Hydrobiological Assessment of the Zambezi River System: A Review

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FOREWORD

One of the important Projects within the Environment Program is that entitled: *Decision Support Systems for Managing Large International Rivers*. Funded by the Ford Foundation, UNEP, and CNRS France, the Project includes two case studies focused on the Danube and the Zambezi river basins.

The author of this report, Dr. G. Pinay, joined IIASA in February 1987 after completing his PhD at the Centre d'Ecologie des Ressources Renouvelables in Toulouse. Dr. Pinay was assigned the task of reviewing the published literature on water management issues in the Zambezi river basin, and related ecological questions.

At the outset, I thought that a literature review on the Zambezi river basin would be a rather slim report. I am therefore greatly impressed with this Working Paper, which includes a large number of references but more importantly, synthesizes the various studies and provides the scientific basis for investigating a very complex set of management issues. Dr. Pinay's review will be a basic reference for further water management studies in the Zambezi river basin.

R.E. Munn
Leader, Environment Program

ACKNOWLEDGEMENT

I would like to thank the IIASA library which is really part of the research team and without them this work would not have been possible. My thanks to R.E. Munn who kindly reviewed the paper, and to Y. Taher who typed it and helped me improve the language.

Chapter I: The Zambezi River System

1. General Features

1.1. Geography

The Zambezi river system lies between 24–38° E and 12–20° S, and is the largest of the African river systems flowing into the Indian Ocean [(Balek 1977; Davies 1986), Figure 1]. It consists of three sections (Balon and Coche 1974): *Upper* from its sources to the Victoria Falls, *Middle* from the Victoria Falls to the Cahora Bassa rapids, and *Lower* from Cahora Bassa to the Indian Ocean. These three stretches seem to have been independent until the Pliocene era (Balon 1978) following which, due to tectonic movements, they merged to form the actual river system (Table 1).

There is much evidence to support such a picture of evolution particularly in relation with pre-impoundment fish distributions in the river (Jackson 1986). The length of the river itself is controversial. For instance, Welcomme (1977) claims it is 2574 km, Balon and Coche (1974) 2494 km, Balek (1977) 2600 km, and Beadle (1932) 3000 km. It flows eastwards from its sources in the Central African Plateau at 1400 m altitude to the Indian Ocean (Figure 2). The surface of the Zambezi drainage basin varies greatly from 1193500 km^2 (Balon and Coche, 1974) to 1570000 km^2 (Balek 1977). In addition, one can divide the entire Zambezi drainage basin into subcatchments corresponding to the drainage basins of the main tributaries of the Zambezi river (Table 2).

The Zambezi drainage basin is situated south of the equator between 12° and 20° S. The cool dry season is between May and September. The headwaters situated north of the basin belong to the tropical summer rainfall zone (climate zone II in Walter *et al.* 1975). As one moves south, the tropical summer becomes progressively more arid due to a prolongation of the dry season (Figure 3). Thus, the upper and the middle Zambezi are defined as warm temperate regions with dry winter, the warmest month being up to 22° C (Schulze and McGee, 1978) as quoted by Davies (1979), while the Okavango basin and the southern part of the middle

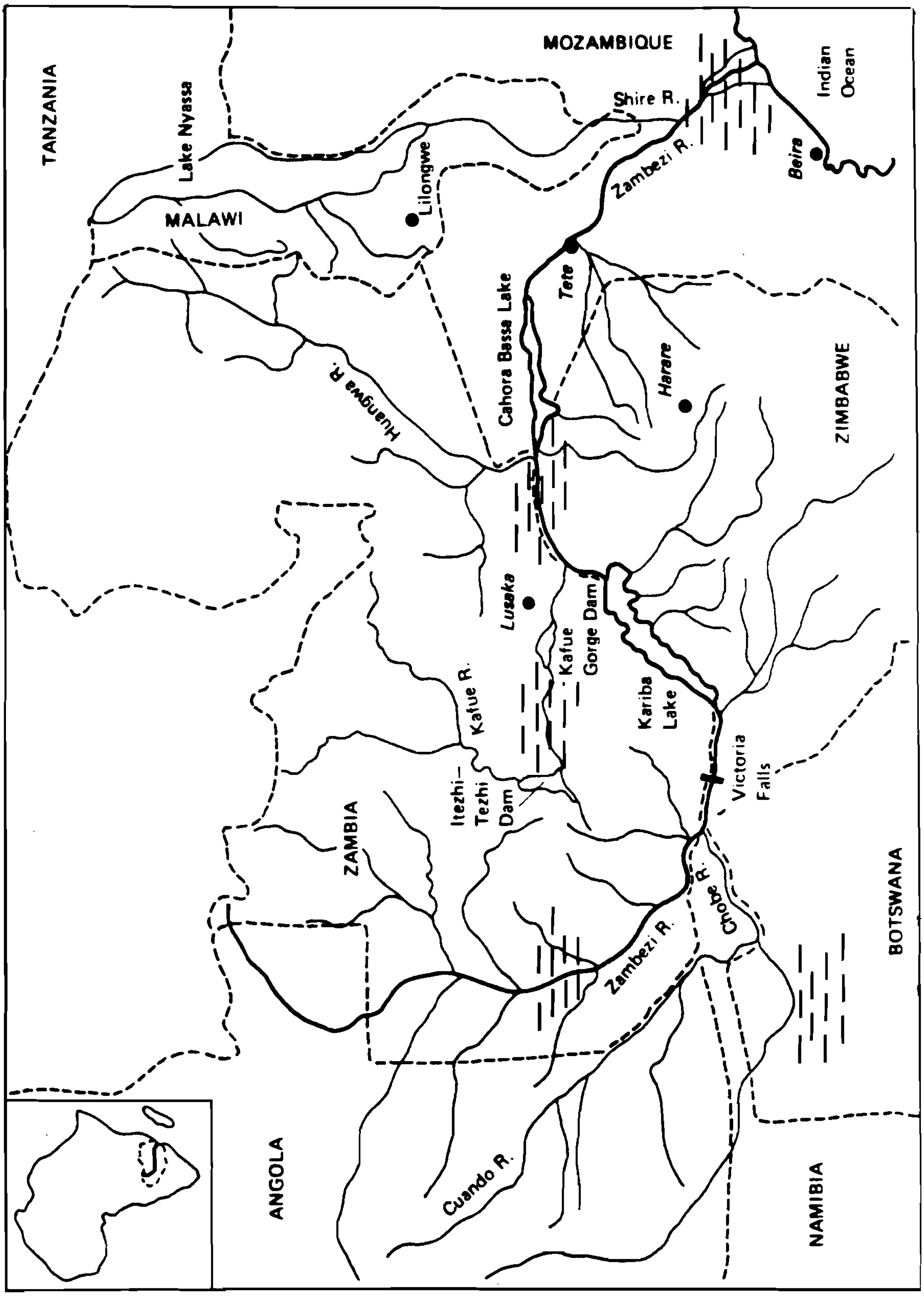


Figure 1. The Zambezi drainage basin.

Table 1. **Main features of the three stretches of the Zambezi river.**

ZAMBEZI	STRETCH	LENGTH km	DRAINAGE SURFACE km^2	MEAN ANNUAL FLOW m^3 s^{-1}
Source	UPPER			
Victoria Falls		1078	320 000	1240
	MIDDLE			
Cahora Bassa rapids		853	1 180 000	2700
	LOWER			
Indian Ocean		593	1 400 000	3500

Table 2. Main subcatchments of the Zambezi river system.

	Chobe	Sanyati	Kafue	Huangwa	Hunyani	Shire
Drainage basin km^2	95800	43500	154200	147500	23900	115000
Annual flow km^3	4.2	3.4	10.3	13.0	1.4	N.D.

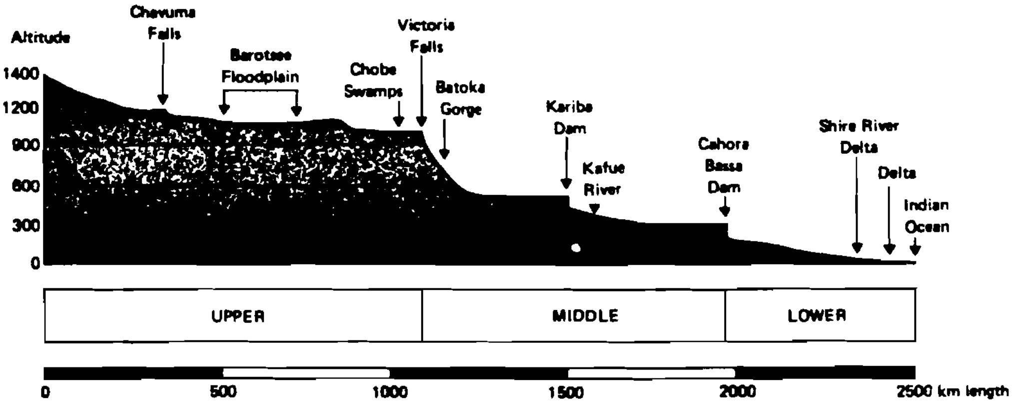


Figure 2. Longitudinal profile of the Zambezi River.

Zambezi belong to the arid steppe zone with a mean annual temperature of more than 18°C. Finally, the lower Zambezi moves from the arid climatic zone in the west to an equatorial climate with dry winters in the east.

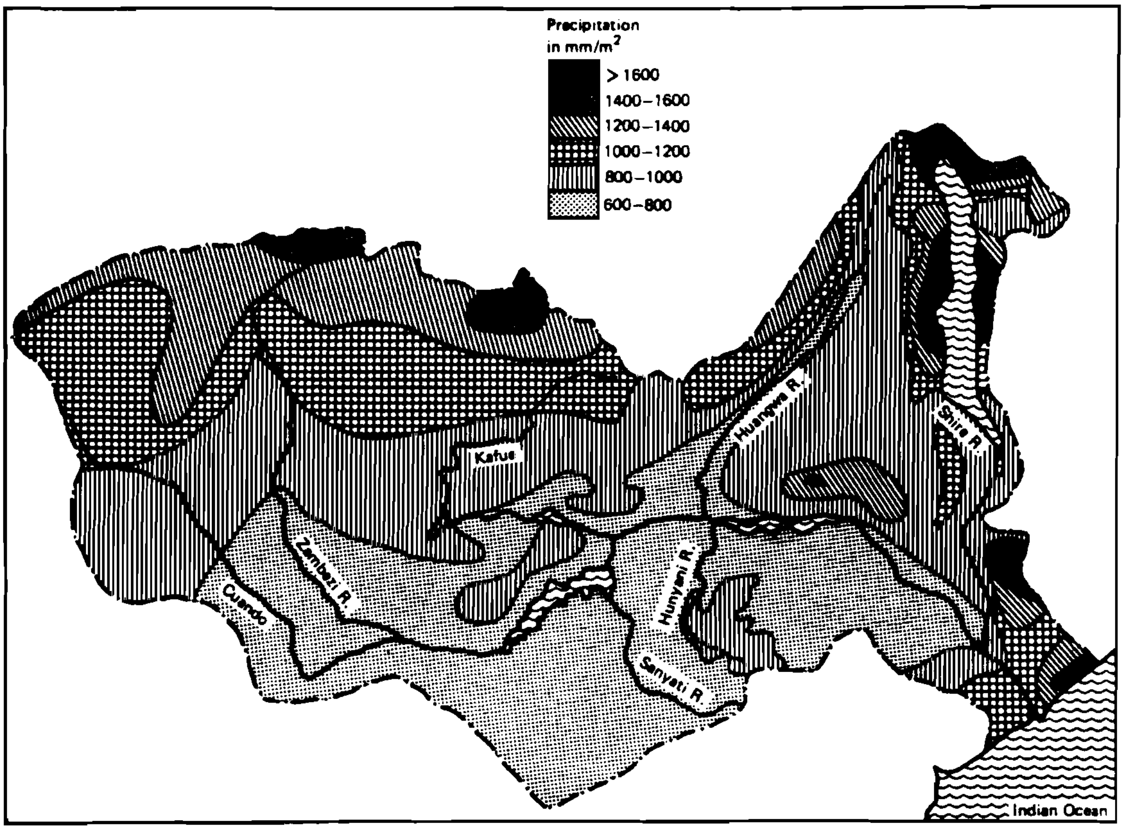


Figure 3. Map showing precipitation repartition on the Zambezi drainage basin adapted from Vieira (1961) and Bolton (1983).

