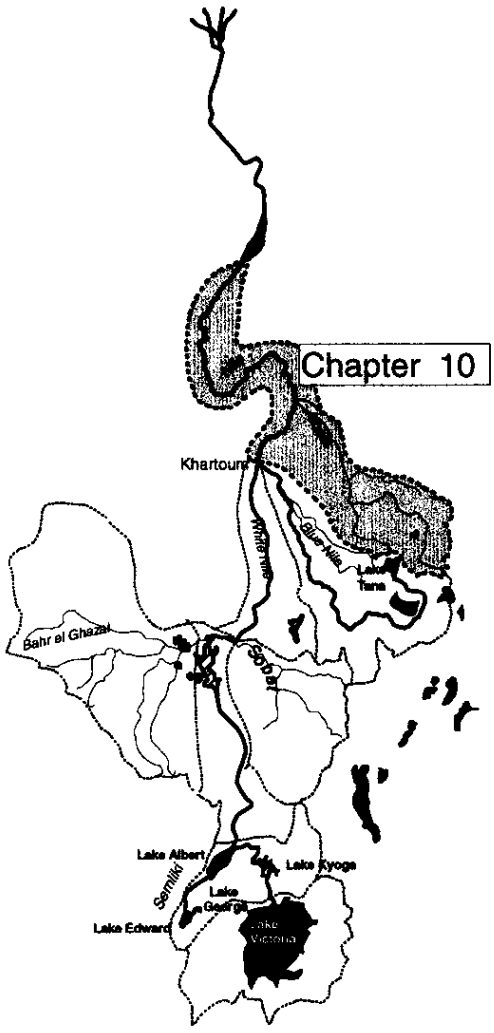
CHAPTER 10

THE ATBARA AND MAIN NILE TO WADI HALFA

INTRODUCTION

The reach from Khartoum to Wadi Halfa is about 1500 km in length and receives the last tributary to join the Main Nile; the Atbara is the most seasonal of the major tributaries. This chapter describes the topography and climate of this reach, and compares the regime of the Atbara with the other tributaries. The flow records at various sites on the main river are presented, and the precision of measurements is discussed. Comparisons over the period of record illustrate channel losses and abstractions for irrigation.



TOPOGRAPHY

This reach stretches from the confluence of the Blue Nile and White Nile down to Wadi Halfa. At 1490 km it is one of the longest discussed so far, but the only tributary is the Atbara. The topography of the river valley has been described by Hurst *et al.* (1959). Except for the Sabaloka gorge about 80 km north of Khartoum, the Nile flows through an arid plain which is dotted with many low hills and rock outcrops. For most of its course from Khartoum to Kerma (19°40'N) there are few hills close to the river. North of Kerma rocky hills approach the river, which runs near Wadi Halfa in a narrow rocky valley. Much of the reach is underlain by Nubian sandstone, which gives way to Basement Complex northeast of a line from Atbara to Dongola. Practically all the rapids and cataracts occur on the Basement Complex, including those between Atbara and Merowe and between Dongola and Wadi Halfa.

The river profile from Khartoum to Aswan (Fig. 10.1), adapted from Shahin (1985, Fig. 2.23), shows the comparatively gentle gradient between Khartoum and the 5th Cataract below the Atbara mouth. There is a steep segment between the 5th and 4th Cataracts and a relatively low gradient between the 4th and 3rd Cataracts, followed by a steep reach between the 3rd and 2nd Cataracts upstream of Wadi Halfa. Sixteen principal rapids between Khartoum and Wadi Halfa with a total fall of 102 m over a length of 228 km are listed by Hurst *et al.* (1959). The gradient of the river is extremely variable, with a minimum of 3.2×10^{-5} and a maximum of 1×10^{-3}. The average channel width, from gauging stations and other sites (Adam *et al.*, 1994), is about 600 m, from which the evaporation over the reach may be estimated.

