CHAPTER 1

AN OUTLINE OF THE NILE BASIN

INTRODUCTION

The hydrology of the Nile basin cannot be understood without some knowledge of its complex geography. This chapter introduces the the important elements of the basin. The Nile is made up of a diverse group of different tributaries, which by a series of accidents meet and flow together into the Mediterranean Sea. The contrast between the size of the basin and the comparatively small volume of runoff is an important feature. The areas which contribute significantly to the total flow are relatively small and isolated: the East African lake region and the Ethiopian highlands. The water balance concept, which forms the basis of much of the discussion, is introduced, and the climate of the basin is discussed briefly. A description of the main tributaries is intended to put into context the later chapters which concentrate on each tributary or river reach in turn.

EXTENT OF THE NILE BASIN

The Nile is the longest river in the world at about 6700 km. It extends (Fig. 1.1) over an extremely wide band of latitude, from 4°S to 32°N, with a total catchment area of nearly 3 million km^2. Rushdi Said (Said, 1993) has pointed out that the present basin is a very recent development, as illustrated by the longitudinal profile (Fig. 1.2). It consists of a series of flat reaches in basins which evolved independently and are now linked by steep channels. He has described how the basin drainage evolved from a relatively short river. This excavated a canyon up to 4000 m deep some 6 million years ago, at a time when the Mediterranean Sea was isolated from the ocean and desiccated. This river was separated from the rest of Africa by the Nubian massif. At the time the Ethiopian plateau drained towards the Indian Ocean, though some flow entered the Sudd to the west. The Sudd formed an enormous lake with a depth of sediment up to 10 km thick which covered much of the present Nile basin within the Sudan. The Equatorial plateau drained towards the west into the Congo, with some flow to the Indian Ocean or north into the Sudd.

The Egyptian Nile formed a connection with the Ethiopian plateau some 750 000 years ago, though this connection was interrupted many times. Meanwhile the formation of the African Rift had caused major changes in the drainage pattern further south. The rivers of the Ethiopian plateau, which had flowed eastwards, were interrupted by the eastern arm of the Rift Valley. They were diverted to flow to the west towards the Nile. Drainage from the Equatorial plateau, towards the Congo basin, was also diverted by the development of the African Rift. This led to the formation of Lake Victoria within the depression between the two arms of the Rift Valley, and to the reversal of west-flowing rivers like the Kagera, the Kafu and the Katonga. Both the Sudd and Lake Victoria were closed basins until they overflowed to the north through Sabaloka gorge and Jinja respectively some 12 500 years ago. The levels of Lake Turkana (Rudolf) were sufficiently high about 9500 years ago that the lake contributed to the Nile system through the Sobat. This amalgamation of separate entities is illustrated by the longitudinal profile of the Nile, which is made up of a succession of steep