2. Main Water Retention Systems

Several kinds of water storage systems such as natural lakes, man-made lakes, and swamps exist along the Zambezi river and its tributaries.

2.1. Natural lakes

The only large natural lake on the Zambezi watershed is Lake Malawi. It is the third largest lake in Africa with a maximum length of 580 km and a width of between 16 and 80 km, and a surface of about 30000 km^2. Its volume capacity is almost 8000 km^3. The hydrological balance of the lake is dominated by permanent rainfall which reaches 2270 mm per annum in the lake area. The lake is subject to abrupt annual and seasonal changes in its water level as a result of variations in rainfall. The Shire river in the southern part of the lake constitutes its outlet; this river flows through a small lake, the Malombe, before it joins the Zambezi in its lower reach.

2.2. Man-Made Lakes

Two man-made lakes, the Kariba and Cahora Bassa, are on the Zambezi river regulating almost 570 km of the length of the river. These impoundments represent 65 per cent of the middle Zambezi. Some other man-made lakes lie on the Zambezi tributaries, mainly in Zambia on the Kafue river and in Zimbabwe. The characteristic features of the larger lakes are given in Chapter III, while the main features of the most important ones are given in Table 3 (Marshall and Falconer 1973a–b; Mitchell and Marshall 1974; Jackson and Davies 1976) and their locations in Figures 1 and 4.

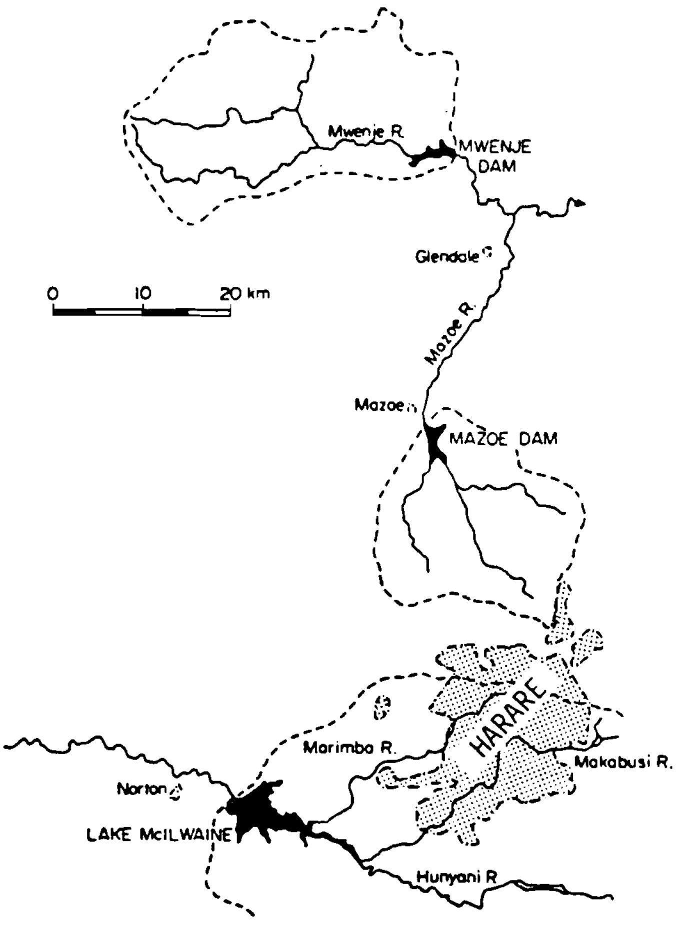


Figure 4. Locations of man-made lakes around Harare, Zimbabwe.

Certain characteristics of man-made lakes are typical for most of them, and, therefore, are distinguishable from natural lake systems. The development of the shoreline is slightly higher than that for natural lakes; if the river is confined

Table 3. Hydrological features of the main reservoirs of the Zambezi drainage basin.

	Lake surface (km^2)	Lake volume ($10^6 m^3$)	Drainage basin (km^2)
Kariba	5 250	155 000	409 600
Cahora Bassa	2 739	70 000	200 000
Ithezithezi	365	5 700	106 190
Kafue Gorge	810	740	153 000
McIlwaine	26.3	250	2 200
Mazoe	0.44	30.5	645
Mwenje	0.2	13	550

between high banks, the new lake will be long and narrow; if there are tributaries, water will be held back giving the new lake a dendrite form. In comparison, the extent of shoreline modification in a reservoir is greater than in a natural lake because the annual drawdown exposes a larger area to the effects of shore processes. Whereas normally natural lakes are deepest near the centre, man-made lakes are almost always deepest just upstream from the dam. They are then referred to as "half-lakes" (Ellis 1941). The incoming water does not mix immediately with the water in the reservoir due to differences in temperature and content of dissolved or suspended solids. It leads to density currents and hypolimnetic withdrawals (Baxter 1977). The retention time in man-made lakes is very short compared to that of natural lakes. For instance, the retention time of water in the Kariba was measured at four years, while it is about one year for the Cahora Bassa.

2.3. Swamps

According to Wetzel (1975) a swamp is a more or less permanently waterlogged system with persistent standing water in the vegetation. In Africa herbaceous swamps may be defined as flat areas that are flooded to a shallow depth densely covered with herbaceous vegetation whose shoots rise above the water level to more than one metre. The swamps are bottom-rooted or floating (Howard-Williams and Gaudet 1979). There are several reasons why swamps should be taken into consideration for their hydrological and biological processes. Among them water retention, water loss by evapotranspiration, the sedimentation process, fishery resources, and grazing pastures may be mentioned. The present chapter presents some features of the main swamps in the Zambezi drainage basin, and the different processes will be discussed later. General features of hydrological processes are given in Table 4, and the main swamps are located in Figure 5.

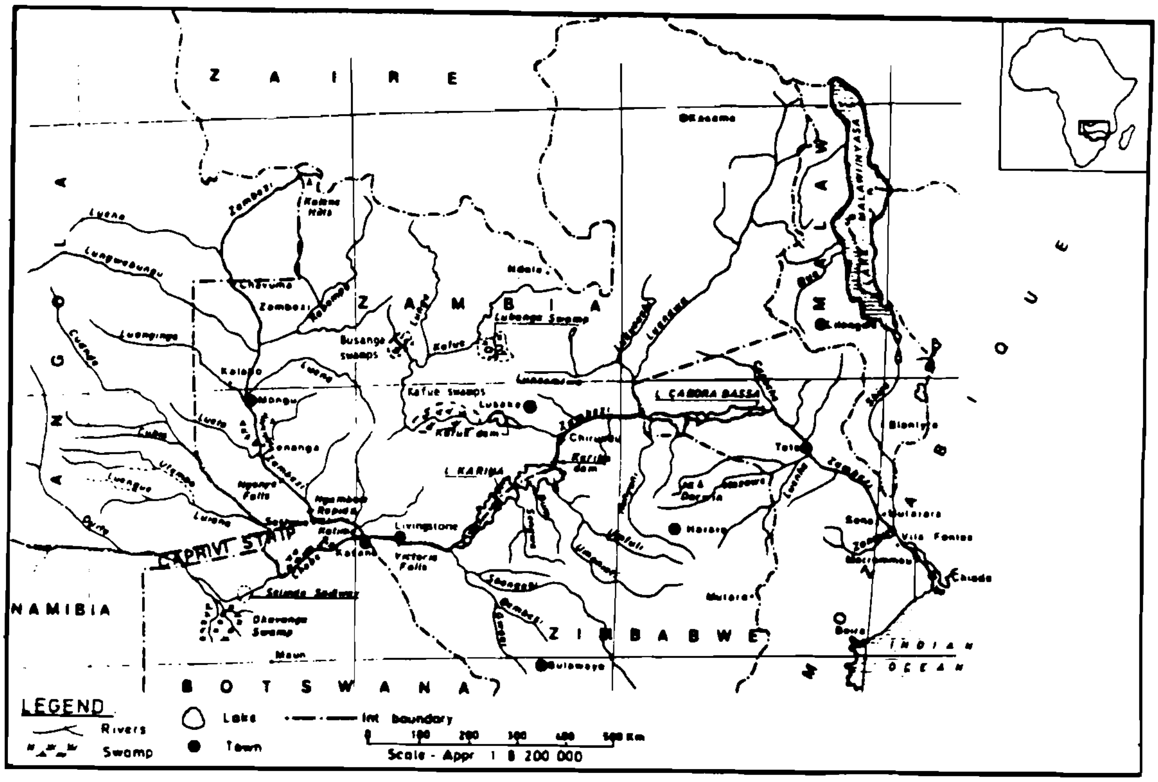


Figure 5. Location of the main swamps on the Zambezi river basin from UNEP (1986).

Table 4. Characteristics of the main swamps. Evapotranspiration has not been evaluated in all the swamps (ND).

Swamps	Surface at high water period (km^2)	Precipitation in mm per year	Evapotranspiration in mm per year
Barotse	7500	1050	N.D.
Okavango	10000	500	2830
Lukanga	2100	970	N.D.
Busanga	1000	970	N.D.
Kafue	5650	1000	2700

2.3.1. Barotse swamps

The Barotse floodplain lies on the upper course of the Zambezi river in the Central African plateau in western Zambia. It is a 240 km long and 40 km wide floodplain through which the Zambezi river meanders. The annual rainfall is about 1050 mm of which 90 per cent occurs between November and March. Flooding of the upper Zambezi normally commences in November, but may vary depending on the intensity of the early rains in the headwater catchments. Usually the flood peaks are in April in the Barotse floodplain, and recede slowly over a period of six months between May and October (FAO–UN 1969; Burgis and Symoens 1987).

2.3.2. Okavango delta

The Okavango delta system is rather complex because of its hydrological features leading to general flow patterns as well as sedimentation processes that change the delta's topography. Surprisingly the Okavango delta has a regular conical shape with a slope of about 1 in 3600. Thus, relatively small irregularities provide the pattern of channels, ridges, swamps and pools. Estimates of the area of the Okavango swamp vary between 10000 and 18000 km^2, but the estimation of Wilson and Dincer (1976) from satellite imagery is 10000 km^2. The water balance of deltaic swamps differs from usual river basins or lakes, mainly by varying swamp areas and flow distribution. Thus, hydrological features vary largely as functions of water input (precipitation on the drainage basin) and output (evapotranspiration, runoff).

The Okavango catchment consists mainly of two river systems, the Cubango with a catchment area of 115000 km^2 with an average annual rainfall of 983 mm, and the Cuito with a drainage basin of 65000 km^2 and an average annual rainfall of 876 mm [(Wilson and Dincer 1976) Figure 6]. The two rivers then merge to form the Okavango river before entering the Okavango delta.

