CHAPTER 11

THE MAIN NILE IN EGYPT

INTRODUCTION

The hydrology of the Nile in Egypt largely concerns storage and water use, as no flows are generated below the Atbara confluence. The longest record on the Nile is at Aswan, where flows are available from 1869. Volume XI of *The Nile Basin*, (Hurst *et al.*, 1978) deals with the hydrology below Aswan, and this chapter covers the same topic. The hydrology of the Aswan High Dam, or Sadd al Aali, is discussed, together with projects for providing more water for irrigation after the completion of the dam. The evidence of river flows below Aswan, and the records of the Nilometer at Roda Island, are described.

FLOW RECORDS AT ASWAN

River flows at Aswan have been published from 1869, though the construction of successive dams has complicated the background. The early flows from 1869 to 1902 were deduced from level records and a rating curve derived from Aswan downstream gauge readings and discharges measured in the sluices of the Aswan dam. Flows were first published in *The Nile Basin*, vol. IV (Hurst & Phillips, 1933), based on discharges measured in 1903–1927. They were superseded by flows published in *The Nile Basin*, vol. VII (Hurst *et al.*, 1946) derived from a general rating curve based on discharges measured during 1903–1939. It was suggested in the first reference that a shift in Aswan levels made it probable that the discharges were about 8% too high during the flood period. This was re-examined in the later reference and it was concluded that the revised flows were the best estimate available, with the reservation that the extrapolated flood discharges were rough approximations. After the construction of the first Aswan dam in 1902, the downstream flows have been based on calibrated sluice outflows. The sluices at Aswan were all calibrated (*The Nile Basin*, vol. IV, 1933) and daily discharges were computed from the reservoir level and the sluice openings. Flows during any gaps in the sluice records were estimated by interpolating downstream levels linked to calculated flows by means of a gauge–discharge curve. Measurements at Gaafra, below Aswan, were also made from 1918, especially during the high flow season; these were related to the downstream gauge readings at the old Aswan barrage, and used to complete sluice measurements. A daily record at Aswan from 1916 has been tabulated in *The Nile Basin*, vol. II, supplement 4 *et seq*. The 10-day and monthly flows for the long period 1869–1975 have been reproduced in *The Nile Basin*, vol. XI, Appendix I (Hurst *et al.*, 1978).

From 1902 the Aswan record has been published as "Flows below Aswan", but an additional record of "Water Arriving at Aswan" has been derived by adding the change in reservoir contents to the downstream discharge. From 1925 these were further supplemented by a record of the "Natural River at Aswan". This includes the water abstracted from the Blue Nile in the Gezira main canal, and allows for the regulation of the Sennar reservoir as well as the Aswan reservoir. Although the Jebel Aulia reservoir has affected downstream flows from June 1937, its regulation has not been included. From 1963 this record has included the water taken from the Blue Nile in the Managil canal, but did not take into account the evaporation losses in the Aswan High Dam or in Jebel Aulia, Sennar or Roseires reservoirs. However, from 1978 (*The Nile Basin*, vol. IV, supplement 11, Preface) the Natural River flow series included evaporation from the Aswan High Dam, estimated from water balance methods, and evaporation from Jebel Aulia reservoir. The Flows below Aswan and the Water Arriving form a good basis for analysis. The Natural River record as published does not include all the effects of upstream storage and abstractions, and the basis for calculation has changed over the years.

In view of this, the most useful record appears to be that of the Water Arriving at Aswan, which is presented as Fig. 11.1. This is supplemented by Fig. 11.2, which shows the monthly levels of the Aswan High Dam from 1964. The flows of Fig. 11.1 are reasonably natural before 1964. Later records reveal the decline in recent Blue Nile and Atbara flows. They also reflect reservoir storage and water abstraction within the Sudan, and evaporation losses within the Aswan High Dam after 1964. The early records illustrate the high flows in the period 1870–1900, when the lower envelope confirms the high flows of the White Nile and high Lake Victoria levels around 1878 and 1895. The reservoir levels show the effect of the low flows in the 1980s, followed by the recovery in 1988.

