413
1943	11	67	54	130	217	144	135	128	125	36	35	55	1137
1944	14	30	111	194	139	67	147	141	151	117	130	84	1325
1945	44	44	14	42	222	183	190	204	215	61	55	53	1327
1946	10	10	86	235	169	214	112	217	126	63	41	49	1332
1947	156	80	145	313	202	198	156	160	189	59	23	84	1765
1948	21	9	87	204	185	217	193	169	145	80	48	39	1397
1949	14	34	3	210	168	124	132	179	188	42	35	106	1235
1950	59	28	132	179	226	115	156	124	116	97	33	17	1282
1951	53	60	165	397	177	90	59	134	55	135	162	299	1786
1952	22	61	77	365	300	69	167	115	105	110	39	9	1439
1953	43	5	45	160	157	187	73	100	60	104	83	94	1111
1954	28	43	40	216	253	133	124	177	154	97	37	85	1387
1955	27	114	80	153	157	95	163	213	215	82	82	120	1501
1956	166	86	98	204	202	127	125	184	97	98	68	56	1511
1957	80	42	143	306	254	207	105	131	55	46	80	63	1512
1958	74	106	150	165	214	81	102	143	105	112	44	143	1439
1959	64	82	198	179	173	68	62	109	104	90	149	59	1337
1960	87	86	216	253	135	72	71	122	131	130	103	36	1442
1961	5	68	86	181	168	100	48	178	121	135	454	235	1779
1962	98	45	149	274	259	131	136	108	139	150	73	148	1710
1963	151	85	120	269	226	78	119	164	45	52	230	185	1724
1964	36	130	156	355	134	82	140	99	117	117	33	105	1504
1965	80	30	108	248	171	99	102	90	78	142	136	98	1382
1966	45	160	198	303	91	69	136	188	149	98	98	23	1558
1967	14	46	131	201	267	128	118	103	79	92	198	78	1455
1968	40	203	151	356	149	145	140	135	43	118	140	100	1720
1969	136	163	141	79	137	99	74	74	99	58	101	29	1190
1970	219	114	254	256	217	132	113	167	122	112	60	79	1845
1971	77	10	53	241	214	135	129	189	107	73	42	134	1404
1972	96	146	94	107	191	127	53	103	88	173	159	105	1442
1973	186	161	22	130	219	146	80	155	176	105	126	27	1533
1974	33	37	217	260	146	146	247	93	100	69	57	34	1439
1975	30	36	203	282	180	92	171	205	130	123	44	77	1573
1976	42	59	79	180	195	113	141	158	80	51	105	86	1289
1977	188	68	126	256	188	117	125	93	50	101	211	108	1631
1978	110	173	294	238	159	168	83	125	124	112	91	146	1823
1979	92	172	131	216	189	139	72	113	98	34	73	100	1429
1980	73	24	133	166	219	132	76	77	99	88	139	35	1261
1981	33	51	219	259	200	88	182	145	175	76	55	68	1551
1982	45	64	58	254	223	74	97	166	119	178	255	192	1725
1983	50	81	83	218	100	140	107	133	121	194	92	94	1413
1984	93	36	31	219	85	75	114	134	84	106	157	99	1233
1985	69	81	213	285	174	96	144	108	86	55	121	76	1508
1986	43	54	67	188	147	79	83	89	103	92	96	129	1170
1987	84	105	151	164	197	178	85	126	85	58	175	27	1435
1988	191	54	147	320	174	86	122	199	147	99	103	39	1681
1989	56	120	206	276	185	70	110	187	153	188	90	152	1793
1990	80	159	284	279	198	62	90	176	83	135	89	102	1737

AWACH KABOUN CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	139	61	160	116	270	158	135	102	93	65	407	168	1874
1926	83	153	181	305	181	225	170	200	332	259	184	103	2376
1927	52	40	123	163	121	75	20	131	131	21	136	139	1152
1928	99	110	167	323	233	113	30	110	85	0	111	0	1381
1929	25	23	161	244	303	90	179	161	103	69	127	113	1598
1930	204	0	209	435	186	141	83	194	89	125	123	53	1842
1931	52	62	243	204	201	179	178	265	203	180	84	75	1926
1932	34	144	267	238	208	78	95	166	134	82	38	130	1614
1933	98	119	71	85	110	36	147	202	203	115	55	133	1374
1934	3	11	74	213	260	160	74	143	118	117	177	166	1516
1935	14	225	145	180	158	118	31	56	185	98	53	108	1371