Usually, this input of water is completely retained in the Okavango delta where evapotranspiration is the main process (about 2830 mm/year/m^2). Excess water flows through the Boteti Channel to Makgadikgadi Pans system. During high rainfall years the Okavango swamps system can drain the excess water through Selinda spillway to the Chobe river, and then on to the Zambezi river (Figure 6). The Selinda spillway is the only link between the Okavango drainage basin and the Zambezi, which means that the Okavango drainage basin is related to the Zambezi river only during the heavy rainfall season. Wilson and Dincer (1976) have given a

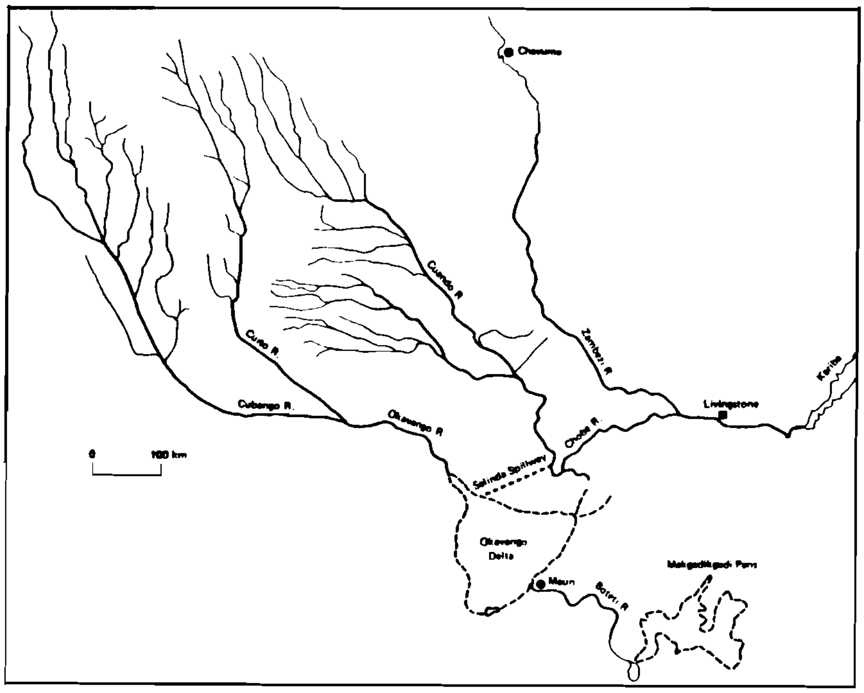


Figure 6. Drainage basin of the Okavango delta and its connection with the Zambezi river system.

tentative water balance for the Okavango delta (Table 5).

Table 5. Water balance for the Okavango delta (Wilson and Dincer 1976).

Processes	Annual input	Annual output
Inflow of Okavango river	$11 \times 10^9 m^3$	
Precipitation	$5 \times 10^9 m^3$	
Total	$16 \times 10^9 m^3$	$16 \times 10^9 m^3$
Evapotranspiration		$15.4 \times 10^9 m^3$
Outflow (Boteti river)		$0.3 \times 10^9 m^3$
Groundwater outflow		$0.3 \times 10^9 m^3$

To complicate the hydrology, the function of the Chobe river is to reverse the flow when the upper Zambezi is flooded (Davies 1986). Although the Okavango drainage basin (almost 200 000 km^2) is a part of the Zambezi drainage basin, it has not the expected effects on the Zambezi river itself (runoff) due to the buffer effect of the Okavango delta and the unstable connection between them.

2.3.3. Kafue swamps

The Kafue river is the largest tributary of the Zambezi river. Almost 1 500 km in length it drains an area of about 155 000 km^2. Three main swamps make up the drainage basin (Figure 7).

Lukanga swamp

This occupies a shallow depression extending to about 2 600 km^2, but 2 100 km^2 only is permanent swamp. The average water capacity is estimated at 7.38.10 m^3 (Burgis and Symoens 1987). It receives water from several catchment streams as well as from the Lukanga river, a tributary of the Kafue, which drains an area of 14 245 km^2. During high water level periods, it also receives water from the Kafue river itself.

Busanga swamp

This comprises about 1 000 km^2 along the Lufupa river, a tributary of the Kafue river. Although it is not well known ecologically nor is it exploited because it is in the tsetse fly zone, this swamp is similar to the Lukanga swamp from the physiographical point of view (Burgis and Symoens 1987).

Kafue flats

At Itezhitezhi the Kafue river breaks through a range of low hills before it flows eastward across the Kafue flats. Here it meanders for 410 km traversing a distance of 250 km across the floodplain at an average gradient of only 2.7cm/km (White 1973; Dudley 1974). During its course through the flats, the river falls only 15 m in 410 km (Rees 1978a). After flowing through the floodplain, the river plunges down 670 m as it flows through the 30 km Kafue Gorge to the Zambezi river.

It is typical for the waters of the Kafue river to start to rise in late November or early December shortly after the start of the rainy season. The highest water levels are in April/May, about one month after the termination of the local rainfalls (Dudley 1979), when about 5 650 km^2 may be inundated; the water recedes slowly until November. The natural hydrological cycle of the Kafue flats varies tremendously. Three-quarters of the floodplain can change from an aquatic to a terrestrial environment within one season. At the eastern end of the Kafue flats, a shallow area of about 1 215 km^2 is flooded more or less permanently (Burgis and Symoens 1987). The major input of water to the system is from the headwater

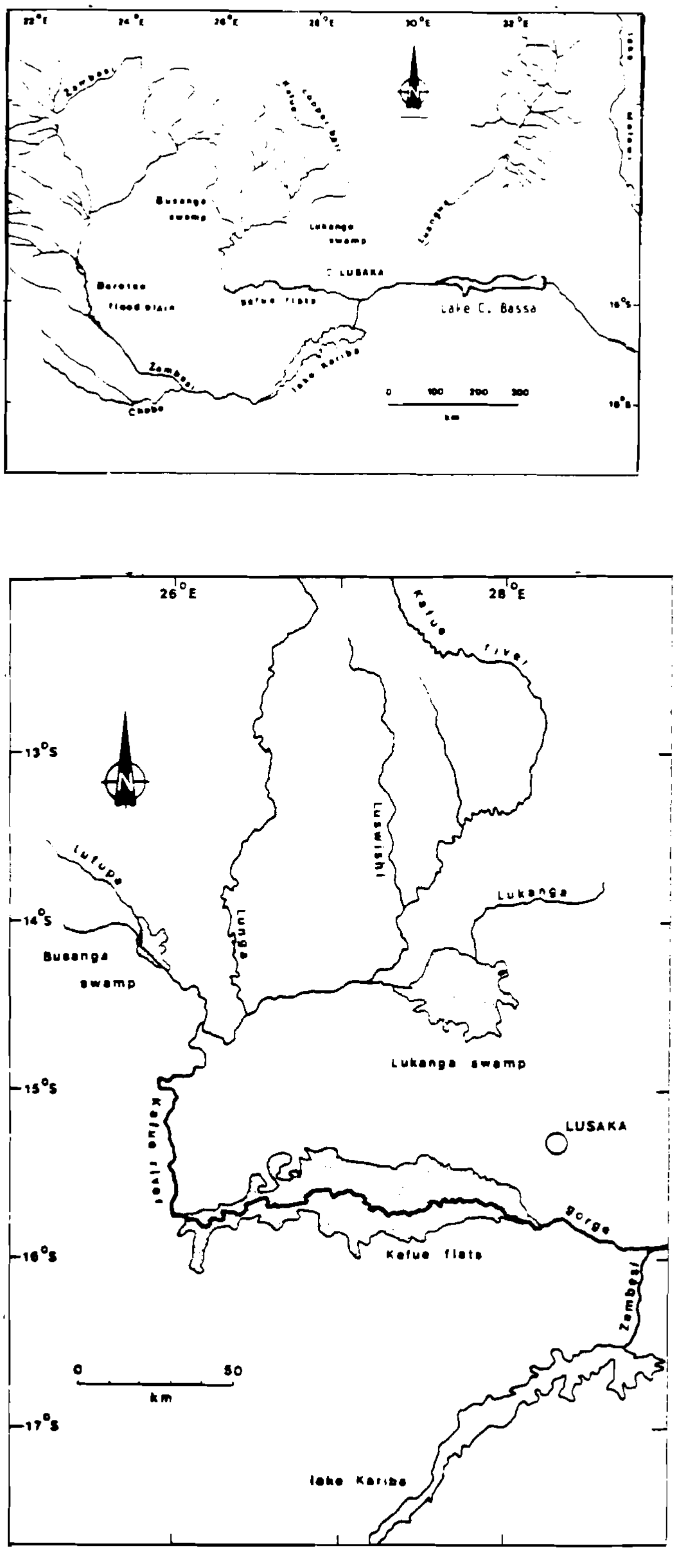


Figure 7. Location of swamps on the Kafue river system (Burgis and Symoens, 1987).

areas of the Kafue river above Itezhitezhi (controlled by a dam since 1978), direct rainfall, and seasonal runoff from the surrounding higher grounds. Water is lost by discharge through the Kafue Gorge (regulated by a dam since 1972) and by evapotranspiration.

A tentative water balance in the Kafue river system is given by Burgis and Symoens (1977) (Figure 8). Thus, it has been estimated that from the entire runoff of the Kafue drainage basin, which is about $12.16.10^{9}m^{3}$, 73 per cent (or $8.88.10^{9}m^{3}$) reaches the Kafue Rail Bridge (downstream Kafue flats). The remaining 27 per cent (or $3.28.10^{9}m^{3}$) is believed to be lost through evapotranspiration jointly from the Kafue floodplains and the Lukanga and Busanga swamps.

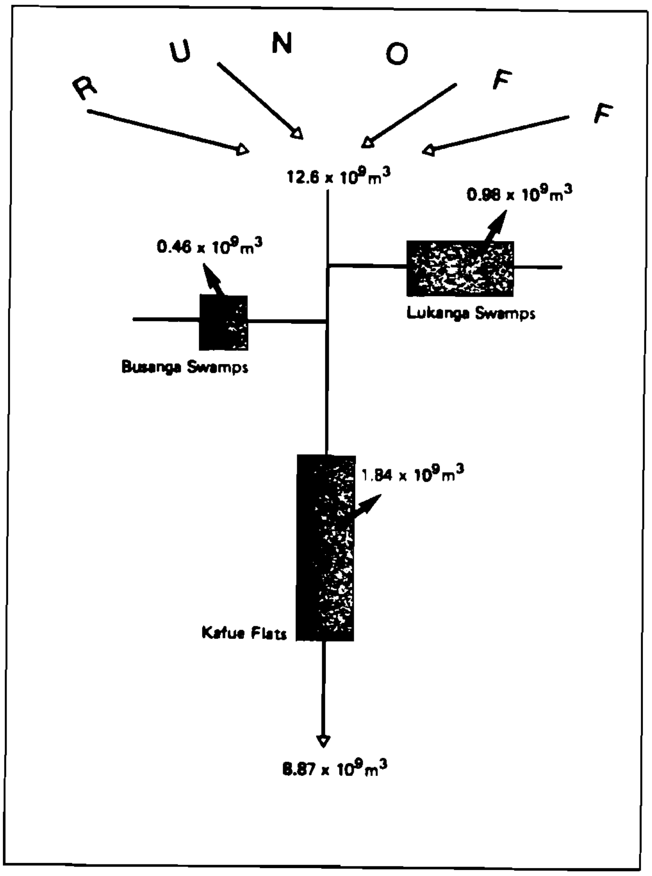


Figure 8. Water balance of the Kafue river system (Burgis and Symoens, 1987).

A review of the examples cited above, mainly of the Okavango delta and the Kafue flats for which more data are available, shows the importance of swamps in the water balance of an entire drainage basin, especially in those tropical regions where the evapotranspiration process is intensified.

3. Flow Regime of the Zambezi

The general feature of hydrological cycles in the tropics is very similar to those in more moderate regions, although several factors affecting water movement from the atmosphere through and over the earth's surface into the rivers are of particular importance, and the resulting effects deviate from that experienced outside the tropics. For instance, the specific function of interception, different time and space distribution of rainfall, the pronounced influence of swamps, and soil problems are exacerbated in these regions (Balek 1977). global water balance for the entire Zambezi river is estimated and evaluated for the different subcatchment basins corresponding to the three stretches identified above (Table 6).

Table 6. Water balance of the Zambezi drainage basin (Balon and Coche 1974; UNEP 1986a; Davies 1986).

Zambezi stretches	Drainage basin (km^2)	Precipitation (km^3)	Evapotranspiration (km^3)	Runoff (km^3)
Upper	320 000	360	245	49.2
Middle	1 118 000	830	688	74.8
Lower	1 400 000	1 317	1 000	106.4

As shown above, water retention systems like swamps and man-made lakes play a crucial role in the global water balance of the Zambezi river system, also in the dynamics of the flow itself. For the sake of presentation and because it corresponds to reality from the hydrological point of view, the Zambezi river will be examined in three sections which more or less coincide with the three natural stretches.