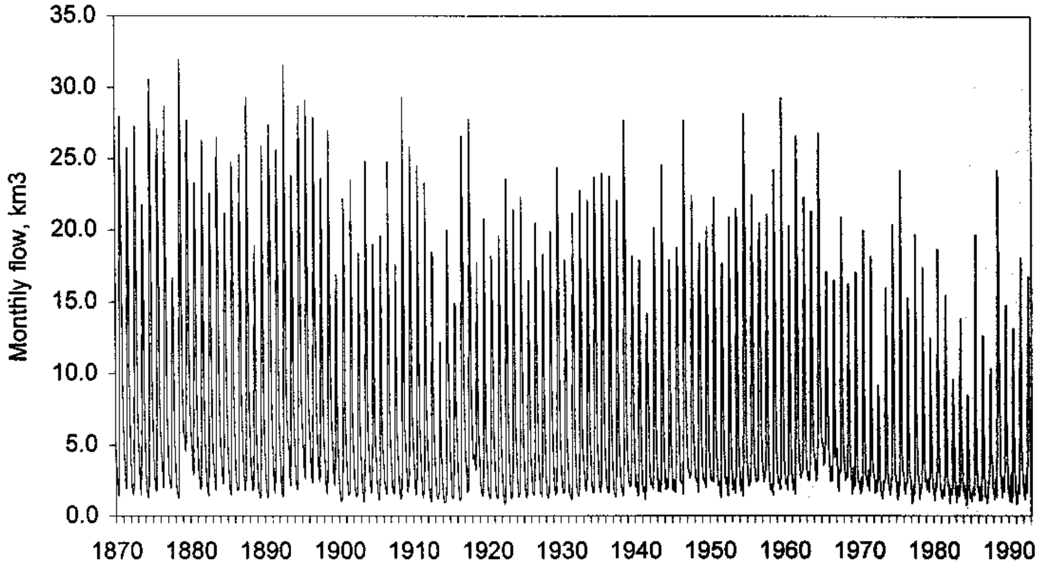

Fig. 11.1 Main Nile at Aswan: Water Arriving, monthly values, 1870–1992.

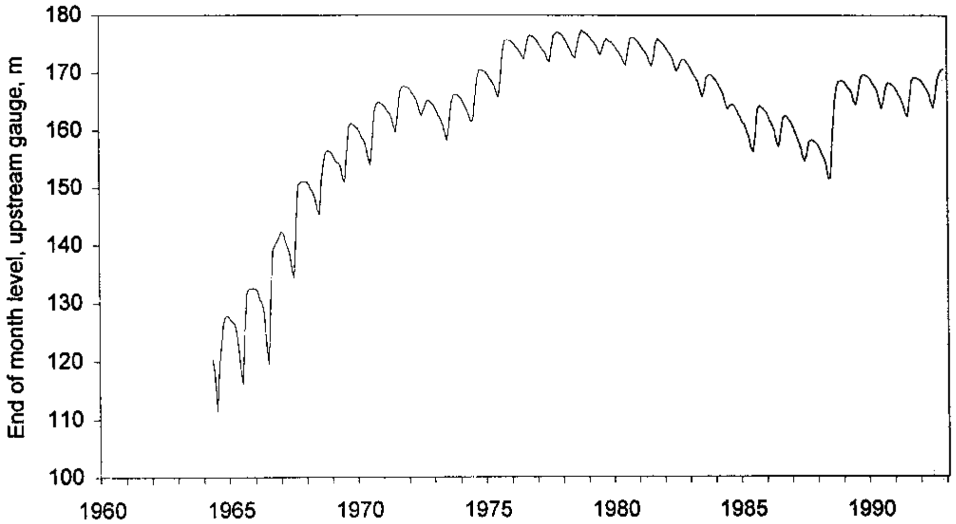

Fig. 11.2 Aswan High Dam: monthly levels, 1964–1992.

COMPARISON WITH UPSTREAM FLOWS

It is useful to compare the flows measured at Wadi Halfa/Kajnarty/Dongola with these different measures of inflow to Aswan, as comparisons can indicate the precision of the series. The apparent losses above Aswan have been deduced by comparing the annual upstream flows with the Water Arriving at Aswan (Fig. 11.3). This suggests a small gain between 1890 and 1910, followed by losses of similar magnitude between 1910 and 1960. These are likely to be due to measurement errors as evaporation losses over this short reach should be comparatively small. The most likely explanation is due to the start of gaugings at Wadi Halfa in 1911. After 1965 the losses increase rapidly to about 15 km^3, which must be largely due to evaporation losses from the Aswan High Dam, but these decrease after 1975 as the reservoir levels fall. Comparison of the Water Arriving at Aswan with the flows measured after 1910 at Tamaniat and Atbara mouth shows a similar pattern of losses to that deduced from the Dongola record. In Fig. 11.4 the apparent losses between 1965 and 1992 are compared with evaporation losses of 2.7 m (Hurst *et al.*, 1966, pp. 41–45) over the mean annual reservoir area. The losses can clearly be explained by the rise and fall of the

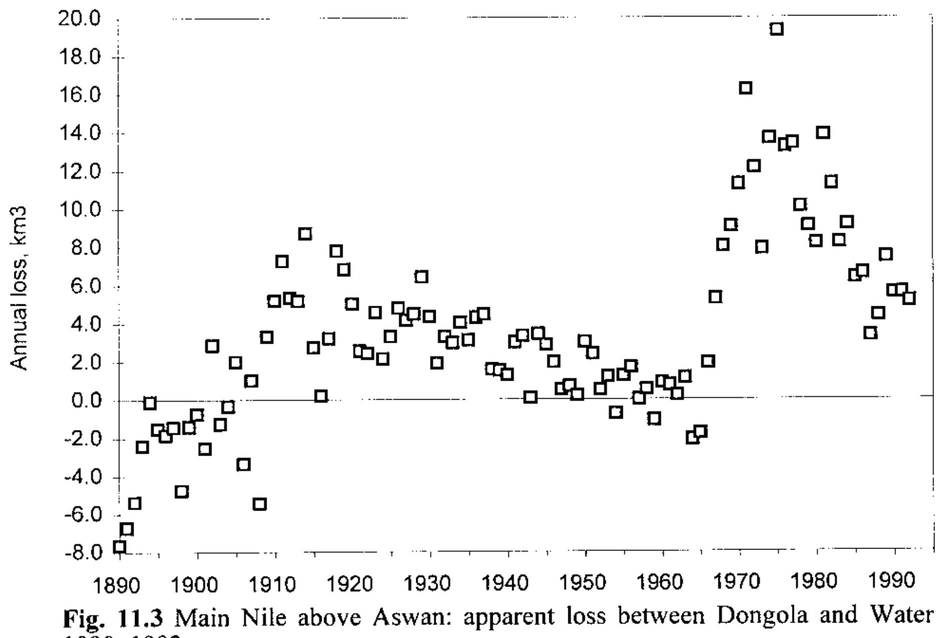

Fig. 11.3 Main Nile above Aswan: apparent loss between Dongola and Water Arriving, 1890–1992.