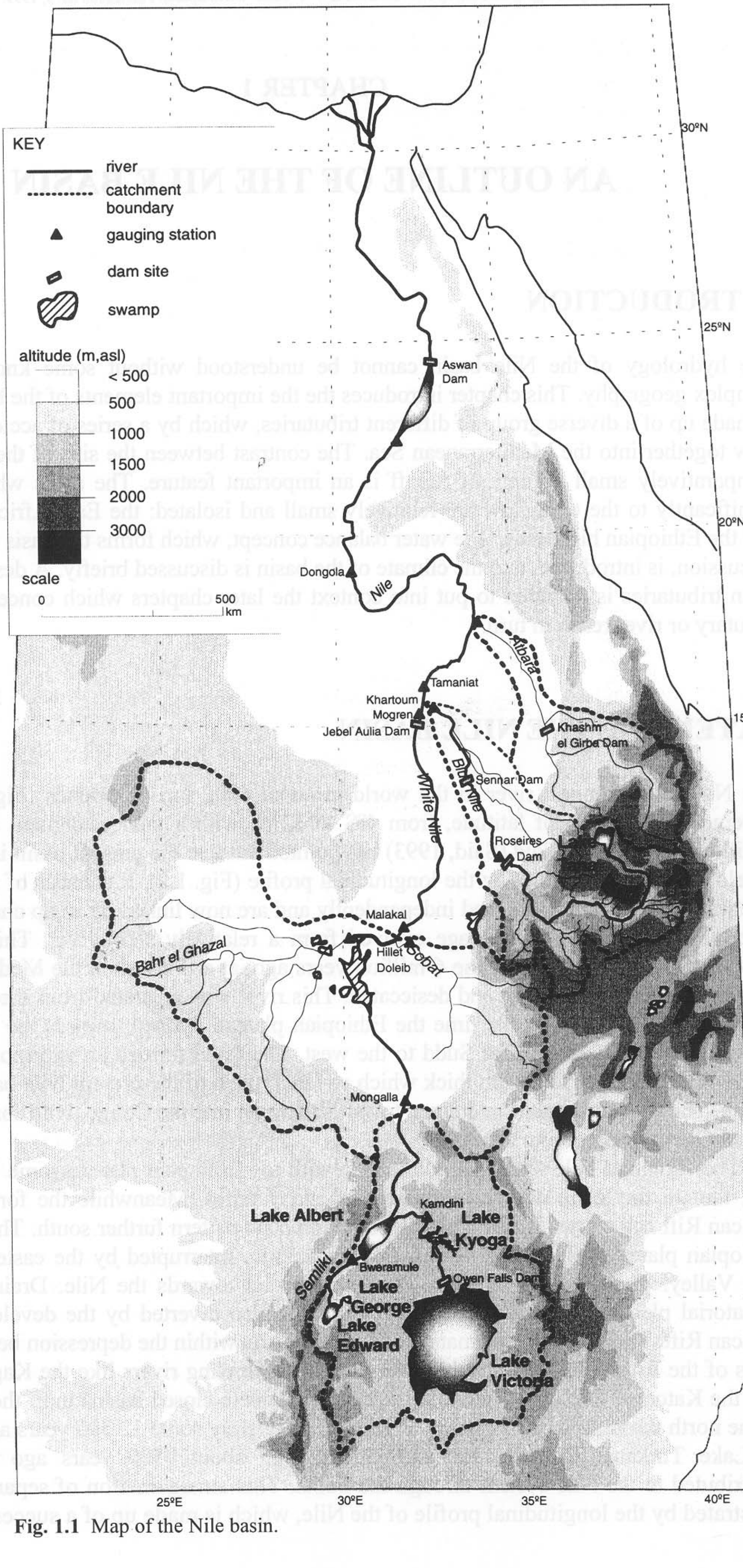

Fig. 1.1 Map of the Nile basin.