3.1. The Upper Stretch

The upper stretch corresponds to the section between the source of the Zambezi in a marshy bog near the Kalene hills about 1 500 m above sea-level and the Victoria Falls near the town of Livingstone. The 1 650 wide Victoria Falls with a mean annual discharge of 1 237 m^3/s form a 98 m high barrier between the upper and the middle Zambezi. The upper stretch is the most natural to the Zambezi river owing to the absence of impoundments. Rainfall in the drainage basin range from 1 400 mm/year in the headwater zone to 700 mm southward. Temperatures reach 20–22° C with a range of 6–8° C. The rainy season is between November and April, and the dry season from May to July. The double flood peak recorded during the rainy season upstream from the Barotse is balanced by the dry season. The resulting single flood peak due to the buffer effect of the Barotse swamps is then further equalized by the Chobe swamps (Balon and Coche 1974).

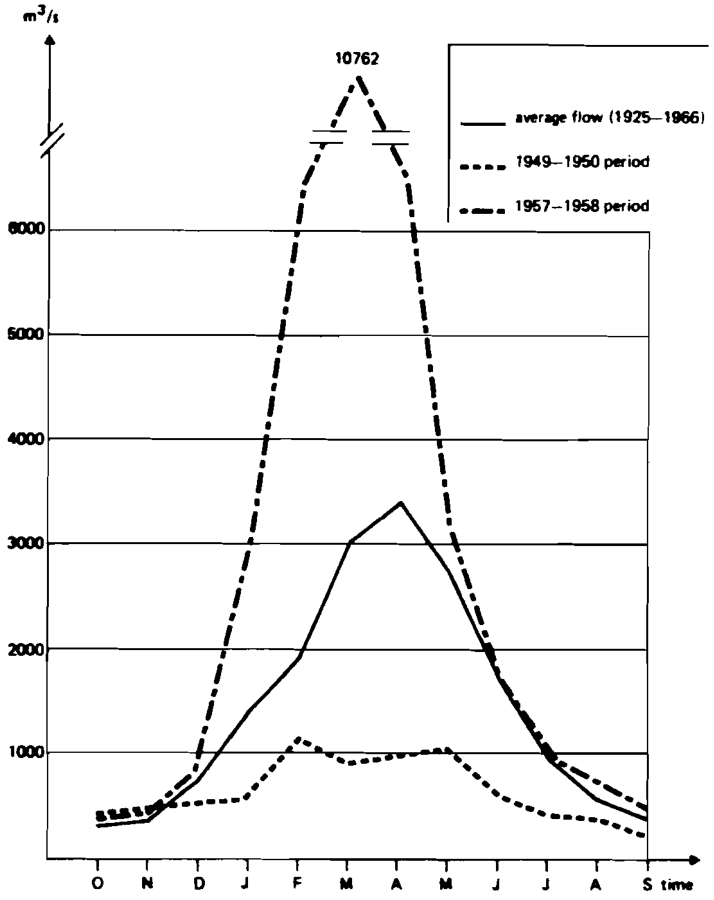


Figure 9. Average flow regime (1925–1966) at Livingstone, and flow regime during a dry (1949–1950) and a wet (1957–1958) period (Balon and Coche, 1974).

Next, a characteristic flood peak is observed at Livingstone. Figure 9 gives the average monthly runoff at the Livingstone pump station calculated from the data obtained between 1925 and 1966. The flow starts to increase in December to reach a peak in April (3 500 m^3/s), then it decreases to about 350 m^3/s in October. However, because of the erratic rainfall pattern of the region, the Zambezi flow varies greatly from year to year. Table 7 gives the frequency per month of the minimum or maximum discharge.

Thus, Balon (Balon and Coche 1974) has estimated that it normally takes approximately three to four weeks for the base flood peak to move from Balovale, upstream to Barotse swamps, to Kariba. The annual runoff from the upper Zambezi

Table 7. Frequency of minimum and maximum discharge between 1925 and 1966 (Balon and Coche 1974).

Minimum discharge		Maximum discharge	
Months	Frequency	Months	Frequency
September	9	February	2
October	26	March	11
November	20	April	23
December	1	May	6
		June	1

catchment during the period 1924–1979 (Figure 10) shows a rise during the late 1940s and early 1950s. According to DuToit (1982), only 30 per cent of the increase could be explained by an increase of rainfall over the catchment area. Various explanations for the increase in river flow have been suggested, such as changes in rainfall patterns (spatial and seasonal distribution of mean water depths as well as intensities) and changes in the watershed response (Puzo 1978).

To support this idea, DuToit (1982) observed that the variations of the mean annual discharge became more pronounced in the years 1950–1980, suggesting that the surface runoff increased at the expense of the underground water table recharge and increasing the differences in runoff between wet and dry years. Undoubtedly, future man-made drainage of the Barotse and Chobe swamps would promote this effect.

Other hypotheses concern changes in the features of the catchment rather than changes in the rainfall (Puzo 1978). Variations in the annual flow from high to low flow years have become more pronounced, which might suggest that when rain does occur, it flows off the land rapidly due to superficial changes rather than percolation, maintaining a supporting flow through a following drier year (DuToit 1982). Possible drainage of Barotse and Chode swamps should heighten this effect. In any case, the problem remains unsolved. Since 1980–1981, the upper Zambezi catchment has experienced an unprecedented drought causing other problems for the management of the Kariba Reservoir.

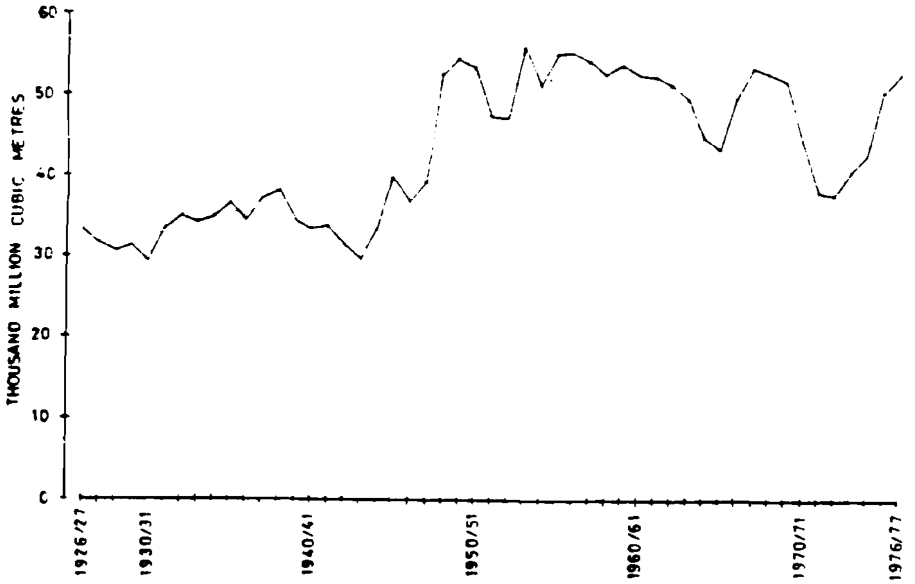


Figure 10. Annual runoffs of the upper Zambezi catchment during the period 1924–1979 (five years running means, DuToit, 1983).

3.2. The Middle Stretch

The natural river situation of the middle as well as the lower stretches has changed drastically by creating lakes Kariba and Cahora Bassa, both within the flooded area and downstream from the dams. Before the impoundments, this river was defined as a "sand-bank" river, like the Huangwa and the Limpopo rivers, by Jackson (1961). Due to the creation of the two man-made lakes, this part of the river should now be considered as a "reservoir river", such as the Kafue or the Shire rivers. In its natural stage, the middle Zambezi has had two high flood periods every year (Figure 11): the "Gumbura" as called by the local people comes usually in February, with less turbulent flood waters, carrying local runoff. The second high flood, known as the"Murorwe" used to come in April, but since the Kariba was constructed, it no longer inundates the floodplain below the wall.

One can notice that the Kafue catchment runoff joining the Zambezi downstream and the Kariba is flattened due to an accentuation of the natural "reservoir river" of the Kafue river by its impoundments (Itezhitezhi, Kafue Gorge dams). Figure 12 represents the situation in recent years for the monthly inflows and spillages for Lake Kariba. This graph reveals the fact that for the period considered, the Kariba scheme does not seem to have regulated the Zambezi flow on a monthly scale, although the inflow is somewhat greater than the outflow during the first part of every rainy season, and the outflow is somewhat greater than the inflow during the dry season. On the other hand, the Kariba scheme has regulated well

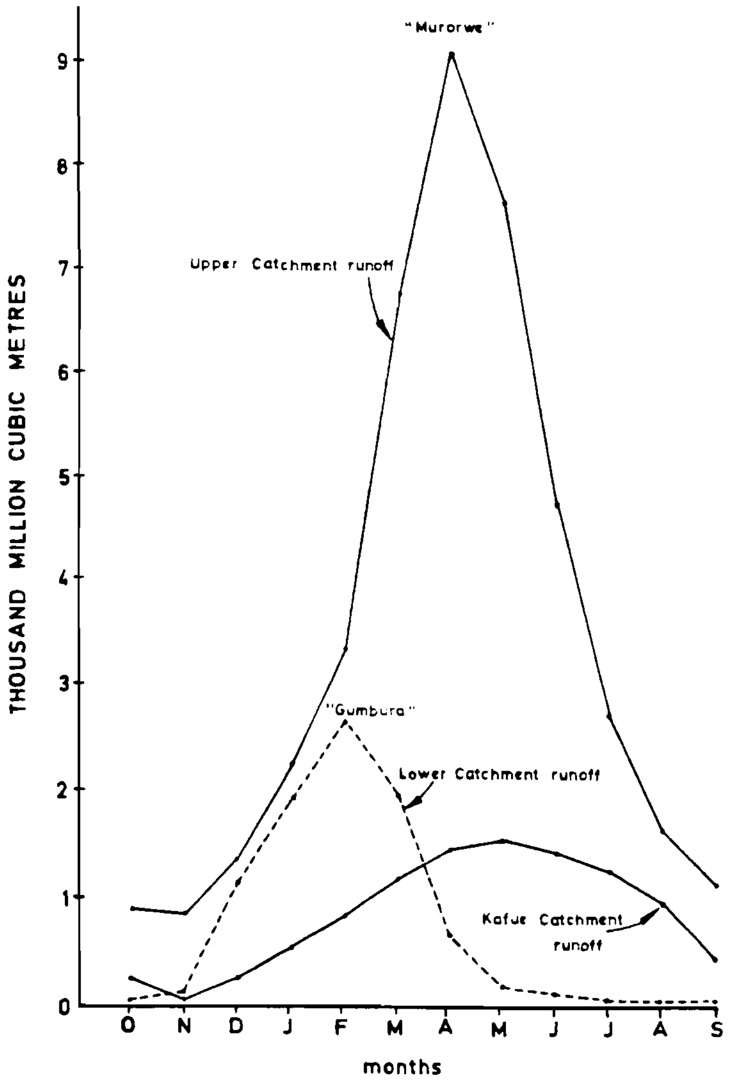


Figure 11. **Mean monthly flows upstream from Kariba** for the period 1924–1979 (DuToit, 1982).

the sharp flood peaks of 1963, 1969 and 1970. For instance, the flood peak at Victoria Falls in 1969 was estimated at 8 100 m^3/s, while the spilling through two floodgates amounted no more than 3 000 m^3/s.