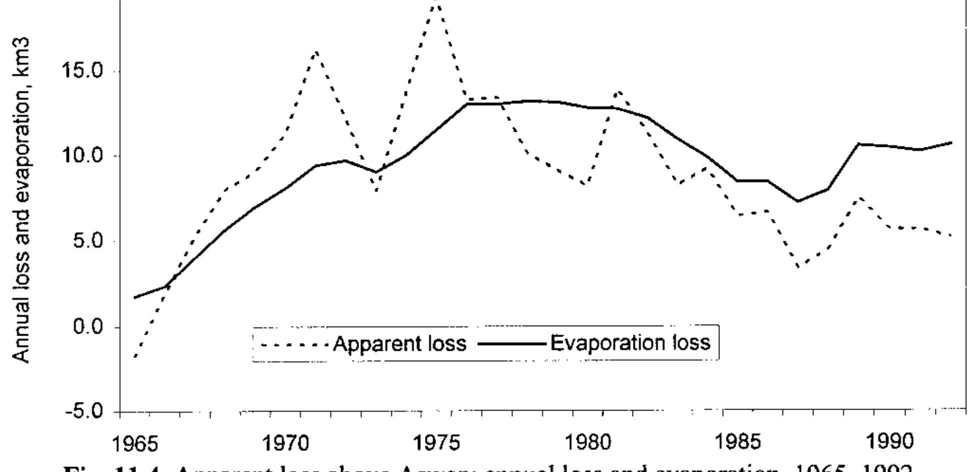

Fig. 11.4 Apparent loss above Aswan: annual loss and evaporation, 1965–1992.

reservoir. The losses also suggest losses to bank storage on a rising reservoir offset by gains when the reservoir falls.

The losses estimated from the Natural River flows at Aswan are similar, but show an apparent large gain of about 15 km^3 after 1978. This coincides with the change in the basis for calculating these flows, when the evaporation losses from both the Aswan and Jebel Aulia reservoirs are added to upstream abstractions for the first time.

THE GENESIS OF THE ASWAN HIGH DAM

The concept of the Aswan High Dam or Sadd al Aali arose from theoretical work related to storage in the East African lakes. This was described by Hurst *et al.* (1959, 1978) in *The Nile Basin*, vols IX and XI. The first dam at Aswan had been constructed by 1902 with a capacity of 1 km^3 and was heightened in 1912 with a capacity of 2.25 km^3; a second heightening was completed in 1933 with a total capacity of 5.25 km^3. The role of this reservoir was to provide annual storage and to augment the low flow of the Nile during the irrigation season; the flood flow was used for basin irrigation.

Overyear storage had been planned in the East African lakes in order to limit the effect of low years, and to supplement "timely flows" during the irrigation season. Losses in the Sudd were to be reduced by the construction of the Jonglei Canal. This project, known as the Equatorial Nile Project, clearly required the agreement of a number of countries. The original proposals would have reversed the seasonal flooding in the Bahr el Jebel swamps, and this was deemed unacceptable to the Sudan by the Jonglei Investigation Team (1954). There was also a plan to supplement storage in Lake Tana in Ethiopia. Against this background research on overyear storage had continued (Hurst *et al.*, 1964).

"Century Storage" was defined as the size of reservoir needed to guarantee a supply equal to the mean inflow over a period of 100 years. The range R of reservoir storage, ignoring rainfall and evaporation, should increase over a period of N years according to:

$$\log(R/\sigma) = K \log(N/2)$$

with $K = 0.5$ if the inflows are drawn from a random series of standard deviation σ. However, it was found empirically, from Nile flows and other physical time series, that the range increased with K values varying randomly about a mean of 0.73. Thus a markedly larger reservoir would be required to guarantee a draft equal to the mean flow from a natural rather than a random series. The same was found for drafts less than the mean inflow. In practice, the storage available in Lake Albert would be unlikely to provide the mean flow with this level of security. However, a small decrease in draft leads to a large reduction in storage (Hurst *et al.*, 1965, p. 39).

This empirical finding has become known as the Hurst phenomenon. It has not been explained in physical terms but can be simulated by various statistical models with a degree of autoregression (O'Connell, 1971). It has also given rise to advances in theoretical and practical statistics. It played an important role in Mandelbrot's work on the "Joseph effect" (Mandelbrot & Wallis, 1968). This was named after Pharaoh's dream of seven sleek and fat cows coming up from the Nile, followed by seven gaunt and lean cows; Joseph interpreted this dream as seven years of plenty followed by seven years of famine and recommended storage. This work in turn gave birth to a flourishing branch of applied mathematics (Gleick, 1987), epitomized by *The Fractal Geometry of Nature* (Mandelbrot, 1977).