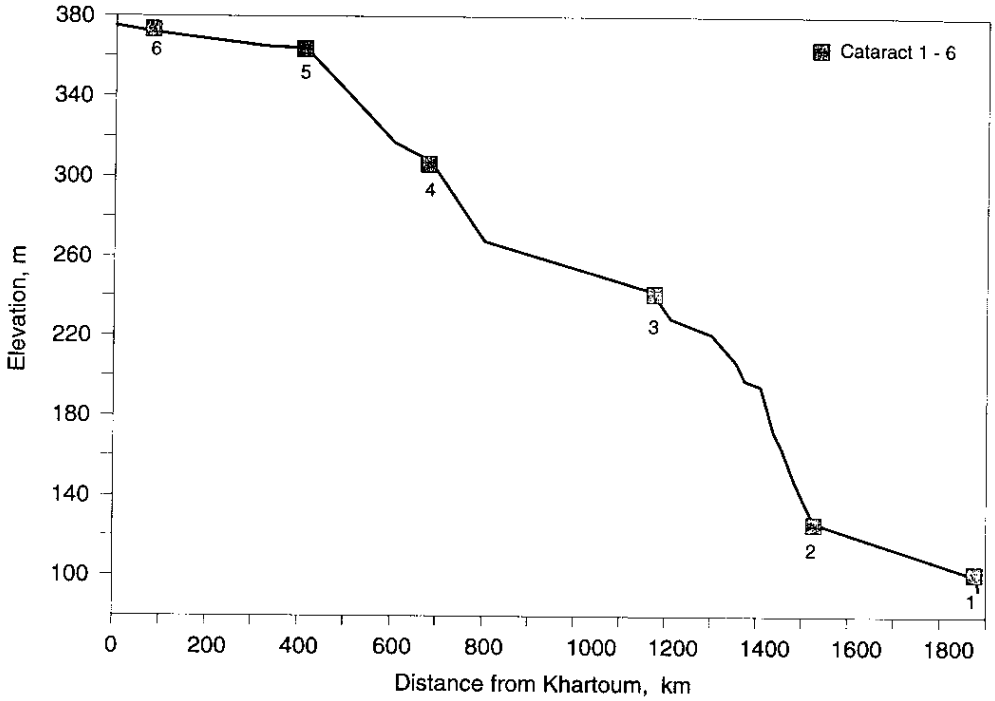


Fig. 10.1 Nile profile from Khartoum to Aswan (after Shahin, 1985).

The Atbara basin has been described by Hurst (1950). The Atbara, and in particular its more northern tributary the Setit or Tekeze, drains a wide area, 68 800 km^2, of northern Ethiopia and part of Eritrea. The Atbara, above its confluence with the Setit, drains about 31 400 km^2 of the mountains north of Lake Tana and the plain to the west. The country is rough and uneven, with some acacia bush. The lower basin within the Sudan is eroded below the plain and is joined by intermittent streams or "khors". The mean annual rainfall has been estimated (Hurst *et al.*, 1959) as about 950 mm, with the rainfall season shorter than the Blue Nile basin and concentrated in August and September.

LAND USE AND CLIMATE

Because of the arid climate, natural vegetation along the Nile is sparse, with some acacia scrub and Dom palms. Originally the local people along the river relied on livestock and small areas of irrigated land, but pumped irrigation has allowed this area to be developed to a considerable extent. Much of the irrigated land lies between the Sabaloka gorge and Atbara, and below Merowe and Dongola. Irrigation abstraction has risen since 1950 to about 1 km^3 over some 150 000 ha. The economy was sufficiently developed by 1988 for a fair amount of

Table 10.1 Average rainfall and evaporation at sites on main Nile (mm).

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average rainfall													
Khartoum	0.0	0.0	0.1	0.3	4.6	5.6	41.0	64.7	22.0	3.8	0.5	0.0	142.6
Atbara	0.0	0.1	0.0	0.8	2.9	1.5	19.7	31.8	6.1	1.5	0.0	0.0	64.4
Wadi Halfa	0.1	0.0	0.0	0.0	0.3	0.0	0.6	0.3	0.0	0.3	0.0	0.1	1.7
Open water evaporation (Penman estimate (after Shahin, 1985))													
Khartoum	223	218	288	315	322	303	260	211	213	276	246	220	3095
Atbara	170	174	232	318	288	270	273	267	258	307	195	174	2926
Wadi Halfa	140	162	220	261	288	294	298	288	258	239	183	124	2755

damage to be caused by flooding. There was some flood irrigation along the upper Atbara before the construction in 1960–1964 of the Khashm el Girba dam with an initial capacity of 1.3 km^3; since then irrigation has taken about 1.4 km^3 of water annually.