3.3. The Lower Stretch

Before the Kariba impoundment was built, the Zambezi showed a regular annual cycle, usually reaching its peak in February or March at 5 000–20 000 m^3/sec and falling to 200–800 m^3/sec in October–November. Now 90 per cent of the flow into the Cahora Bassa reservoir is regulated. The Kariba dam has resulted in an increase in dry season flows and a delay in the timing of floods

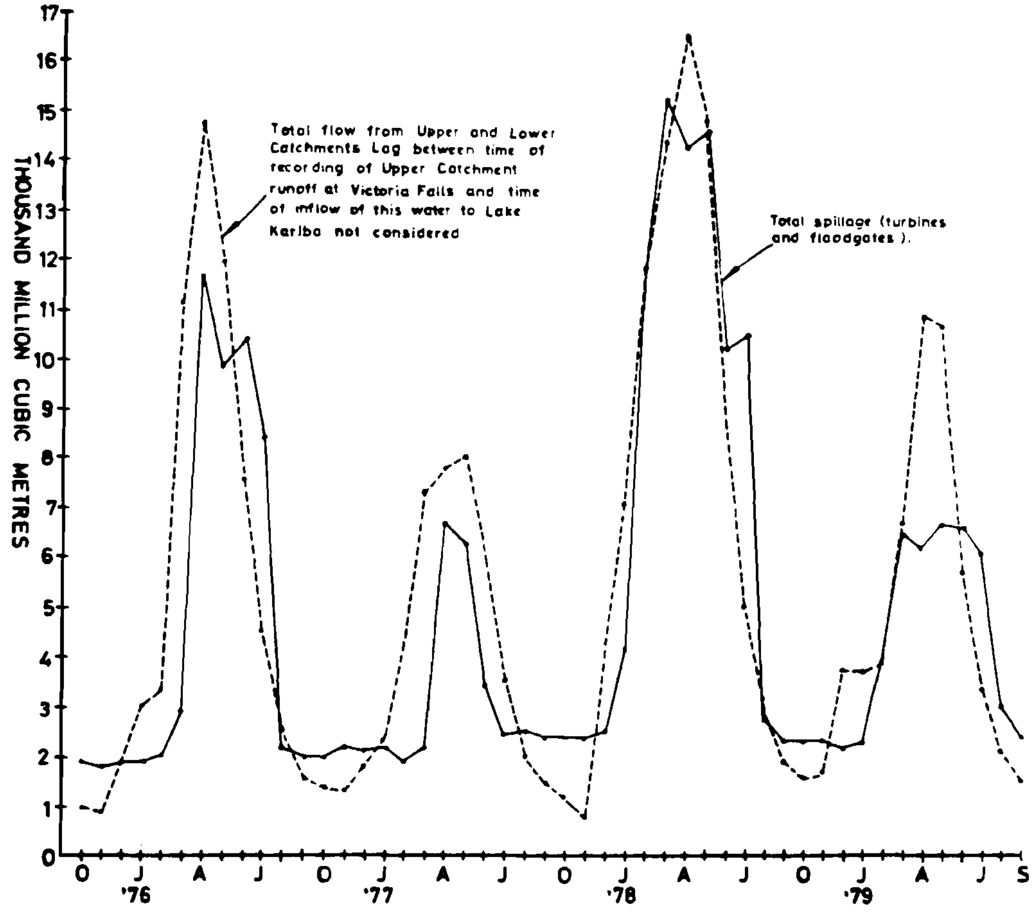


Figure 12. Monthly inflow and outflow for Kariba from October 1976 to September 1979 (DuToit, 1982).

during the wet season (Bernacsek and Lopes 1984). The flood magnitude has been decreased by an average of 24 per cent during eight years in the 1970–80 period. The erratic water management of Cahora Bassa has completely altered the normal water flow downstream to the floodplain and the delta. As shown in Figure 13, maximum discharges almost always take place out of season. Most years tend to have two flood releases, and in some cases even three as in 1981 (Figure 13).

Since the closure of the Cahora Bassa dam in December 1974, a period of two years (1979 and 1980) may be considered as "normal" from the hydrological and operational perspectives, although even during this period the Zambezi hydrological cycle was tremendously disturbed (Figure 14) with a retention of flood peak in the reservoir between February and May, creating two artificial flood peaks out of season.

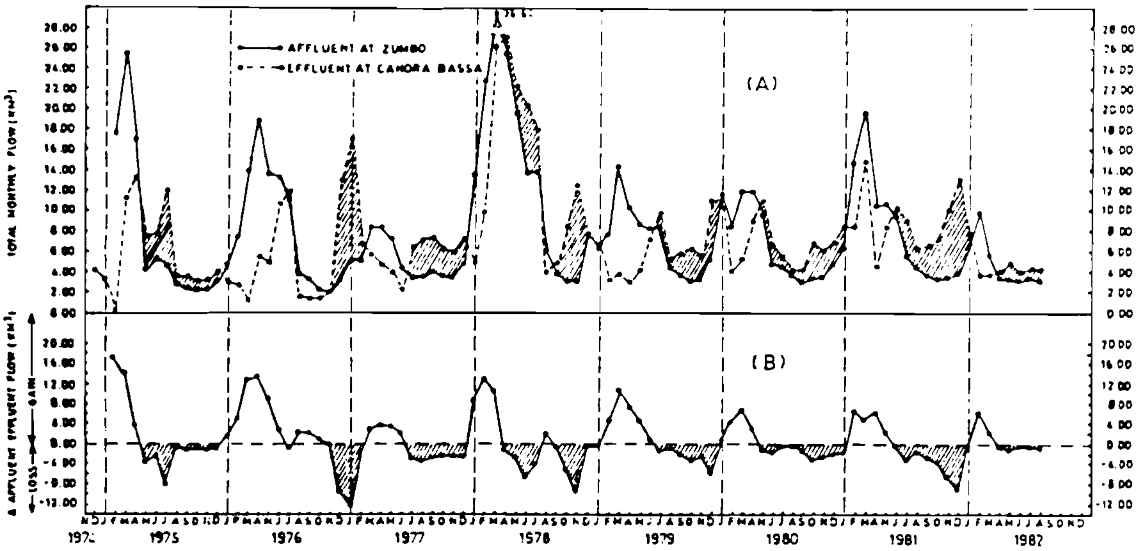


Figure 13. Water flow through Cahora Bassa reservoir. (A) total monthly inflow and outflow volume; (B) difference in monthly inflows (Bernacsek and Lopes, 1984).

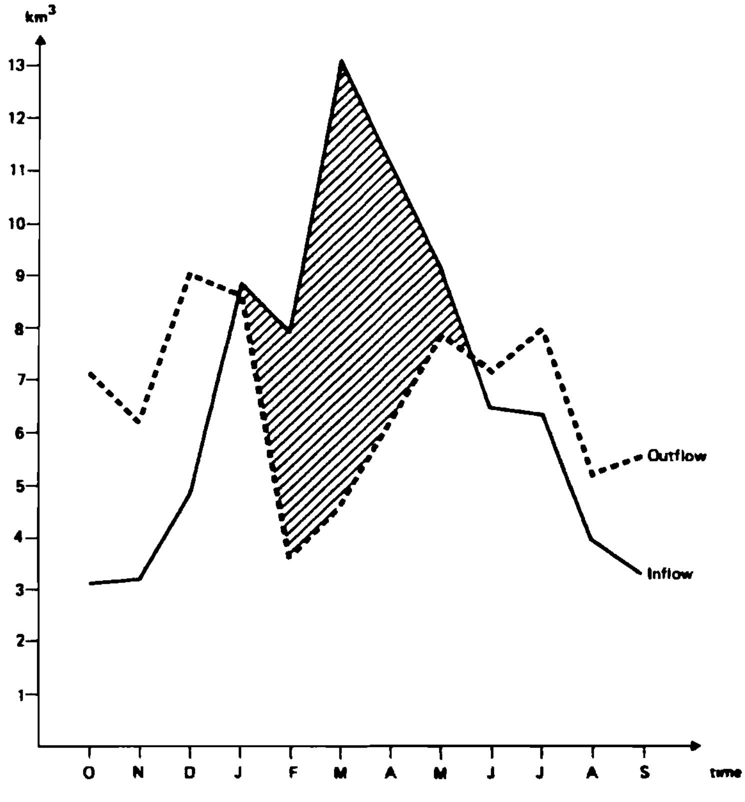


Figure 14. Water flow through Cahora Bassa reservoir in 1980. Shaded area represents buffering effect of the lake during floods.

3.4. Conclusions

As shown above, now the Zambezi is far from from the description of Jackson's in 1961 as having sand-bank characteristics: "have very deep beds with well-defined step banks cut in the alluvial earth, through which the rivers meander at low level, often little more than a connection between a series of pools fringed with rocks and sand banks with little aquatic vegetation, and still less marginal vegetation on the banks, while the flood is violent but of comparatively short duration, with the floodplains inundated for a relatively short space of time." (Jackson 1961) The impoundment of the middle and lower Zambezi and its main tributaries (Kafue and Shire) has transformed this river to a "reservoir system" dependent on anthropogenic management. The international status of the Zambezi river escalates the problems related to its management. As underlined by Bernacsek and Lopes (1984) for instance, despite the fact that about 90 per cent of the inflow into Cahora Bassa reservoir is regulated, major problems in flood prediction and management remain. The following chapter is devoted to these international characteristics of the Zambezi river basin.

Chapter II: The Zambezi Drainage Basin

1. Political Boundaries

The Zambezi drainage basin is shared by eight countries of the southern African region. They are Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe (Figure 15). According to their geographical locations, they share the catchment with a large range of surface contributions. Table 8 summarizes the contributions of the eight countries to the Zambezi drainage basin.

Table 8. Share of the Zambezi drainage basin by the eight countries.

Countries	Total surface km^2	Surface in the watershed km^2	% territory	% watershed
Angola	1 246 700	260 000	20.86	18.3
Botswana	581 730	40 000	6.87	2.8
Malawi	118 480	110 000	93.69	7.7
Mozambique	801 590	161 000	20.09	11.4
Namibia	824 290	17 000	2.06	1.2
Tanzania	945 090	28 000	2.96	2.0
Zambia	752 610	577 600	76.75	40.7
Zimbabwe	390 580	226 360	57.95	15.9

The concept of the drainage basin means that all land drained to a river or its tributaries belongs to the catchment of this river. One must also consider that some countries do not have direct contact with the Zambezi river itself, but that part of the territory is drained by a tributary of the Zambezi. This is the case in Malawi and Tanzania that are drained towards Lake Malawi and the Shire (Figure 15). These boundary differences among countries entail different interests in the Zambezi river. Complicating the political situation in each country as well as for international negotiations, many ministries share water administration and management in each nation. Table 9 gives the number of ministries concerned with water management in each country.