Meanwhile an early account of the phenomenon was read by an Egyptian agricultural engineer, Adrian Daninos, who called on R. P. Black at the Physical Department in 1948. He asked whether the possibility of overyear storage at Aswan had been considered and what minimum volume of storage would be required; the rough figure of 150 km^3 was given. An initial survey, followed by an air survey, showed that such a volume could be obtained. A dam was proposed with maximum water level of 182 m, with 30 km^3 dead storage for sedimentation, 90 km^3 for overyear storage and 37 km^3 for annual storage and flood protection. It was later decided to raise the maximum storage level to 183 m, which allowed another 6 km^3 of storage. This initiative led eventually to the construction of the Aswan High Dam by 1964.

This project, which concentrated the storage for Nile control near Aswan, had obvious political advantages over schemes like the Equatorial Nile Project requiring wide international agreement. It also removed the earlier emphasis on "timely flow" which had led to the objections of the Jonglei Investigation Team (1954) to a reversal of seasonal flow through the Bahr el Jebel. An agreement between Egypt and Sudan was reached in 1959 which divided the expected yield of the project (74 km^3) between the two countries, with 55.5 km^3 allocated to Egypt and 18.5 km^3 to Sudan. This estimate of the yield was based on a long-term annual flow of 84 km^3 less an estimated evaporation loss of 10 km^3. In addition, any waters to be contributed by conservation measures to reduce evaporation in the swamps of the upper Nile were to be shared between Egypt and Sudan. These included the Jonglei Canal scheme in the Sudd, with a second phase involving upstream storage, the Bahr el Ghazal diversion project and a project involving the Baro and Machar marshes.

ELIMINATION OF FLOOD RESERVE

In vol. XI of *The Nile Basin* (Hurst *et al.*, 1978) an overview of possible options was made. A large reservoir in Lake Albert was unacceptable to the Uganda Government. The Jonglei Investigation Team maintained that the economy of the swamps would remain pastoral, and that virtual storage and season reversal were unacceptable. This jeopardized the value of the Bahr el Jebel and Bahr el Ghazal conservation projects. The prospects of regulation of the Baro were unlikely to provide increased supplies in the near future.

An alternative way of increasing the yield of the Aswan High Dam was to reduce the need for flood provision. An important role of the dam was to prevent downstream flooding of urban areas and agricultural areas adapted to perennial irrigation. Considerable flood damage had been caused in 1878 and other occasions in a less developed economy. However, the allocation of 30 km^3 for flood storage reduced the storage available for overyear control.

A possible alternative was the Toshka Flood Escape, where a natural depression in the western desert about 250 km above Aswan, and close to the reservoir, could be adapted to pass excess floods to the desert rather than to the sea. The prospect of flood provision through the Toshka Escape was examined by studying the effect of passing the flood series of 1870/71 to 1898/99 to the Toshka Depression. This showed that the flood storage could be reduced and overyear storage capacity increased by some 26 km^3; the annual quota could be increased by about 2 km^3 without the need to reach agreement with other users of Nile waters. By avoiding the downstream release of water during periods of flood, the project would reduce the risk of degradation below Aswan. Much of the estimated annual suspended sediment load of 130 million tonnes would be deposited above Aswan, and the downstream flood would be sediment free. The Toshka project came into operation in recent years.

THE EFFECTS OF THE ASWAN HIGH DAM

The benefits and effects of the Aswan High Dam have been described by Rushdi Said (Said, 1993, pp. 228–254). The dominant effect has been the storage of the flood water which used to flow to the Mediterranean, though about a third of this is lost to reservoir evaporation. As a result, Egyptian agriculture survived the droughts of the 1970s and 1980s. Because the threat of floods was removed, areas of basin irrigation could be converted to perennial irrigation with two or three crops annually. Irrigated areas in both Egypt and the Sudan were expanded as a direct result of the increased water availability. Hydroelectric power production made a significant contribution to the economy, providing half the total electric power used in Egypt in 1977.

On the other hand, the reservoir flooding led to the resettlement of the Nubian population, either to new lands reclaimed in Egypt or to the Khashm el Girba development on the Atbara in the Sudan. The Nile sediment load is now deposited above Aswan, though the dead storage of 30 km^3 has been estimated to last 400 years. In fact the sediment has accumulated in the upper 250 km of the reservoir, at an average rate of 109 $m^3 \times 10^6$ $year^{-1}$. The river flow below the dam is now free of sediment; with the flood discharge eliminated, scouring occurred at a rate of 0.02–0.03 m $year^{-1}$ after 1966, but has been stabilized by limiting flows. The loss of silt deposition is limited to the areas of basin irrigation; Egypt had relied heavily on chemical fertilizers in areas of perennial irrigation where yields have increased. Water quality has decreased downstream, and the variety of commercial fish species has decreased. In the eastern Mediterranean, sardine fisheries which had averaged annually about 18 000 tonnes have declined to a trickle. However, new fishing grounds were created in the reservoir, and the annual catch rose to 34 000 tonnes in 1987, though this may not be sustainable. Many of these side effects were anticipated, but the benefits of the dam were considered greatly to outweigh the disadvantages. The water benefits can be illustrated by the downstream flows.