The main feature of the climate of the main Nile reach is the low precipitation. The most recent normals for key stations are given in Table 10.1. This rainfall is so low by comparison with open water evaporation, also tabulated, that the focus of attention in this reach has been on channel losses. There is unlikely to be any significant inflow from local drainage, except during exceptional storms like that of August 1988 (Chapter 9).

EARLY ACCOUNT OF THE HYDROLOGY OF THE REACH FROM KHARTOUM TO WADI HALFA

The main hydrological interest of this reach is in the time of travel, which varies according to flow, and in channel losses. These are a compound of actual losses through open water evaporation and bank storage, abstractions for irrigation and other uses, and also include measurement errors at gauging sites.

The times of travel have been studied by examples of fluctuations in flood flow from the Blue Nile and of releases from Jebel Aulia reservoir (Hurst *et al.*, 1959). The travel times from Khartoum to Atbara (300 km) were found to vary from 1 day at high levels to 5 days at low levels; this is equivalent to a rate of travel varying from 300 to 60 km day^{-1}. A number of gauge fluctuations were traced between Atbara and Wadi Halfa, a distance of 1170 km; the times of travel varied between 5 and 12 days, corresponding to velocities of 230 to 100 km day^{-1}.

The average losses from Khartoum to Atbara were estimated by Hurst *et al.* (1959) from 1912–1952 flows at Tamaniat and Hassanab as 1.2 km^3, or 1.6% of the upstream discharge. The net losses during the high flood of 1946, when 700–800 km^2 were inundated, were estimated as 1.8 km^3. Comparisons of 1912–1952 flows at Hassanab, Atbara mouth and Wadi Halfa or Kajnarty led to an estimated annual loss between Atbara and Wadi Halfa of 0.800 km^3. The distribution of losses between the two reaches seems disproportionate; however, the early flows at Hassanab were not based on contemporary gaugings, and the estimates before 1922 do not provide consistent estimates of losses. This topic is dealt with later using more recent records.

AVAILABLE FLOW RECORDS

These results on channel losses can be brought up to date, by comparing flows between successive stations. The differences between the flows of the main Nile at Tamaniat or Hassanab, plus the Atbara at its mouth, and the flows of the Nile downstream at Dongola are a useful indication of channel losses. The records cover the period 1911–1994, though the Dongola flows are a composite record. They are made up of flows at Wadi Halfa from 1911 to 1931, when the heightening of the Aswan dam affected the discharge site. Flows were then measured at Kajnarty, 47 km above Wadi Halfa, for the period from 1931 to 1962, when the Aswan High Dam made another move necessary, and at Dongola, 430 km above Wadi Halfa, for the period from 1963 to the present. The flows of the Atbara are measured at the mouth for the period up to 1992, and therefore include the storage in the Khashm el Girba reservoir from 1964. From 1993, the outflows from the Khashm el Girba reservoir have been substituted and the losses include those down the course of the River Atbara.

The upstream flows may also be compared with the recorded inflows to Aswan reservoir. Several flow records (Chapter 11) have been compiled for this site, including downstream flows, "Water Arriving", and "Natural Flows" which take account of reservoir regulation at Aswan and Sennar dams, and also abstractions above Sennar dam.

FLOW MEASUREMENTS

Before comparing flows at different sites, it is useful to compare the precision of estimation at each site. Because this depends to a large extent on the number of discharge measurements during each year, this is summarized in Table 2.1 for key stations from *The Nile Basin*, vol. II. Gaugings at Tamaniat began in 1907 and were frequent from 1911, averaging about 70 a year, until 1976, when the number decreased. Gaugings just above the Atbara confluence at Hassanab or Hodeiba began in 1922, with over 100 gaugings a year until 1930 and 70 a year thereafter. After gaugings of the Atbara at its mouth in 1913, measurements were regular from 1921 at about 30–80 a year. However, there was no level gauge near the mouth until June 1923 and these early gaugings were related to levels at the Khashm el Girba gauge some 440 km upstream. Gaugings have been sporadic since 1976. Gaugings at Wadi Halfa began in 1911, with a gap from 1915 to 1920, and then continued frequently until 1939; measurements at Kajnarty, upstream of Wadi Halfa, were begun in 1931 and continued at over 100 measurements a year until 1964; measurements at Dongola were begun in 1962 and have continued at about 100 a year to the present. Measurements at Aswan downstream are discussed in Chapter 11.