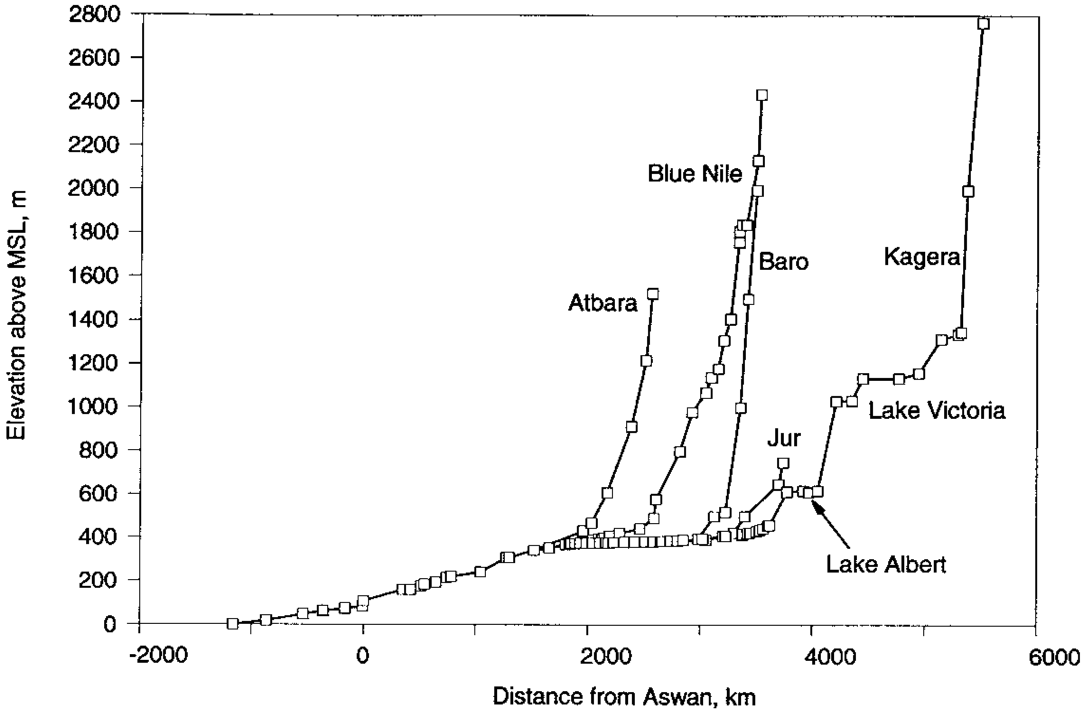

Fig. 1.2 Profile of the Nile and its tributaries.

sections and landings which show interior drainage basins. The present shape of the Nile basin is believed to be only 10 000 years old.

RAINFALL AND RUNOFF

A water balance often leads to the understanding of hydrological systems. This states that the water inflow to an area must equal the outflow, plus any increase of water storage within the area. Inflow is largely made up of rainfall and river inflow, while outflow consists mainly of river outflow or diversion, and evaporation from open water and vegetation. Groundwater flow is a component of inflow and outflow, but is generally small compared with river flows in this basin. Water storage is made up of soil moisture and groundwater storage, together with channel storage and lake or wetland storage. Lake and wetland storage are of particular importance in the White Nile basin, where spill from the river into wetlands and subsequent evaporation are major components of the balance. In these wetlands and adjoining plains a distinctive vegetation has adapted to the conditions. The vegetation provides a useful pointer to the hydrological conditions, and the links between vegetation type and flooding conditions are a key to interpreting this information.

Because of its extent over 36 degrees of latitude, the climate of the Nile basin is extremely variable. Table 1.1 illustrates the rainfall of the different parts of the system. This table is based on rainfall averages up to 1972 of the stations available in each case; the number of stations varies from five to over 50 and the periods of record vary. The table mainly indicates the seasonal pattern of the rainfall regime. It shows how the regime changes from the bimodal rainfall of the Lake Plateau area, with a transitional zone between Lake Albert and Mongalla, to a single rainfall season between Mongalla and Lake No. The trend towards shorter rainfall seasons continues to the north, from the Bahr el Ghazal and Baro tributaries, and the Ethiopian stations, to the relatively dry regime of the lower Blue Nile and main Nile reaches. The rainfall regimes of the important tributaries are discussed in later chapters.

Table 1.1 Average monthly rainfall over parts of the Nile basin (mm).

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lake Victoria basin (excluding the lake)												
75	90	134	194	145	61	47	68	72	89	111	100	1186
Lake Kyoga basin												
38	64	108	176	159	99	89	127	121	120	109	66	1276
Lake Albert basin												
27	55	95	149	137	81	87	128	134	142	121	58	1214
Lake Albert to Mongalla												
9	25	62	122	154	131	150	162	139	135	68	23	1180
Mongalla to Lake No												
2	6	25	70	119	121	147	141	125	90	19	6	871
Bahr el Ghazal basin												
4	12	39	90	143	162	186	205	174	118	31	5	1169
River Baro basin												
18	25	61	118	198	207	220	244	202	125	63	22	1503
Pibor, Akobo, Veveno basin												
4	12	33	89	122	118	155	165	123	88	35	10	954
Ethiopia												
14	28	57	91	125	137	237	243	167	73	34	21	1227
Lower Blue Nile basin												
0	0	0	2	8	24	84	109	44	8	0	0	279
Main Nile												
0	0	0	0	2	1	12	18	3	0	0	0	36

(from *The Nile Basin*, vol. VI, supplement 7)

Compared with the size of its basin, the total flow of the Nile is relatively small, though this does not affect its importance to the countries through which it flows. The average annual runoff from the entire basin is very low at about 30 mm expressed as a depth over the basin. However, this runoff is far from uniform. Although the basin is spread over 10 countries, the areas which actually contribute significant volumes to the river flow are relatively small and isolated. These are largely confined to the East African lake region, where rainfall is high and distributed between two rainfall seasons, and to the Ethiopian highlands where high rainfall within a single season and steep topography give rise to relatively high and concentrated runoff. Over most of the basin the runoff is low; in a number of areas the tributary inflow is in fact reduced by evaporation from wetlands or by channel losses. Moreover, both the total flow and the relative contributions of the different tributaries have varied considerably over the years. The relatively low runoff depths mean that runoff is sensitive to changes in basin rainfall. This leads to great variability of runoff from year to year.