FLOWS DOWN THE NILE BELOW ASWAN

The flows at various sites on the Nile below Aswan (Plate 11) have been published in vol. IV of *The Nile Basin* and its supplements. These include the Water Arriving at Aswan, the

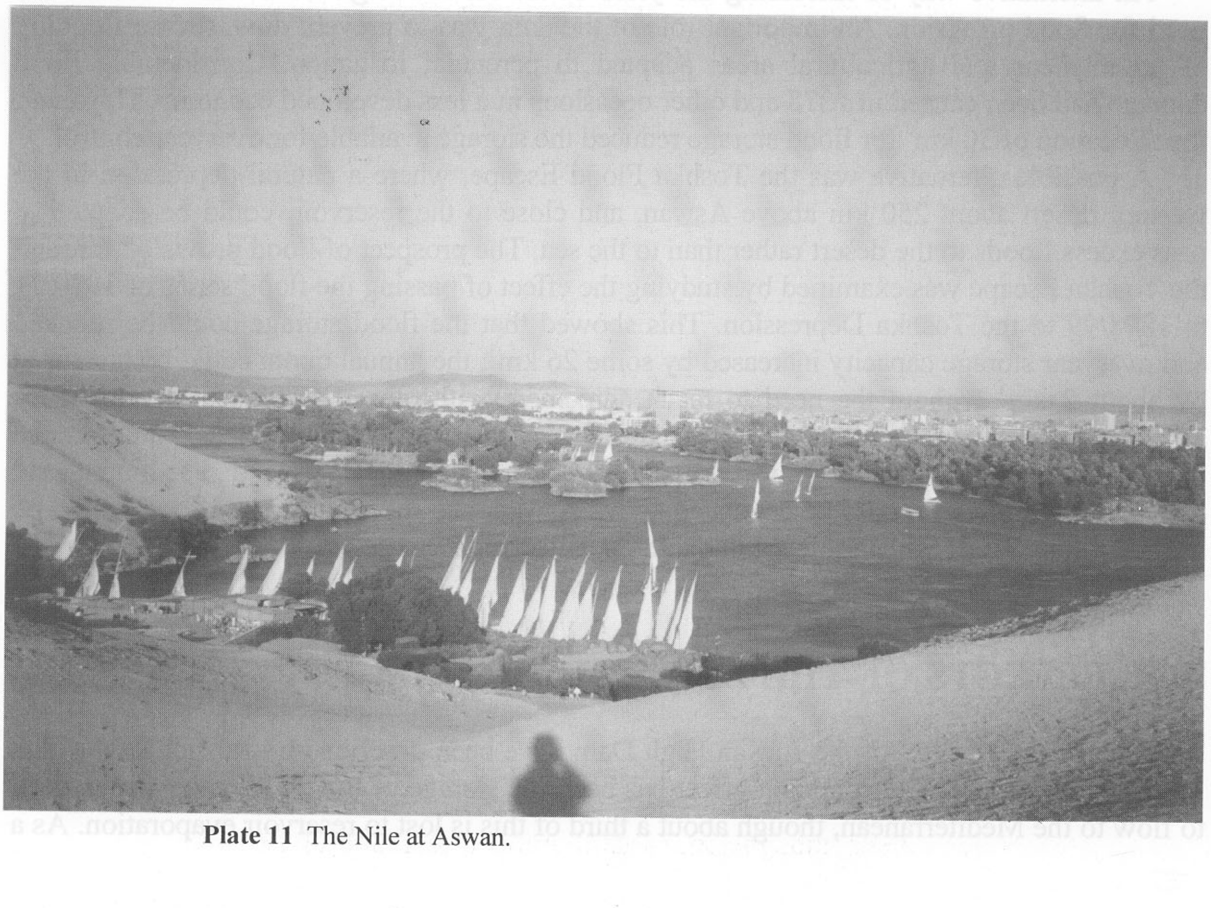

Plate 11 The Nile at Aswan.