1936	126	205	282	265	134	129	92	194	127	164	69	228	2015
1937	99	205	315	454	236	204	138	104	88	122	155	63	2183
1938	46	14	152	144	216	126	115	136	189	180	120	59	1497
1939	5	100	126	260	139	145	77	106	73	142	97	75	1345
1940	137	102	132	243	233	46	119	104	42	59	239	100	1556
1941	13	161	78	345	194	181	80	214	117	85	339	219	2026
1942	58	14	362	269	164	219	43	261	124	37	59	103	1713
1943	0	92	33	203	244	134	28	211	120	57	42	38	1202
1944	43	49	181	237	157	60	73	190	233	88	214	163	1688
1945	85	78	53	75	239	149	188	151	217	129	87	23	1474
1946	67	4	125	115	250	148	132	205	118	122	104	64	1454
1947	90	73	190	321	309	120	132	152	175	146	107	99	1914
1948	33	11	135	276	237	248	120	186	135	132	43	35	1591
1949	32	28	13	268	235	172	178	130	170	98	23	209	1556
1950	26	61	143	293	145	116	156	202	80	95	21	16	1354
1951	62	116	190	433	169	184	86	138	89	172	210	256	2105
1952	3	74	185	265	292	86	135	146	145	188	75	12	1606
1953	41	21	93	219	190	195	57	62	219	211	177	78	1563
1954	45	71	112	323	317	159	71	109	270	141	36	168	1822
1955	57	99	91	288	237	82	143	234	256	142	210	175	2014
1956	83	16	56	283	347	148	81	165	202	240	129	89	1839
1957	88	85	80	265	246	157	79	172	106	90	200	105	1673
1958	47	119	204	246	222	225	85	190	128	202	69	160	1897
1959	80	105	244	206	152	93	27	92	208	168	184	61	1620
1960	124	93	287	230	181	88	56	80	267	81	162	55	1704
1961	19	68	168	154	224	130	62	152	143	231	521	183	2055
1962	52	24	240	297	281	259	66	131	360	247	98	115	2170
1963	120	128	172	343	245	119	83	107	58	71	182	268	1896
1964	48	133	143	444	163	107	154	113	201	149	94	144	1893
1965	24	66	218	352	226	84	99	74	79	134	132	131	1619
1966	65	126	158	234	66	121	74	101	98	104	85	61	1293
1967	25	62	125	199	263	160	91	98	99	111	158	52	1443
1968	5	213	256	330	207	143	96	254	101	182	271	115	2173
1969	211	219	152	99	180	126	59	112	119	136	155	60	1628
1970	137	77	346	270	192	125	137	103	48	74	207	97	1813
1971	60	0	52	220	153	74	151	112	117	99	88	156	1282
1972	89	125	126	186	178	127	84	122	127	219	235	94	1712
1973	168	70	21	159	281	263	104	222	263	88	150	63	1852
1974	48	41	203	316	170	175	187	77	226	166	126	64	1799
1975	64	43	160	250	242	174	155	155	227	167	92	71	1800
1976	114	185	96	226	338	157	201	118	142	82	143	102	1904
1977	157	64	139	352	264	155	127	301	135	157	351	128	2330
1978	82	205	304	255	168	169	58	186	153	165	215	145	2105
1979	92	150	104	209	168	121	99	174	42	41	109	120	1429
1980	47	75	184	183	256	156	111	115	128	62	123	127	1567
1981	48	75	190	280	161	139	153	161	156	64	100	83	1610
1982	69	94	83	252	249	140	92	223	72	189	367	310	2140
1983	93	72	101	228	189	98	135	124	148	240	206	114	1748
1984	36	56	30	178	107	169	215	128	83	87	182	104	1375
1985	62	76	203	266	221	98	140	103	146	109	154	53	1631
1986	25	62	123	272	140	136	110	198	116	150	110	141	1583
1987	93	58	151	229	211	165	139	138	162	132	111	44	1633
1988	97	36	232	225	252	139	124	137	212	177	134	85	1850
1989	70	155	231	295	186	51	77	184	134	148	162	230	1923
1990	111	302	336	373	222	30	89	110	118	99	109	121	2020

KAGERA CATCHMENT RAINFALL (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1925	52	101	102	79	148	18	18	6	35	78	129	105	871
1926	80	68	158	194	76	25	30	21	75	115	139	78	1059
1927	88	88	178	165	83	5	0	46	90	59	97	149	1048