The areas of high rainfall are naturally associated with the mountainous portions of the basin. The high ground is also concentrated in two main areas flanking the Rift Valley. This passes through Lakes Tanganyika, Edward and Albert and also to the east of Lake Victoria through Lake Turkana to the Ethiopian lakes. The mountains of Burundi, Rwanda and western Uganda, near the western arm of the Rift Valley, and the mountains of southwest Kenya and Mount Elgon in the eastern branch, form the rim of an area draining to Lake Victoria. The lake lies in a depression between these two arms. Further to the north, the mountains to the west of the Ethiopian Rift Valley form the source of a number of tributaries, including the Blue Nile and Atbara, which contribute most of the annual volume.

MAIN TRIBUTARIES

White Nile

The furthest tributary of the Nile is the Kagera which drains the mountains of Burundi and Rwanda, with average rainfall up to 1800 mm. It flows into Lake Victoria (about 1134 m elevation) after meandering through a series of lakes and swamps adjoining the river channel. A number of tributaries drain the forested escarpment to the northeast of the lake. Other less productive water courses drain the plains of the Serengeti to the southeast of the lake and the swamps of Uganda to the northwest. The water balance of the lake has presented a problem to hydrologists over many years. The outflow has been sensitive to periods of high rainfall, though the lake storage dampens both seasonal and short-term fluctuations.

The outflow from the lake is confined to a single channel heading north towards Lake Kyoga, through several shallow falls and rapids. The outflow from the lake was controlled naturally by the geometry of the Ripon Falls. Since 1953, when the Owen Falls dam was constructed just downstream, the outflow has been controlled by international agreement according to the same relation between lake level and outflow. The Victoria Nile reaches Lake Kyoga (1031 m) some 100 km north of its outfall. This lake is essentially a grass-filled valley which used to drain to the west towards the Congo. In some periods the lake causes a net loss of river flow and in other periods provides a net gain.

The Kyoga Nile flows west from the lake towards the western arm of the Rift Valley through level reaches with swamp vegetation, interrupted by rapids and falls culminating in the Murchison Falls. The river enters Lake Albert (Mobutu Sese Seko) (620 m) through a swamp near the northern end of the lake. The lake also receives the inflow of the river Semliki, draining Lake Edward (912 m) and the Ruwenzori and other mountains. The lake is within the Rift Valley and rainfall over the lake is low compared with evaporation.

The Albert Nile or Bahr el Jebel leaves Lake Albert at its northern end and flows northeast towards Nimule in a flat reach flanked by swamp vegetation. At Nimule the river crosses the Sudan border, turns abruptly to the northwest and flows in a steeper channel, with several rapids, towards Juba and Mongalla. Here the river enters the Sudd or Bahr el Jebel swamps. In the reach between Lake Albert and Mongalla the river receives seasonal runoff from a number of streams known as the torrents; these provide the high flows of the river following the single rainfall season. Thus the river flow at Mongalla is made up of a damped contribution from the East African lakes, which is liable to medium-term fluctuations between periods of high and low flow, and also the seasonal and sediment-laden flows of the torrents.

Within the Sudd the higher flows spill from the main channel into swamps and seasonally flooded areas. Evaporation from the flooded areas greatly exceeds rainfall, which itself is confined to a few months before the river rises. The effect of this spilling is that the outflow from the swamp is only about half the inflow and has little seasonal variation. The large volumes of water evaporated from these swamps gave rise to the proposal in 1904 for a canal, later known as the Jonglei Canal, to bypass the swamps and reduce the losses. This has ensured that hydrological attention has been focussed on this region. However, the complexity of the channels and the problem of measuring evaporation from swamp vegetation have meant that the flow processes within the Sudd were not understood until research into evaporation made it possible to estimate the water balance of the area as a whole.