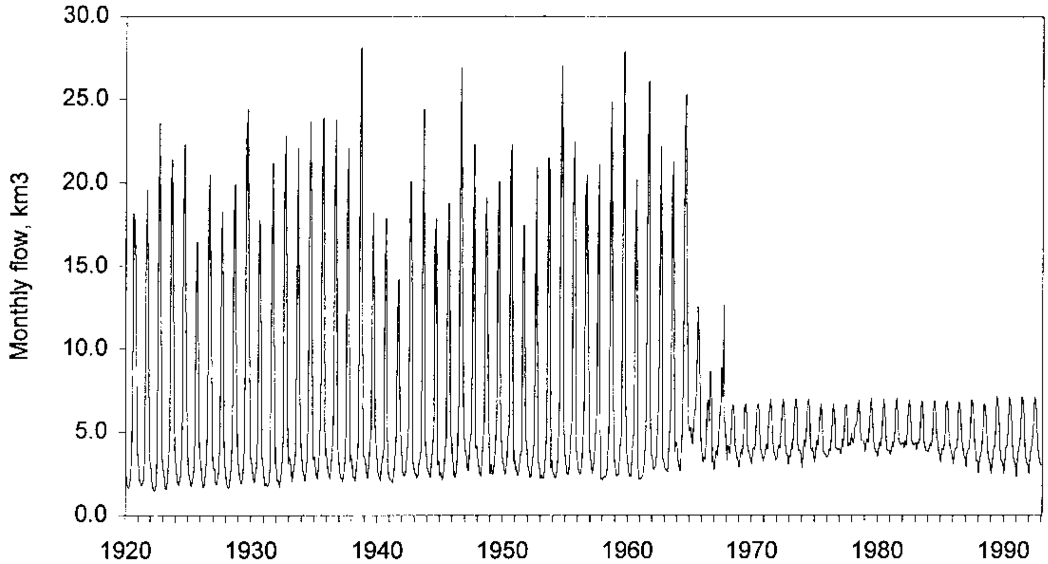

Fig. 11.5 Main Nile at Aswan: monthly downstream flows, 1920–1992.

outflows from Aswan reservoir and the successive downstream flows at the Esna barrage 166 km below Aswan from 1933, the Nag-Hammadi barrage 359 km below Aswan from 1940, and the Assiut barrage 539 km below Aswan from 1926. The Aswan outflows are shown from 1920 in Fig. 11.5, which shows the effect of the Aswan High Dam in increasing firm outflows. The annual inflows and outflows at Aswan and the flows at successive sites are presented in Fig. 11.6. In the early years there is little difference between the inflows and outflows at Aswan. After 1964 the outflows are relatively constant, showing the effect of overyear storage.

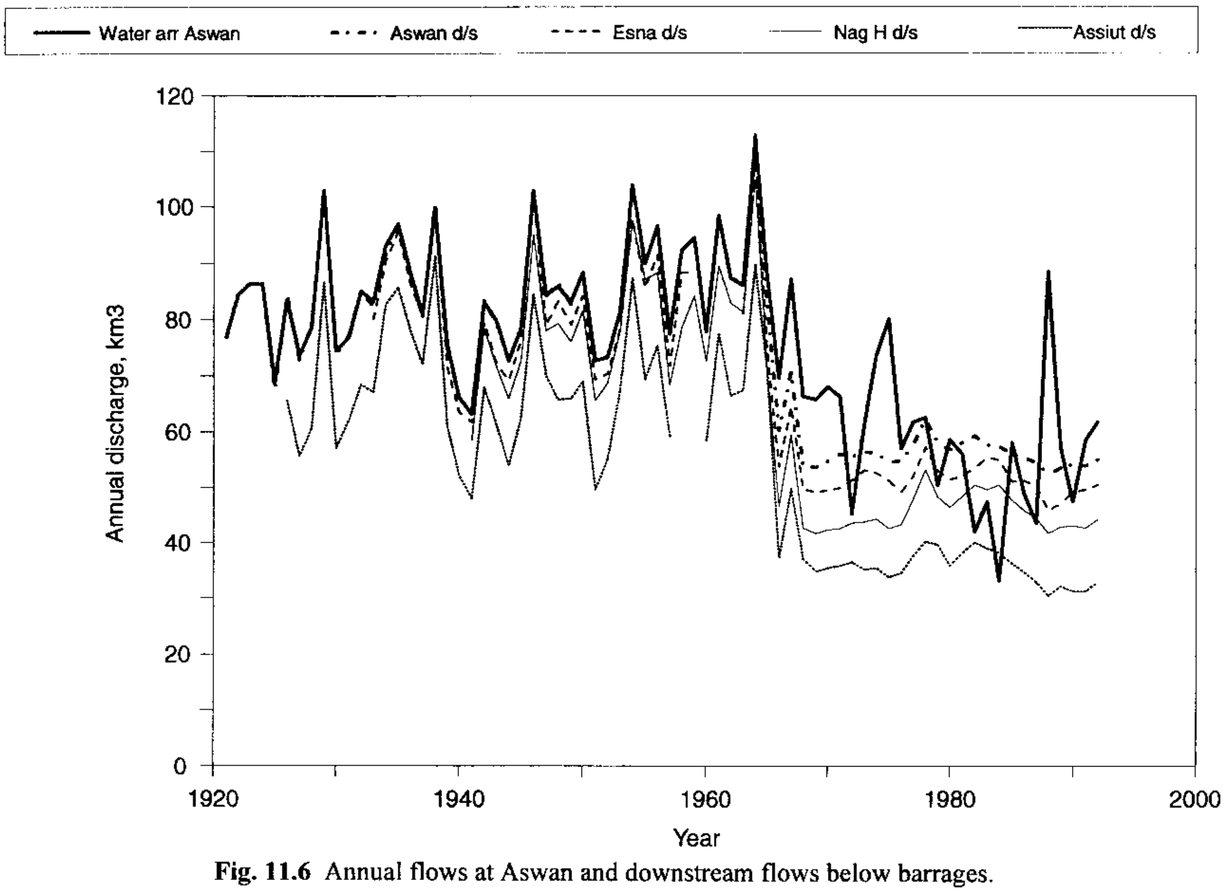

Fig. 11.6 Annual flows at Aswan and downstream flows below barrages.