The flows published in *The Nile Basin*, vol. IV, are related to the available gaugings, though rating curves are in general looped with different curves for rising and falling rivers. The flows at Tamaniat are based on gauge–discharge curves from gaugings during the year, except for a few periods when flows are based on a general curve or on interpolation between measurements. From October 1928 to September 1929 gaugings were unreliable and flows were derived from the sum of Khartoum and Mogren flows. In later years flows were all based on annual rating curves. There was no level gauge at Hassanab before 1922, but flows from August 1908 were derived from the nearest gauge upstream at Shendi by relating gaugings at Hassanab during the period 1922–1925 against levels at Shendi and using this rating curve to estimate flows for the period 1908–1921; the flows for the period 1908–1913 were later corrected for a change in gauge zero at Shendi which had been overlooked and the revised flows published. From 1922 the flows were estimated from rating curves derived from gaugings during each year, though flows in 1923–1924 were interpolated between measurements.

The published flows of the River Atbara were estimated for the period 1903–1920 (excluding 1913) from a general rating curve based on all gaugings available, with the gaugings made near the mouth compared with levels at the Khashm el Girba gauge. Although an allowance was made for the lag between Khashm el Girba and the Atbara mouth, this procedure must increase the scatter and implies a stable section at Khashm el Girba. These early flows, published in *The Nile Basin*, vol. IV (1933) were later revised based on all observations during the years 1923–1936. The flows from 1921, and for 1913, were based on annual gaugings and rating curves; the rating near the Atbara mouth is affected by levels in the main Nile. From 1973, these flows have been supplemented by published discharges from the Khashm el Girba dam, constructed in 1960–1964, and abstractions through the Khashm el Girba canal. The latter began in 1965 and reached 1.0 km^3 in 1967; recent abstractions average about 1.4 km^3 per year and constitute a reduction in the natural flows of the Atbara.

Flows are available at Wadi Halfa from 1890, but the early flows, from 1890 to 1920, were estimated from a general gauge–discharge curve based on all observations, which as

noted earlier began in 1911. The flows after 1921, and 1912–1914, were based on annual ratings, except for high flow periods. The early years were revised, after extending the rating curve to higher levels, and published in *The Nile Basin*, vol. IV, supplement 2 (1939). Flood discharges between 1921 and 1927 were revised using later measurements. From 1931, a site was established at Kajnarty about 50 km above Wadi Halfa and above the 2nd Cataract to replace the earlier gauge which would be affected by the heightening of the Aswan dam. The two stations were used to give a combined record from 1931 to 1939, when gaugings ceased at Wadi Halfa, and Kajnarty provided the flow records based on annual ratings. This station was maintained until June 1964, but another station was established at Dongola, above the influence of the Aswan High Dam, from August 1962. Flow records at this station have been maintained since that date using annual rating curves. Thus a complete record is available for Wadi Halfa/Kajnarty/Dongola from 1890 to the present.

HYDROLOGY OF INDIVIDUAL COMPONENTS

The monthly flows of the main Nile at Tamaniat are presented in Fig. 10.2. These show a number of interesting features. The seasonal distribution of flows reflects the variable contribution of the Blue Nile, together with the Dinder and Rahad, contrasted with the more constant flows of the White Nile. However, concentration on the lower envelope of each year's monthly flows reveals the effect of the 1917 flood on the White Nile, which persisted during its passage through the Sudd. It also shows the increase in low flows after the construction in 1937 of the Jebel Aulia dam, which was operated to provide "timely flows" to Egypt in the period before the construction of the Aswan High Dam. The rise of Lake Victoria in 1961–1964, and the subsequent increase in lake outflows, are also reflected in the higher threshold of flows after this date but follow the general decrease in lake outflows in recent years. The Jebel Aulia dam has continued to prolong the low flow season by retaining the White Nile flood until after the Blue Nile flood has passed, and this effect may be seen in the aftermath of the 1988 Blue Nile flood.