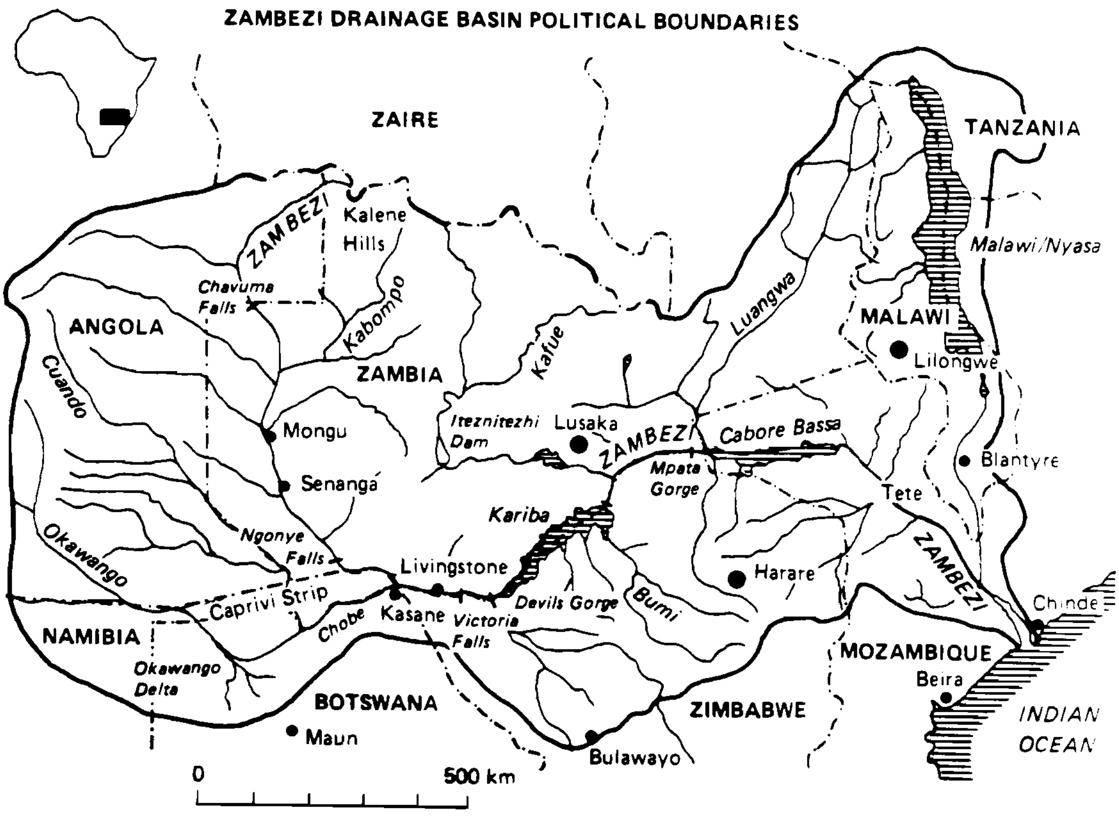


Figure 15. Political boundaries of the Zambezi drainage basin.

Table 9. Number of ministries sharing water administration in the Zambezi countries.

Countries	Number of ministries
Angola	ND
Botswana	6
Malawi	5
Mozambique	6
Namibia	ND
Tanzania	8
Zambia	7
Zimbabwe	8

2. Economic Situation

2.1. Population

Within its area of about 1400000 km^2, the Zambezi drainage basin has more than 20 million inhabitants. Table 10 gives the population distribution within the catchment for each country.

Among them Malawi, Mozambique, Zambia and Zimbabwe account for 94.70 per cent of the population in the basin, while the others share 5.3 per cent although the drainage area they cover is a quarter of the total Zambezi catchment. The general pattern is towards an increase of population in each country since 1965, and a decrease in percentage of population economically active in agriculture (Figure 16). Nonetheless, more than 70 per cent of the population is involved in agriculture in all the riparian countries, except Botswana (66 per cent) and Namibia (38.3 per cent).

Table 10. Population distribution of the Zambezi drainage basin.

	Total population	Basin population	% of total population	% of basin population
Angola	8900000	303740	3.41	1.38
Botswana	1149000	8100	0.70	0.04
Malawi	7178000	7178000	100	32.70
Mozambique	14342000	2566708	17.89	11.69
Namibia	1596000	40010	2.50	0.18
Tanzania	23334000	815420	3.49	3.71
Zambia	6898000	4482396	70.2	20.42
Zimbabwe	9099000	6560379	72.1	29.88
Total	72496000	21954753	30.3	100

vast region generally with sandy soil. Predominant crops are sorghum and bulrush millet. (c) Eastern Cuando-Cubango is a region of poor soil and sparse population. Subsistence farming and food collecting are dominant with pastoralism in the dry southeastern area.

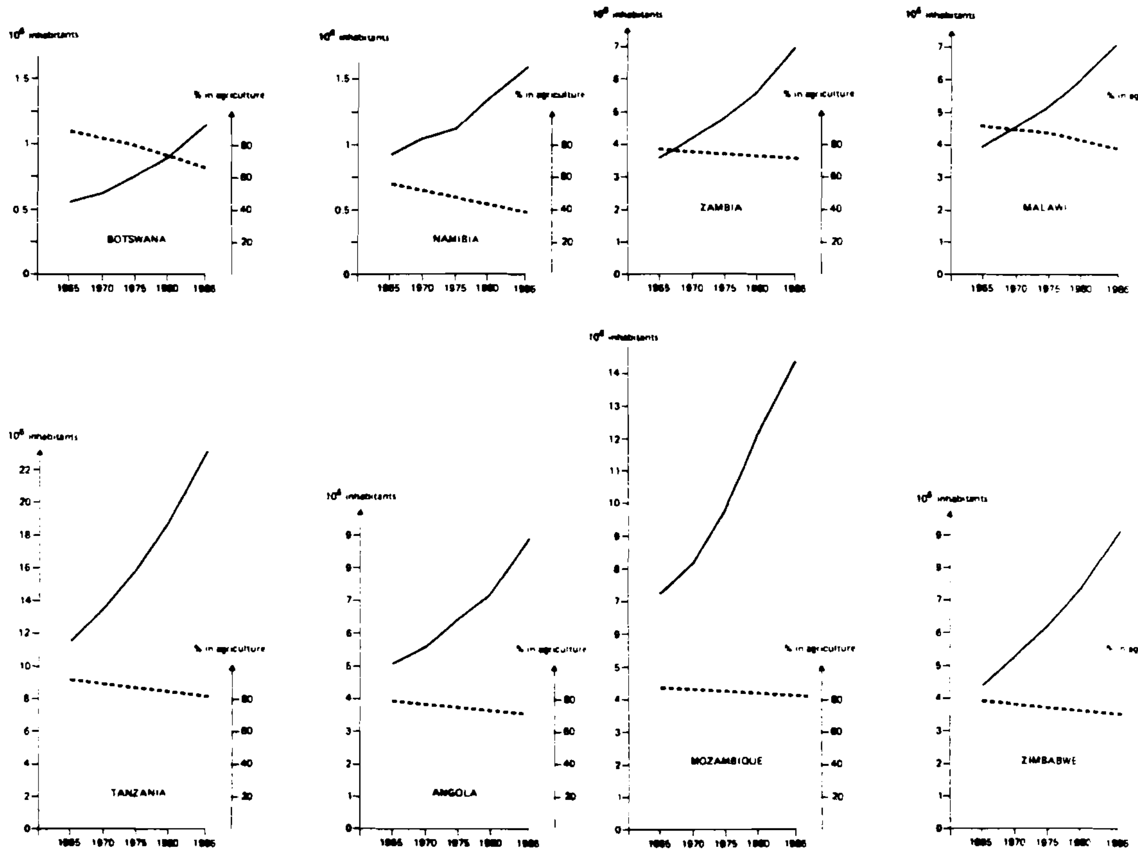


Figure 16. Evolution of population in the Zambezi riparian countries (.—.) and percentage of population economically active in agriculture (.---.) (FAO, 1986).

2.2. Land-Use

For each country sharing the Zambezi river basin, the statistics shown below were taken from the FAO Production Yearbook (1977–1987) concerning the whole country, and not just the part belonging to the Zambezi catchment. Nevertheless, these data provide a quite appropriate idea of the situation on the drainage basin, at least for Malawi, Mozambique, Zambia and Zimbabwe. Concerning the other countries, it shows at least the main features and tendency.

2.2.1. Angola

Since 1965, statistics show an increase in arable land mainly between 1970 and 1975 which is certainly due to increased deforestation during the same period. However, permanent crop area has not increased. The part of Angola belonging to the Zambezi drainage basin covers three regions: (a) East Central Moxico, with river basins subject to flooding, and villages located on low elevations. Hoe cultivation of subsistence crops is done during the rainy season. The region close to the Zambezi river is a more favoured area for crop farming with relatively important stock raising, except in the tsetse-infested zones. (b) Southern Moxico is a

Table 11. Land-use in Angola. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	10 500	29 100	29 500	29 500	29 500
Permanent crop	5 200	5 500	5 500	5 500	5 500
Permanent pasture	290 000	290 000	290 000	290 000	290 000
Forest	726 000	546 400	537 600	534 000	531 000
Irrigation	–	–	–	–	–

2.2.2. Botswana

As shown above, Botswana's area belonging to the Zambezi drainage basin is mainly represented by the Okavango region.

In Botswana, there is a major study called "Southern Okavango Integrated Water Development Study" under preparation. It seems that some 150 km^2 would be suitable for large-scale irrigation for agricultural development (UNEP 1986b). The Okavango delta is also subject to large-scale cattle raising, mainly in the southern part of the delta. Development of this region is due partly to the eradication of the tsetse fly which has allowed settlement by people.

Table 12. Land-use in Botswana. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	14 200	11 690	13 600	13 600	13 600
Permanent crop	–	–	–	–	–
Permanent pasture	408 400	428 000	440 000	440 000	440 000
Forest	9 580	9 580	9 620	9 620	9 620
Irrigation	20	60	100	140	160

2.2.3. Malawi

Almost 100 per cent of Malawi territory belongs to the Zambezi drainage basin.

Table 13. Land-use in Malawi. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	19 530	20 900	23 100	23 200	23 760
Permanent crop	180	180	230	250	260
Permanent pasture	18 400	18 400	18 400	18 400	18 400
Forest	23 140	50 800	50 740	46 300	45 200
Irrigation	20	40	180	220	200

Tea and tobacco are two main crops that cover 210 and 900 km^2, respectively. Coffee now survives largely as a small-holder cash crop in the north. Commercial sugar production is impossible without irrigation. More and more land is becoming permanently cultivated and use of artificial fertilizer is increasing, although no fertilizer is used to grow cassava, millet, maize, sorghum, cotton and rice, except when cotton and rice are grown in organized land schemes where fertilizer use is encouraged.

2.2.4. Mozambique

With about 20 per cent of its territory, the area belonging to the Zambezi drainage basin has great agricultural potential. Thus, almost 2500 km^2 were identified as potential arable land mainly on the Zambezi flood plains.

Table 14. Land-use in Mozambique. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	24 560	27 850	28 500	28 500	28 600
Permanent crop	2 130	2 240	2 300	2 300	2 300
Permanent pasture	440 000	440 000	440 000	440 000	440 000
Forest	194 000	166 400	160 500	156 890	150 900
Irrigation	460	260	380	620	820

Tete highlands region is predominantly humid and temperate with mainly ferrallitic soils on which maize and potatoes are cultivated. Close to the Zambezi river, soils are predominantly brown soils with sorghum, millet, maize and cotton production. The main types of farming in the regions belonging to the Zambezi watershed are semi-subsistence farming and subsistence farming with livestock.

2.2.5. Namibia

The area of Namibia belonging to the Zambezi drainage basin is called the Caprivi strip, a region very sparsely populated. Statistics for the whole country given in Table 15 cannot be taken as representative of the Caprivi strip land use.

Table 15. Land-use in Namibia. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	ND	27 000	21 540	35 520	37 400
Permanent crop	ND	–	–	–	–
Permanent pasture	ND	103 000	106 260	96 680	92 000
Forest	ND	35 000	32 000	29 000	26 000
Irrigation	ND	60	70	80	80

2.2.6. Tanzania

Almost three per cent of Tanzania territory which is drained to Lake Malawi is still at its early stage of agricultural development. As shown in Table 16, it is not the case for the main part of the territory. In this small area, irrigation practices are not well developed. Except for tobacco, no substantial cash crop is grown, but normal subsistence crops are produced.

Table 16. Land-use in Tanzania. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	26 130	41 800	50 000	41 100	41 300
Permanent crop	7 360	9 500	10 700	10 500	10 600
Permanent pasture	452 400	449 600	447 600	350 000	350 000
Forest	339 420	310 740	310 740	432 600	426 650
Irrigation	330	460	550	1 200	1 400

2.2.7. Zambia

In Zambia, the total area of arable land is estimated at about 10 million hectares. At present, the development of this resource base has high priority in the national development planning.

Although the amounts vary considerably from year to year, maize, groundnuts and cotton are most important sectors of involvement. The two main types of timber are pine and eucalyptus for use in the mining and construction industries. Commercial cultivation is mainly along the Kafue river system and the southern agricultural belt.