The Aswan outflows are compared with flows downstream, with the difference representing the diversions for irrigation. As other sites are included the diversions from different reaches of the river can be observed. The abstractions between Aswan and Assiut have increased over recent years. After the completion of the dam annual releases have decreased, but firm flows have increased.

EVIDENCE OF THE RODA GAUGE

Because of the sensitivity of basin irrigation to the peak river level, flood levels have been recorded since early times (Said, 1993, pp. 127–169). For example, the Palermo stone records over 60 flood levels as far back as 3000 BC. Flood marks at Semna, about 50 km above Wadi Halfa, suggest exceptionally high levels between 1840 and 1770 BC. Nilometers were located at Aswan, Karnak and Memphis, and early qualitative records of floods exist. However, the longest quantitative records are from the Roda gauge (Plate 12) at the upstream end of Roda Island in Cairo.

This long record has been a continuing source of analysis and speculation. The series (Toussoun, 1925) records the annual maximum and minimum river levels for the period 622

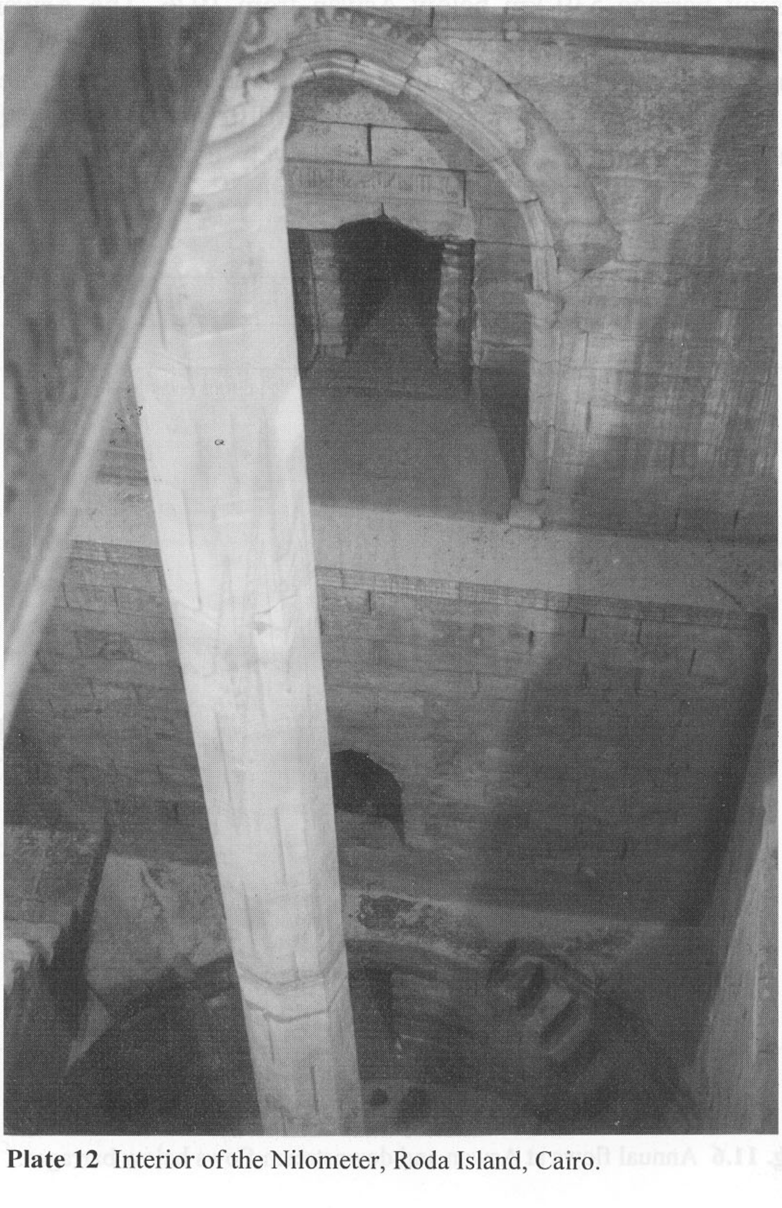

Plate 12 Interior of the Nilometer, Roda Island, Cairo.

AD to 1921 AD, and the record was preserved because of the significance of the flood level when flood irrigation was practised. The record has been criticized (Popper, 1951) for inconsistencies of scale and zero and has some gaps, especially in recent centuries. However, much can be deduced about recent flows from the record as it exists.

It is clear from mean and maximum flood levels over successive centuries (Fig. 11.7) that there has been significant channel aggradation over the period of record, so that evidence on flood series cannot be transferred over too long a period. A comparison (Fig. 11.8) of annual maximum Roda levels with annual maximum 10-day flows at Aswan, over the common period 1869–1921, shows that there is a reasonable relation between the two. Thus the Roda record provides useful information about the incidence of floods, which should be treated with caution when extrapolated backwards in time. The Roda gauge records before this period suggest that the 1878 flood was also the highest since 1824. There was an exceptionally high level of Lake Victoria in 1878; Lado on the Bahr el Jebel was flooded in the same year and the flood of 1878 is well known in the Sudd. Thus an event which involved the Blue Nile basin, which would have been responsible for the peak Aswan flow in September 1878, also included the East African lake basin.