The volume of the highest monthly flow reflects the peak of the Blue Nile flood, and this in turn is related to the annual total flow and is little affected by abstractions. The decreased Blue Nile flows of recent years are illustrated by the lower peaks occurring in the years after 1972, with the exception of 1988. Thus the Tamaniat record illustrates the history of flows of

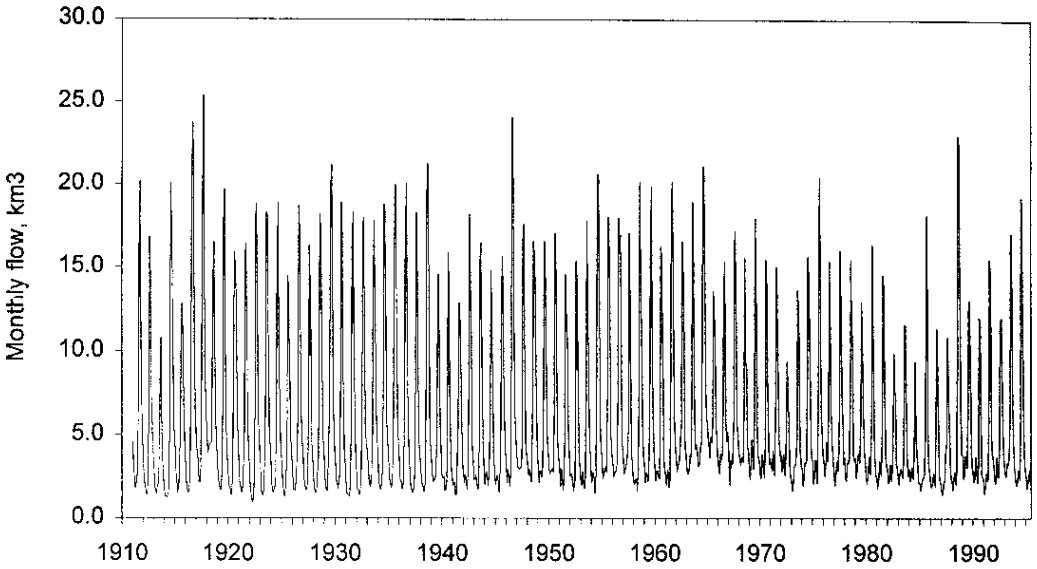


Fig. 10.2 Main Nile at Tamaniat: monthly flows, 1911–1993.