1928	62	111	133	188	144	28	14	40	40	82	78	104	1024
1929	68	40	144	199	94	26	48	14	54	110	85	145	1027
1930	83	134	199	291	135	27	22	44	109	53	119	80	1296
1931	96	103	211	210	109	9	16	29	61	54	110	151	1159
1932	60	78	153	153	144	8	12	13	113	86	138	97	1055
1933	161	118	138	98	114	14	21	43	77	76	63	87	1010
1934	71	75	151	202	87	7	12	57	53	148	118	141	1122
1935	33	155	119	122	145	79	0	30	116	85	162	149	1195
1936	160	181	111	234	59	79	3	28	71	75	104	193	1298
1937	107	144	214	247	199	15	5	17	64	117	174	85	1388
1938	46	122	165	185	115	7	16	39	69	121	122	107	1114
1939	77	107	199	244	92	16	16	31	63	52	125	56	1078
1940	126	178	167	190	146	11	12	19	42	80	123	65	1159
1941	118	143	153	227	120	30	7	45	38	87	191	139	1298
1942	126	91	219	247	164	2	8	62	22	56	100	63	1160
1943	45	126	82	178	115	25	0	48	40	73	110	96	938
1944	126	80	140	153	163	1	2	18	85	101	142	95	1106
1945	89	87	87	144	236	32	23	62	99	75	134	78	1146
1946	78	68	77	233	96	18	7	23	66	97	143	127	1033
1947	109	107	119	288	190	32	35	3	55	97	76	112	1223
1948	105	65	126	200	83	13	9	18	85	80	102	115	1001
1949	69	93	49	219	76	13	20	43	82	87	90	123	964
1950	86	70	214	192	141	3	6	68	65	106	94	113	1158
1951	101	137	162	239	139	41	9	35	40	128	166	179	1376
1952	29	87	145	160	171	11	3	112	50	91	101	39	999
1953	104	36	172	222	110	48	1	42	105	96	152	61	1149
1954	48	121	88	243	188	22	17	23	62	89	92	152	1145
1955	149	157	128	170	72	12	35	20	141	91	80	170	1225
1956	134	78	114	216	143	13	5	39	50	77	113	114	1096
1957	100	93	155	258	131	42	14	35	18	66	104	145	1161
1958	70	85	130	201	101	12	6	41	48	69	122	150	1035
1959	89	123	114	202	104	17	9	14	64	86	155	103	1080
1960	137	123	165	242	58	9	0	5	50	91	112	69	1061
1961	69	164	176	124	111	7	11	26	89	160	336	132	1405
1962	76	61	119	138	198	25	6	75	74	134	110	95	1111
1963	117	120	171	224	229	35	1	20	61	71	188	163	1400
1964	70	159	167	313	38	15	23	25	40	87	105	133	1175
1965	22	96	181	179	149	5	17	22	90	92	199	90	1142
1966	117	112	177	191	23	15	0	28	77	84	149	94	1067
1967	52	73	132	146	180	33	7	16	111	103	197	87	1137
1968	86	190	184	223	142	66	7	1	34	113	199	129	1374
1969	144	184	130	196	159	5	8	4	76	82	132	100	1220
1970	156	96	170	247	108	5	24	39	77	85	135	108	1250
1971	83	94	117	213	120	13	34	49	54	95	134	79	1085
1972	112	178	122	144	155	76	6	29	92	117	179	140	1350
1973	78	109	100	242	153	12	0	26	113	80	129	113	1155
1974	76	82	132	190	61	57	38	22	60	43	109	90	960
1975	66	115	164	206	113	6	35	25	147	101	99	117	1194
1976	56	124	108	186	108	15	10	48	86	57	99	106	1003
1977	152	70	126	314	116	44	4	73	54	66	163	115	1297
1978	56	140	173	204	85	8	1	40	59	108	130	154	1158
1979	116	132	138	197	107	22	2	14	26	64	137	160	1115
1980	67	78	133	118	171	12	2	15	121	74	139	96	1026
1981	76	78	181	153	90	16	7	85	54	89	61	90	980
1982	95	48	73	231	161	11	3	2	73	135	201	116	1149
1983	37	81	114	266	61	21	4	38	46	99	83	71	921
1984	77	103	111	199	31	0	39	36	42	103	155	102	998
1985	100	111	133	302	81	2	0	2	96	86	173	112	1198
1986	94	104	162	274	94	7	0	3	37	99	185	147	1206
1987	156	118	143	169	129	30	0	6	111	93	225	68	1248
1988	93	97	134	221	108	0	24	80	112	142	162	77	1250
1989	107	82	105	305	99	35	1	31	93	196	103	139	1296
1990	40	196	242	172	84	0	0	14	51	119	192	122	1232