At Lake No the Bahr el Jebel turns east and becomes the White Nile, and the Bahr el Ghazal flows into the lake from the west. The Bahr el Ghazal basin is relatively large and has the highest rainfall of any basin within the Sudan. However, the flows of the various tributaries of the Bahr el Ghazal are spilled into seasonal and permanent swamps, and virtually no flow reaches the White Nile.

The White Nile is joined from the east by the Sobat, whose tributaries, the Baro and Akobo, drain the southwestern part of the Ethiopian highlands. The Pibor also receives occasional high runoff from an indeterminate area of southeast Sudan. However, the Baro and Akobo both spill in high flow periods into adjoining wetlands; the Baro also spills north across the Ethiopia–Sudan border towards the little known Machar marshes. Thus the hydrological regime of the Sobat is also complicated by the influence of wetlands; the relative remoteness of these wetlands has meant that hydrological measurements and study have been less advanced than in the other tributaries.

The regime of the White Nile from the Sobat mouth near Malakal to its confluence with the Blue Nile at Khartoum is relatively simple. The river flows in a single trough and only receives significant local inflow in years of exceptional conditions in the Machar marshes. Its balance over the years has been influenced by the construction of the Jebel Aulia dam (1937) above the Blue Nile confluence to maintain downstream flows during the low flow season; this has resulted in wider areas of flooding and increased evaporation losses. Irrigation along the White Nile has grown considerably over the years, with abstraction made easier by the raised levels of the river upstream of the dam.

Blue Nile and main Nile

The bulk of the flow of the main Nile at Khartoum is provided by the Blue Nile, with its smaller tributaries the Dinder and Rahad. The Blue Nile drains a major part of the western Ethiopian highlands, with a small part of its basin subject to storage in Lake Tana. The rainfall over this basin is confined to a single season, and the river flows are therefore concentrated in a short period. Consequent problems of erosion and potential sedimentation make storage of flood waters difficult to achieve. Relatively small dams have been built at Sennar (1925) and at Roseires (1966) near the Sudan–Ethiopian border, in order to provide water for irrigation in the Gezira and other areas. Hydroelectric power has also been developed at these sites. The rainfall regime depends on the seasonal fluctuation of the ITCZ (InterTropical Convergence Zone). Thus the length of the rainfall and runoff seasons decreases from the Sobat in the south to the Blue Nile and its northern tributaries. This results in a short season of runoff in the Dinder and Rahad basins, which dry up for about half the year.

The main Nile below Khartoum flows north through the Sabaloka gorge and is joined 325 km north by its last tributary, the Atbara, which drains the northern portion of the highlands of Ethiopia and also part of Eritrea. The runoff season is even shorter than the Dinder and Rahad and the river is dry for much of the year. The Khashm el Girba reservoir was built on the upper Atbara in 1960–1964 to store this runoff for irrigation, but the flashy nature of the inflow has resulted in considerable siltation. Below the Atbara mouth the river flows in a series of wide loops through an arid area of successive cataracts and flatter reaches. The river flows are reduced by evaporation and irrigation abstractions. The Nile enters Egypt below Wadi Halfa where the reservoir formed by the Aswan High Dam now extends south of the border.

In order to store increasing portions of the Nile flow for irrigation and more recently for hydroelectric power, successive dams have been built at Aswan. The latest reservoir, above the Aswan High Dam or Sadd al Aali, has a capacity of nearly twice the mean annual flow. It was designed to provide overyear storage to alleviate periods of low annual flows. Flow records are available since 1870 at or above Aswan, though the site of the upstream river gauging station has been moved on several occasions as the dam was raised. These flow records summarize the changes of regime which have occurred over the past century on both the White and Blue Niles. Comparisons of flows along the reach between Khartoum and

Aswan reveal the effect of channel losses and abstractions as well as evaporation from the Aswan reservoir. The flow records below Aswan reflect both the role of the reservoir in equalizing flows and successive diversions for irrigation down the final reach between the High Dam and the Delta barrages.