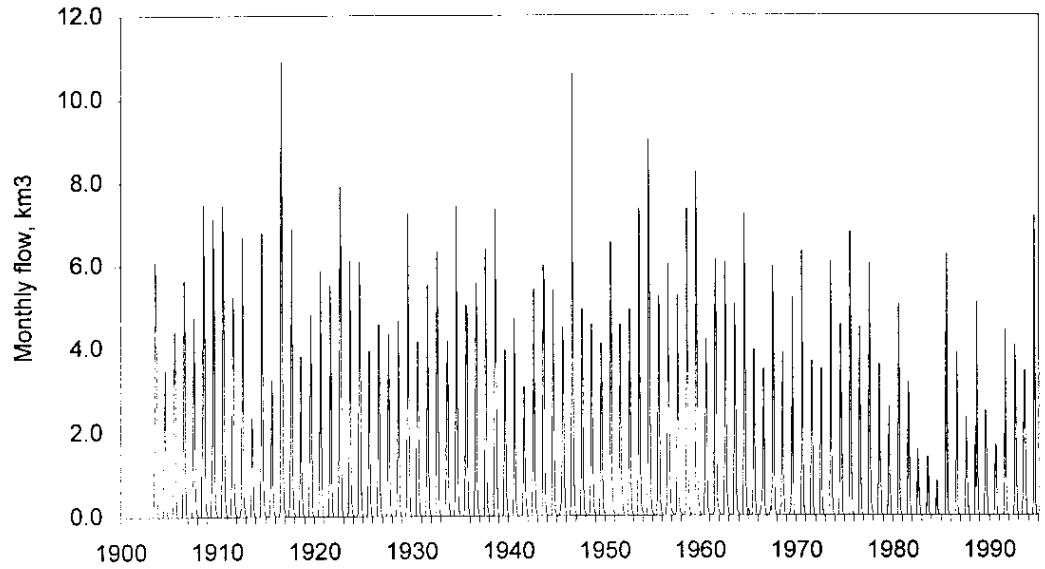


Fig. 10.3 Atbara near mouth: monthly flows, 1903–1994.

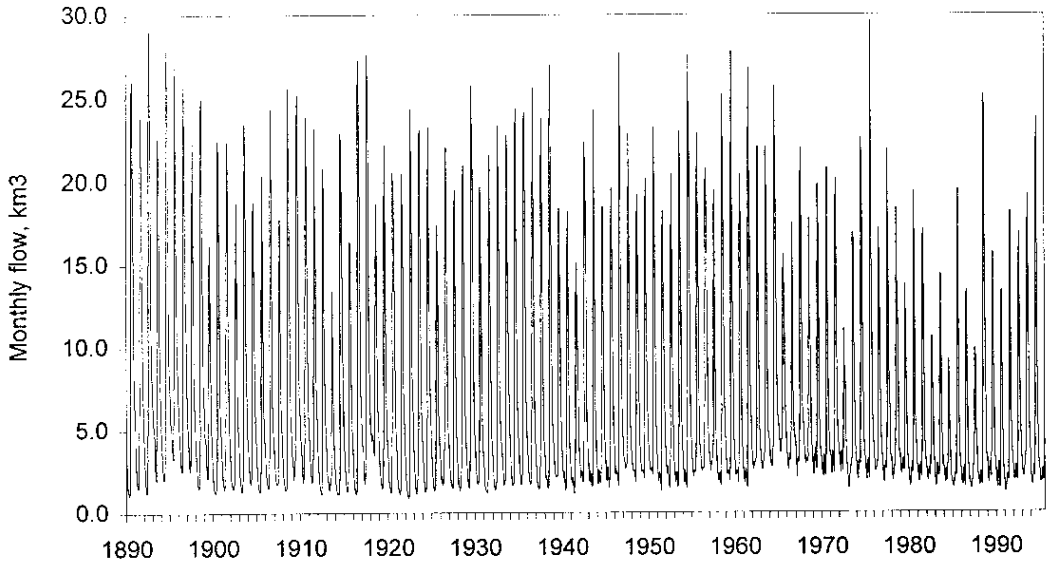


Fig. 10.4 Main Nile at Wadi Halfa/Kajnarty/Dongola: monthly flows, 1890–1995.

both the Blue and White Niles. The contributions of these two rivers to the flows at Dongola, discussed later, reflect the changing importance of the main sources (Fig. 9.10).

The monthly flows of the river Atbara (Fig. 10.3) show a similar pattern to those of the Blue Nile. The exceptional year of 1913, and the lower flows of recent years, are both illustrated by this record. The recent decline has been exaggerated by the effect of the Khashm el Girba reservoir on flows at the mouth. The extremely seasonal pattern of the Atbara flows is shown in this diagram.

The monthly flow record of the Nile at Wadi Halfa/Kajnarty/Dongola (Fig. 10.4) is similar to that at Tamaniat. However, its start in 1890 shows clearly the high Blue Nile flows of the decade 1890–1900 and also the peak flow of the White Nile around 1895. This confirms the evidence for high Lake Victoria levels at that date. However, the inflow record at Aswan (Chapter 11) takes this evidence back even further to 1870.

The seasonal distributions of flows at the different sites, and the variation in mean flows during different periods of record, are illustrated in Table 10.2. This table demonstrates the decline in flows between the periods before and after 1960, though some of this is due to increased abstraction. The increase in the White Nile contribution, as a result of Jebel Aulia

Table 10.2 Average discharges at key stations ($m^3 \times 10^6$).