Although the annual Roda minima could provide information about the White Nile flows and thus Lake Victoria levels, this evidence is more sensitive to aggradation and eventually to

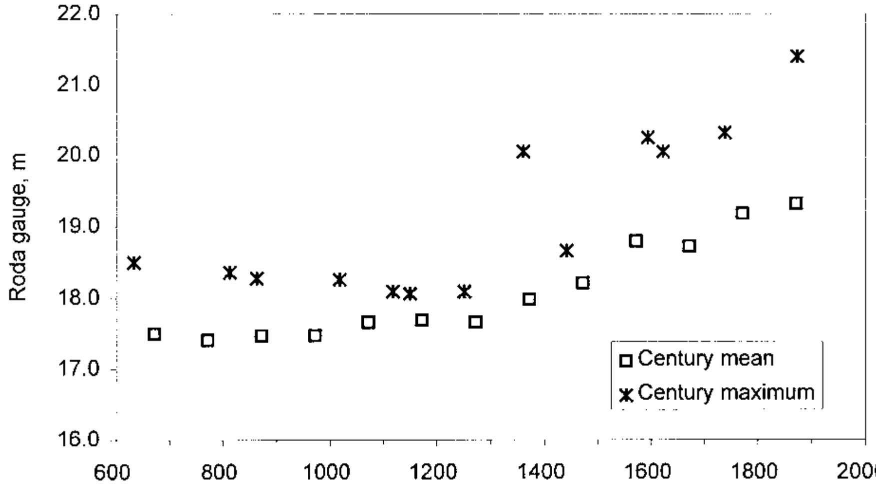

Fig. 11.7 Roda gauge: century mean and maximum flood levels, 622–1921 AD (after Sutcliffe & Lazenby, 1994).

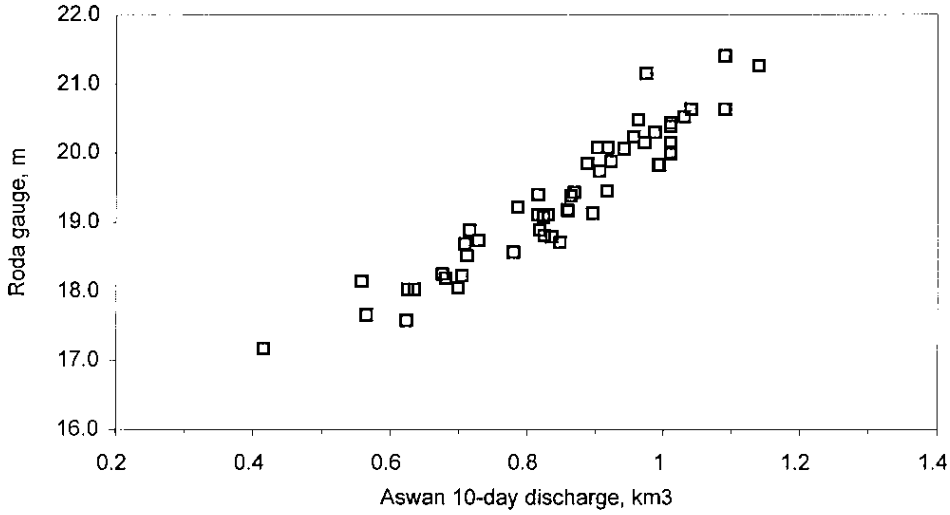

Fig. 11.8 Roda gauge and Aswan 10-day floods, 1869–1921 (after Sutcliffe & Lazenby, 1994).

the effect of reservoir storage. The evidence for high Lake Victoria levels in 1878 and 1895 is supported by high Roda minima in 1879 and 1895–1899, but the evidence from Aswan flows is more useful. As described earlier, the monthly series of inflows at Aswan (Fig. 11.1), and in particular the baseflow series, demonstrate clearly the high flows in January–May of the years 1879, 1895–1897 and 1917–1918 when the lake outflows are believed to have been high. The rise in White Nile flows after 1961 is more clearly demonstrated by the flows at Wadi Halfa/Kajnarty/Dongola (Fig. 10.4).

Flohn & Burkhardt (1985) investigated the relative role of Lake Victoria levels and the floods originating in Ethiopia on the dry season inflows to Aswan. They calculated the correlation between Aswan dry season (February–June) flows and each of Lake Victoria end year levels, and previous (August–September) flood inflows. They deduced that about half the variance was due to each source. They then used correlation to obtain a "tentative reconstruction" of the lake level series for the period 1870–1898; this was very similar to that derived by Lyons (1906) from statements by early travellers.

These two examples illustrate the way in which knowledge of one aspect of Nile hydrology can assist in understanding of the behaviour of another aspect. Although the Nile basin is extremely heterogeneous in terms of tributary behaviour, each reach reflects the character of the upstream tributaries. There are therefore links between the hydrology of widely different parts of the basin.

CONCLUSION

The inflows to Aswan integrate the complexities of the hydrology of all the upstream tributaries. The storage at Aswan was designed to release the mean annual flow with a high degree of certainty. It succeeded in doing so throughout the recent Sahel drought, and should continue to provide a firm yield if conditions in upstream basins do not change significantly. The flows below Aswan simply reflect water abstraction.