Table 17. Land-use in Zambia. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	48 150	49 440	49 930	51 000	51 800
Permanent crop	50	60	70	80	80
Permanent pasture	300 000	300 000	330 000	350 000	350 000
Forest	376 310	373 300	373 300	298 900	293 900
Irrigation	20	30	30	190	200

2.2.8. Zimbabwe

Due to its dominance in the economy, the government has declared the development of agriculture as the highest priority in the current five years national development plan (UNEP 1986b). One principal means of increasing agricultural production is to increase the total area of cultivated land mainly in the Zambezi drainage basin.

Table 18. Land-use in Zimbabwe. Statistics in km^2.

Land-Use	1965	1970	1975	1980	1985
Arable	19 810	23 350	24 650	24 650	26 500
Permanent crop	150	150	150	740	840
Permanent pasture	48 560	48 560	48 560	48 560	48 560
Forest	238 100	238 100	238 100	238 100	238 100
Irrigation	270	460	550	1 200	1 750

The area lying in the Zambezi drainage basin is divided into three geographical regions: (a) the high veld, the highest extensive surface which lies largely between 1 200 and 1 500 metres, forms the watershed between the Zambezi river and the north. (b) In the western part of the Zambezi basin the middle veld forms a very extensive plateau. (c) The Zambezi low veld is more limited and is mostly cut-off from the rest of the country by steep escarpments and rugged terrain. The main crops are maize and Virginia tobacco. Forests are important, especially in the northwestern quarter with extensive reserves of indigenous hardwoods covering some 9 500 km^2, and in the eastern highlands there are about 650 km^2 of pines.

3. Water Quality

A water quality survey of the Zambezi river system is not yet very developed (UNEP 1986b), mainly due to the shortage of manpower and equipment. Yet, hydro-chemistry of the middle and lower Zambezi is relatively well documented. A survey has been made principally of the main tributaries of the Zambezi river, and the main impounded zones. Thus, Coche (1968), and Balon and Coche (1974) have detailed the physico-chemistry of Lake Kariba, while McLachlan (1970a), King and Lee (1974) and Bowmaker (1976) have focused on tributaries entering Lake Kariba. Hall *et al.* (1976; 1977) have described the physico-chemical status of the lower Zambezi prior to and during the closure of the Cahora Bassa dam and its main tributaries. Hydro-chemical and hydrobiological surveys have been done also on the Kafue flats (Carey 1971; Salter 1979; 1985). Some information is available on smaller impoundments like the McIlwaine lake on the Hunyani river (Marshall and Falconer 1973a,b).

No major pollution problems have been reported on the Zambezi drainage system (UNEP 1986b), except at some specific sites such as the copperbelt in Zambia, Lusaka and Harare areas, and some other major towns from which domestic and industrial effluents could occur. The regulation of the middle and lower Zambezi and their transformation into a "reservoir river" might aggravate the water quality problems, like eutrophication due to fertilizer leaching. Although soil fertilization is not developed, as shown in Table 19, the situation may change if large scale irrigation development occur, and also because development of agricultural programmes is one of the main goals of the riparian countries. Another problem that could arise soon is sedimentation in man-made lakes due to soil erosion in deforested areas (see Section 3). Presently, the water quality of the middle and lower Zambezi depends mainly on processes that occur in the impoundments. Water quality data will be given in Chapter 3 on impoundments.

Table 19. Fertilization rates in countries sharing the Zambezi drainage basin (FAO Fertilizer Yearbooks 1981, 1986).

	N kg/ha				P kg/ha			
	1970	1976	1980	1984	1970	1976	1980	1984
Angola	2.1				0.3			
Botswana	0.9	0.7	0.4	0.4	0.27	0.31	0.17	0.13
Malawi	3.8	8.3	3.5	5.5	0.27	0.31	0.17	0.13
Mozambique	1.7	2.2	1.5	2.4	2.18	2.18	1.35	0.61
Namibia	ND	ND	ND	ND	ND	ND	ND	ND
Tanzania	1.7	2.6	2.8	3.0	0.31	0.96	0.39	0.44
Zambia	4.1	7.9	7.5	8.5	0.83	1.57	1.27	1.40
Zimbabwe	23.1	24.2	27.8	30.3	5.85	7.55	6.37	7.24

Another problem related to the development of agriculture is the use of pesticides, especially DDT to eradicate tsetse flies which are a *sine qua none* condition before settlement can begin in these infested areas. DDT is also used for the eradication of Anopheles flies, cause of malaria. The use of pesticides is dangerous because of concentration in the food chain. Endosulfane and other "soft" pesticides have been tested as substitutes for DDT.

4. Energy Planning

The Southern African Development Coordination Conference (SADCC) was established in April 1980 by a declaration of the governments of the nine independent states of southern Africa, namely Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia and Zimbabwe. The objectives of the regional energy policy have been summarized by Bhagavan (1985) as follows:

- "to restrict the use of petroleum products solely to applications where alternative resources cannot be envisaged
- to develop regional electrification and extend it to the transport and agricultural sectors, to exploit the vast hydroelectric resources of the region in order to achieve this, and also to make use of small hydroelectric power plants throughout the rural areas
- to promote the interconnection of the national grid system to ensure that production and distribution capacity is utilized more efficiently among the various states in the region
- to develop prospecting and exploitation of fossil fuel deposits, such as oil, natural gas and coal
- to develop new technologies for the utilization of solar energy, biomass and other renewable energy sources and to make them available to the rural areas
- to promote research and development in renewable energy technologies at the regional level
- to promote regional programmes of reforestation and efficient exploitation and utilization of wood."

This review of objectives offers a clear idea of what is at stake on the Zambezi drainage basin since the signing of the declaration by seven of the eight riparian countries of the Zambezi river, and it is assumed by both SADCC and the South West African People's Organisation (SWAPO) that an independent Namibia would join SADCC.

4.1. Fuelwood

Fuelwood is the primary source of energy for all rural households and a large part of the urban households of the riparian countries of the Zambezi river. Table 20 gives the evolution of wood use as a source of energy in the Zambezi riparian countries.

Table 20. Evolution of woodstock in $10^3 m^3$ used as energy source in the Zambezi riparian countries (FAO Forest Products 1975, 1986).

	1965	1970	1975	1980	1985
Angola	5360	5920	6607	7468	7663
Botswana	560	620	691	729	729
Malawi	3520	4000	4622	5317	6402
Mozambique	6960	7700	9239	12306	14270
Namibia	ND	ND	ND	ND	ND
Tanzania	26453	30500	31169	36980	44087
Zambia	4026	4697	4292	4984	5511
Zimbabwe	4500	5050	4170	5154	5733

Fuelwood plays a dominant role in the curing of tobacco and tea, the major cash crops of the region. For instance, Bhagavan (1985) reported that in Malawi and Zimbabwe, tobacco and tea curing accounts for about 40 per cent of the total firewood consumption. As an example, Hosier (1986) gives the energy consumption in Zimbabwe (Figure 17) with the actual end-use and projected requirements for the year 2000. It appears that even in Zimbabwe with abundant supply of coal and electricity, wood resources will continue to be essential for most of the foreseeable future. This poses a major problem due to the increasing scarcity of fuelwood supplies in all the Zambezi riparian countries. Due to this demand for fuelwood in rural and urban households as well as clearing land for agriculture and timber

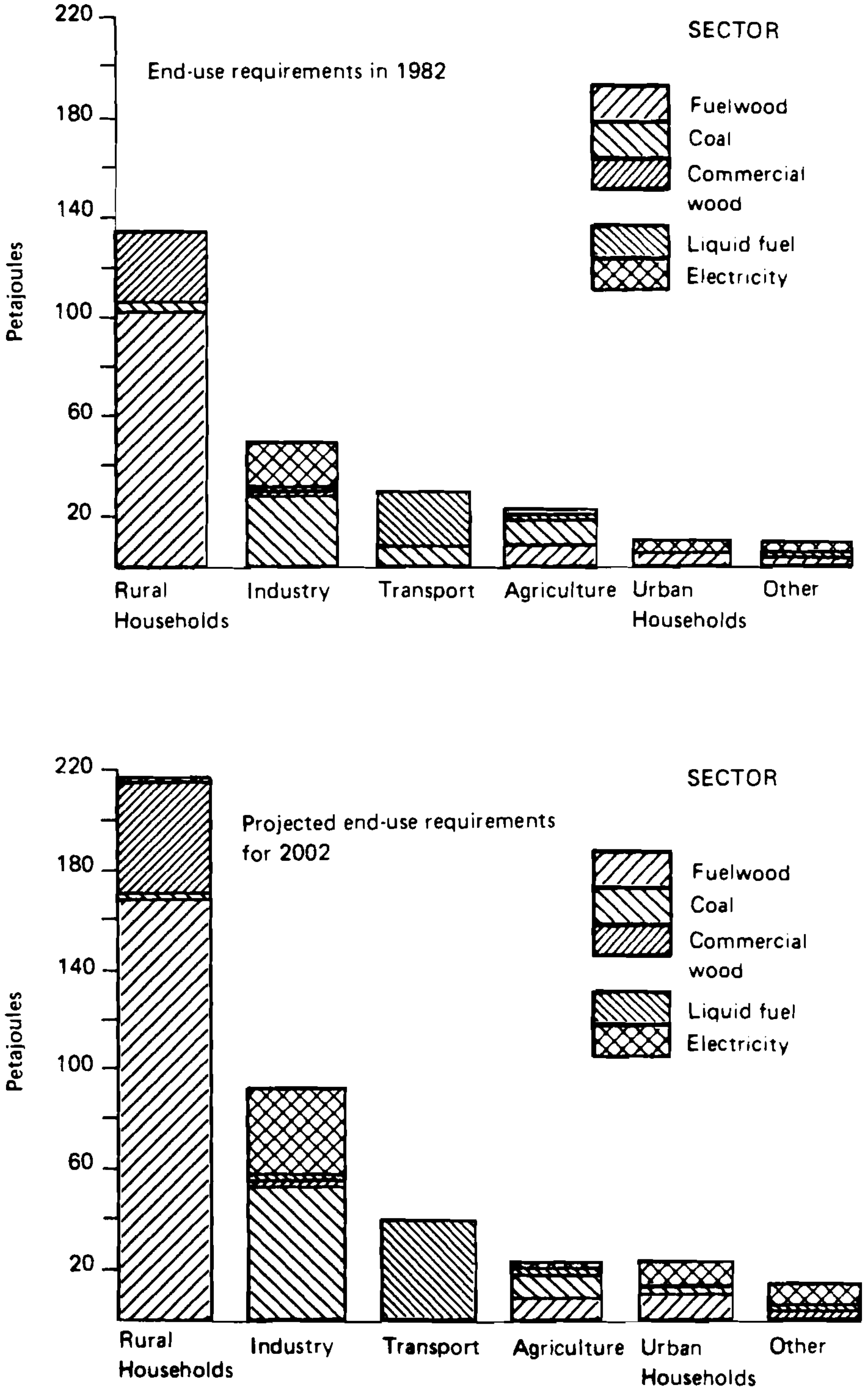


Figure 17. Energy consumption in Zimbabwe (Hosier, 1986).

trade, rapid deforestation is occurring on the Zambezi drainage basin, contributing to soil erosion as well as to changes in runoff from such disturbed areas. Thus, Mumeka (1986) has shown that deforestation led to an increase in streamflow, and a change in the flood hydrograph of the Kafue headwaters. Elwell (1978; 1984) and Elwell and Stocking (1982) have developed models to predict soil losses by arable lands in Zimbabwe. Such estimations of soil loss are very important in determining the impact of sediment transported by rivers on reservoir life of man-made lakes in the Zambezi basin (Bolton 1984; Kabell 1984; Pitt and Thompson 1984; White and Bettess 1984).

4.2. Hydroelectric schemes and other energy sources

First, dealing with oil production, Angola is the only Zambezi riparian country that produces and exports substantial quantity of oil. On the other hand, there are massive deposits of coal in Botswana, Mozambique, Tanzania, Zambia and Zimbabwe. Unfortunately, the decrease in world demand for coal hinders private foreign investment for developing coal reserves for export (Bhagavan 1985). Concerning natural gas, big reserves have been discovered only at two offshore sites in Mozambique.