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Main Nile at Tamaniat						**(1911–1960)**						
3111	2269	2266	2016	2016	2771	6723	16 973	16 988	11 328	5566	4027	76 054
						(1961–1995)						
3082	2349	2537	3324	3168	2988	5921	14 943	13 520	8 037	4333	3491	67 693
						(1911–1995)						
3099	2302	2378	2555	2490	2860	6398	16 151	15 584	9 996	5067	3810	72 691
Main Nile at Hassanab						**(1911–1960)**						
3161	2284	2230	1968	1892	2506	6030	16 095	16 792	11 655	5792	4079	74 483
						(1961–1995)						
3047	2309	2355	3111	3049	2911	5676	14 674	14 059	8 215	4457	3468	67 329
						(1909–1995)						
3146	2320	2286	2428	2359	2690	5937	15 607	15 859	10 460	5351	3894	72 337
River Atbara at mouth						**(1911–1960)**						
22	6	1	0	3	85	1642	5 643	3 731	897	201	63	12 295
						(1961–1994)						
11	6	1	6	17	47	1325	4 206	2 412	511	61	19	8 621
						(1903–1994)						
17	6	1	3	8	88	1536	5 126	3 306	770	145	46	11 052
Main Nile at Wadi Halfa/Kajnarty/Dongola						**(1890–1910)**						
4715	3310	2687	2020	1808	2096	5675	20 124	23 114	16 709	8749	6250	97 256
						(1911–1960)						
3495	2408	2219	1951	1792	1945	5023	19 207	21 745	14 595	7213	4531	86 125
						(1961–1995)						
3010	2290	2086	2781	2942	2531	5373	17 078	17 221	9 403	4887	3489	73 092
						(1890–1995)						
3577	2547	2268	2239	2175	2169	5268	18 701	20 554	13 337	6767	4538	84 138

reservoir operation, is shown in the flows for April and May. The limited period of river flow in the Atbara is clearly shown.

COMPARISONS OF INFLOWS AND OUTFLOWS

The differences between the sum of the annual flows at Tamaniat and the Atbara at its mouth, and the annual flows at Dongola (and earlier records at Wadi Halfa and Kajnarty) are presented in Fig. 10.5. There is a fair amount of scatter, especially in the years before 1924 and after 1974, which as in Chapter 9 is likely to be due to random measurement errors. It has been noted that discharges at Wadi Halfa were based on a general rating curve rather than annual rating curves before 1921; the discharges of the Atbara before 1921 were based on an indirect rating curve. In recent years the abstractions have increased and the numbers of gaugings at all sites have decreased. These factors explain much of the scatter, which is a fairly small percentage of the combined flows.

In general, it appears that the total losses, which include channel evaporation, losses to bank storage and subsequent evaporation, irrigation abstraction and also any systematic measurement errors, have been rising fairly steadily over the period of records. There are some anomalous years. 1916–1917 was a period of sustained high flow from the White Nile when losses could have been higher than normal. In some years in the 1980s (e.g. 1985 and 1988) losses were apparently high, and in three years (1971, 1974, and 1975) there appear to have been net gains, which must be due to measurement errors. In order to eliminate such

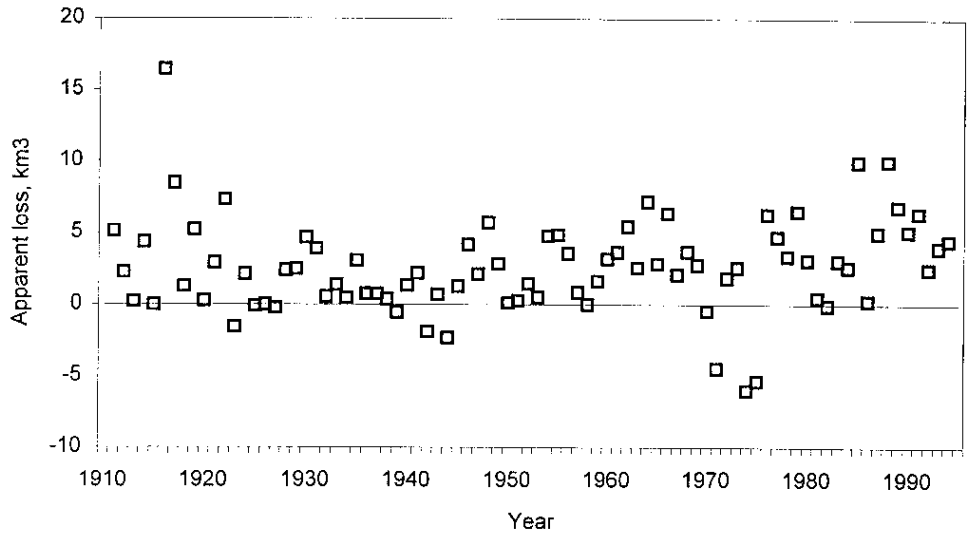


Fig. 10.5 Main Nile: annual losses from Tamaniat and Atbara to Wadi Halfa, 1911–1994.

random errors, it seems reasonable to use the periods 1911–1960 and 1961–1995, included in Table 10.2, to estimate the annual losses. These have increased from 2.2 to 3.2 km^3 over the period. This is consistent with channel evaporation losses of 2.7 m over a length of 1500 km and an average width of 600 m, which would total 2.4 km^3. In addition irrigation abstractions have increased in recent years from negligible volumes in 1950 to about 1.1 km^3 in 1980. The sum of the evaporation losses and irrigation abstractions are consistent with the apparent losses.

The losses estimated by comparisons of flows at Hassanab, Atbara and Dongola (Table 10.2) are similar to those derived from Tamaniat. Comparison of individual years have not been illustrated, but there is more scatter, especially in the early years when the Hassanab flows were derived indirectly.

CONCLUSIONS

The inflows at Tamaniat reflect the contrasting contributions of both the White Nile and the Blue Nile. Apart from the seasonal inflows from the Atbara, this reach acts as a transmission

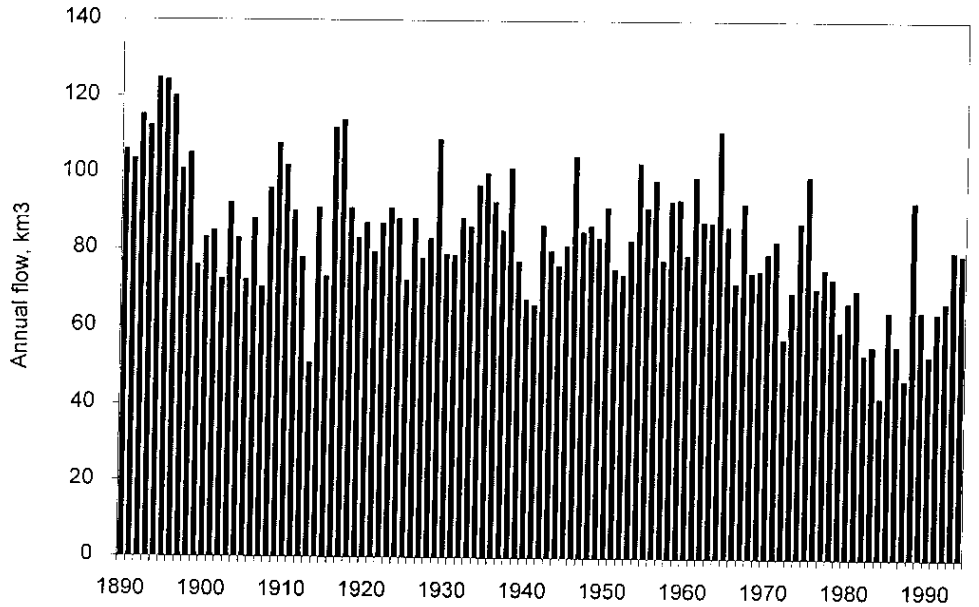


Fig. 10.6 Main Nile at Wadi Halfa/Kajnarty/Dongola: annual flows, 1890–1994.

channel conveying flows from Tamaniat to Wadi Halfa with limited channel losses and irrigation abstraction. Although the irrigation potential of this reach is likely to be limited by availability of land, the reach has hydroelectric potential. The annual flows at Wadi Halfa (Fig. 10.6) show the wide range of flows from 1890 to the present.