Actual and potential hydroelectric power are abundant. There is more than enough installed generation capacity today to meet the current demands of urban households, industries and the service sector. Table 21 gives the net capacity installed in electricity generation plants, while Table 22 shows the utilization of electricity according to the type of plant.

Table 21. Installed capacity of electricity generating plants of the Zambezi riparian countries (UN Yearbooks 1972, 1983, 1987).

	Thermal capacity 10^3 kw				Hydroelectricity capacity 10^3 kw			
	1961	1970	1980	1985	1961	1970	1980	1985
Angola	60	101	200	200	28	211	400	400
Botswana	ND	ND	ND	ND	ND	ND	ND	ND
Malawi	11	21	39	34	1	28	67	126
Mozambique	94	241	280	280	65	114	1520	1523
Namibia	ND	ND	ND	ND	ND	ND	ND	ND
Tanzania	30	94	70	180	20	49	188	260
Zambia	241	184	190	191	43	180	1538	1538
Zimbabwe	502	487	487	906	562	705	705	633

Table 22. Utilization of installed electricity generating capacity according to the type of plant and country.

	Thermal KWH per KW				Hydroelectricity Kwh per KW			
	1961	1970	1980	1985	1961	1970	1980	1985
Angola	517	1228	2000	2275	5357	2464	2750	3338
Botswana	ND	ND	ND	ND	ND	ND	ND	ND
Malawi	3000	609	769	771	2000	5038	6030	3775
Mozambique	1383	1711	1607	1464	1846	2353	8914	1008
Namibia	ND	ND	ND	ND	ND	ND	ND	ND
Tanzania	ND	1851	2571	1444	ND	6224	2819	2365
Zambia	1672	970	526	183	6186	910	5722	6538
Zimbabwe	1147	2388	1094	1051	3925	7443	5685	5355

Nowadays, even if utilization of the existing electricity capacity scheme is below the potential, the supply of electricity comfortably exceeds demand in the Zambezi riparian countries. Bhagavan (1985) underlined that "demand here means ability of the end-use customer to pay the asked for price which effectively leaves out about 70 to 90 per cent of the population, who at present do not have this ability to pay." If attempts were made to meet this larger need, the present supply would be clearly inadequate. Largest installed and potential capacity in hydroelectricity of the Zambezi drainage basin is based mainly on the Zambezi river itself and on the Kafue river (Table 23).

Table 23. Hydroelectric power plants on the Zambezi and the Kafue rivers (Bolton 1983).

Power Plant	Installed capacity in Mw	Provision capacity in Mw
Victoria Falls	108	
Kariba	1266	+ 300
Cahora Bassa	2075	+ 1750
Kafue Gorge	900	

5. Main Issues

From the general features of the Zambezi river system and its drainage basin, it appears that two main issues must be faced from the water management point of view: (a) the soil erosion problem due to intensive deforestation, and (b) reservoir operations in order to optimize their hydroelectric power generation and planned secondary uses. In fact, these two main challenges are interconnected in that the erosion process entails an increase in silt deposition in reservoirs diminishing their real storage capacity. The main man-made lakes on the Zambezi drainage basin lie in the middle stretch of the Zambezi river (Kariba, Cahora Bassa) and on the Kafue river (Figure 18). Reservoir operation along the Zambezi is interconnected. For the sake of presentation, however, the following chapter will deal with each of these impoundments separately. Constraints imposed by operation of upstream dams will also be considered.

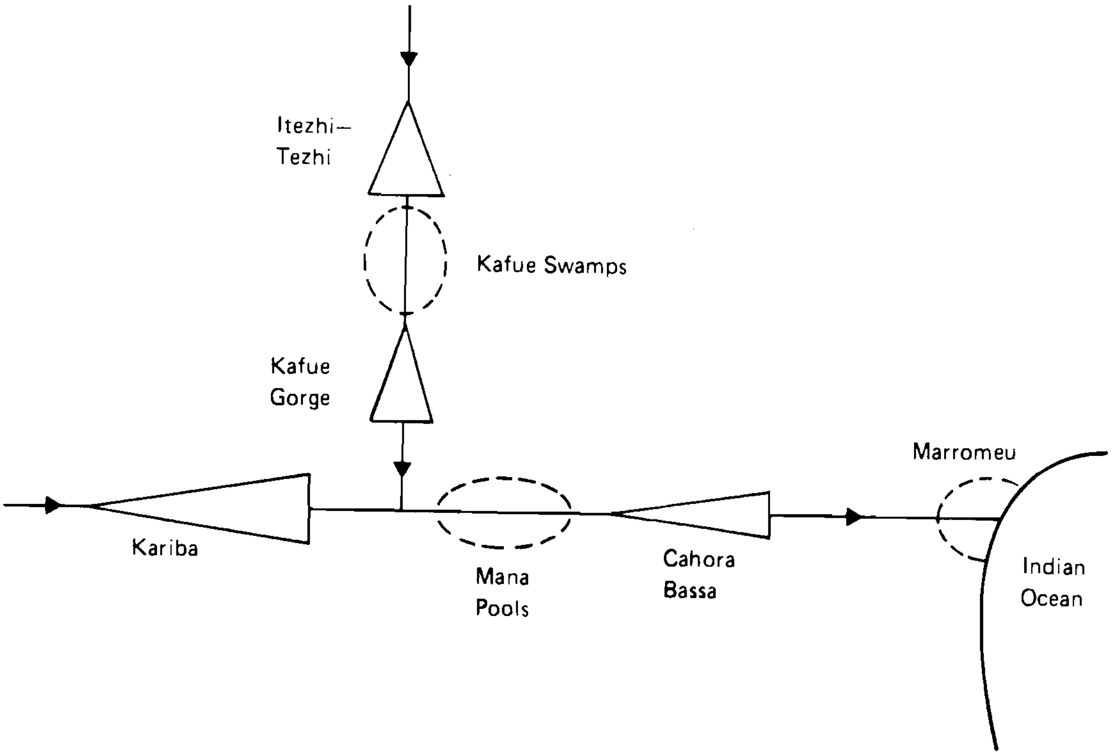


Figure 18. Schematic representation of impoundments on the middle Zambezi (Pinay *et al.*, 1988).

Chapter III: Impoundments on the Zambezi River System

1. Introduction

It has already been mentioned that about 570 km of the Zambezi river are now regulated by man-made lakes, representing 65 per cent of the middle Zambezi stretch. Although the more visible consequence of dam creation is flow control of the river, one must keep in mind that it also leads to development of drainage basin-reservoir interactions (Figure 19). Since these interactions are initiated by reservoir construction, development follows as a matter of course, causing large scale environmental disturbances. Thus, it is essential to consider the relationships between reservoir and its drainage basin. Although these man-made lakes were constructed for the sole purpose of hydro-electric power generation, management of these impoundments have posed far too many ecological problems both in reservoirs and in the river downstream (Begg 1973; Davies 1975a–b; DuToit 1982; Sheppe 1985). Furthermore, now that the lakes are there, it is a challenge to try to use them as a resource for optimal biological production (Table 24). It appears that for every function, the guidelines for optimal use could be a hindrance to achieving other water management goals.

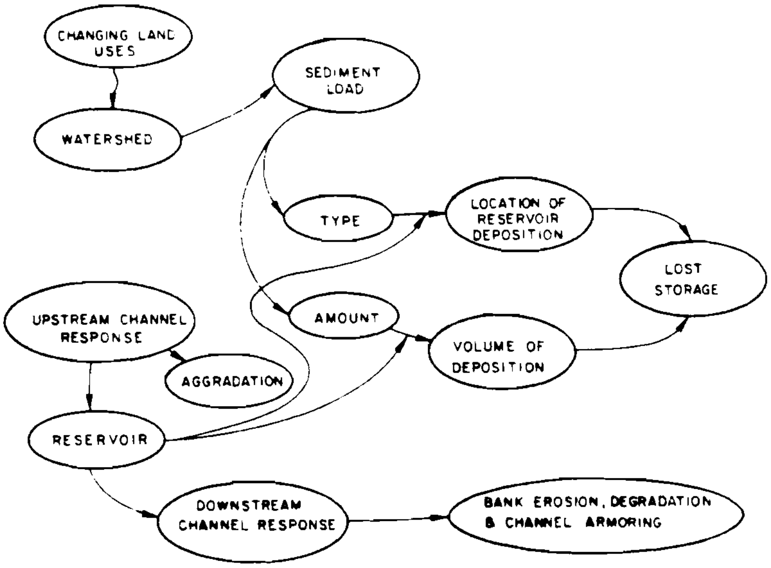


Figure 19. Drainage basin–reservoir interactions (Simons, 1979).

Thus, the following chapter will deal with different uses and their constraints for the main impoundments cited in Table 24.

Table 24. Main upstream and downstream purposes of the major man-made lakes in the Zambezi river system (Pinay *et al.* 1988).

	Kariba	Itezhi-Tezhi	Kafue Gorge	Cahora Bassa
Upstream purposes				
Fisheries	+		+	+
Irrigation	+		+	+
Recreation	+		+	+
Animal husbandry	+		+	+
Swamps			Kafue swamps	
Main purpose of dam	Power generation	Water storage	Power generation	Power generation
Downstream purposes				
Dam operation	Cahora Bassa	Kafue Gorge		
Navigation				+
Irrigation		+		
Animal husbandry	+	+		
Fisheries		+		+
Swamps maintenance	Mana pools	Kafue	Mana pools	Marromeu

2. Kariba Impoundment

2.1. Historical Aspects

Originally the Kariba project was conceived as a national project. It was constructed in the heart of the Federation of Rhodesia and Nyasaland to provide a functional reinforcement of the political structure. A loan from the World Bank in 1956, guaranteed by the United Kingdom and the Federation, was with respect to the purpose of power production by installing a hydro-electric plant having a maximum capacity of 1 200 000 kw (Austin 1968). Lake Kariba was completed in 1959, inundating 5 250 km^2 of the former Gwembe valley on the middle Zambezi. The scheme was vital to the development of the Federal economy, particularly to the expanding copper mining industry in Northern Rhodesia (now Zambia). Justification for the scheme was partly the fact that it would decrease the copperbelt's dependence upon Rhodesian coal. The Federation of Rhodesia and Nyasaland was dissolved at the end of December 1963, and later on October 24, 1964, Northern Rhodesia became the independent state of Zambia. At the break-up of the Federation, the two countries expressed the desire that "the integrated system for the control of the generation of electric power and its transmission in the territories should continue to be operated and fully developed as a single system under the joint ownership of the government." (Austin 1968). The Central African Power Corporation was established in 1963 in order to allow Zambia and Southern Rhodesia that became Zimbabwe in 1980, to share equally the available generating output from the Kariba complex. Thus, an interconnected system between the two countries has been developed (Figure 20).

2.2. Main Features of Man-Made Lake Kariba

The Zambezi river catchment above the Kariba dam is composed of three main geographical entities (Figure 21): (a) Northern Highlands, a belt of high grounds between 1 000 and 2 000 metres covering 220 670 km^2; (b) Central Plains, a relatively flat plateau between 1 000 and 1 500 metres characterized by large swampy areas (Barotse and Chobe swamps), with an area of 286 370 km^2; (c) Rhodesian Highlands comprising of a peneplain lying between 650 and 1 300 metres covering 156 180 km^2. Total area covers about 663 820 km^2, constituting more than a third of the total drainage basin of the Zambezi. Lake Kariba is situated on the Zambezi at an altitude of 485 metres above sea-level. It was completed in 1959 when a concrete arch dam rising 128 m above the river bed and measuring 580 metres long was closed. It is situated at the boundary between Zambia and Zimbabwe. Lake Kariba (Figure 22) is divided into five basins defined by narrow chains of islands and belts of shallow water. General characteristics of the reservoir itself are given in Table 25 and in Annex I.

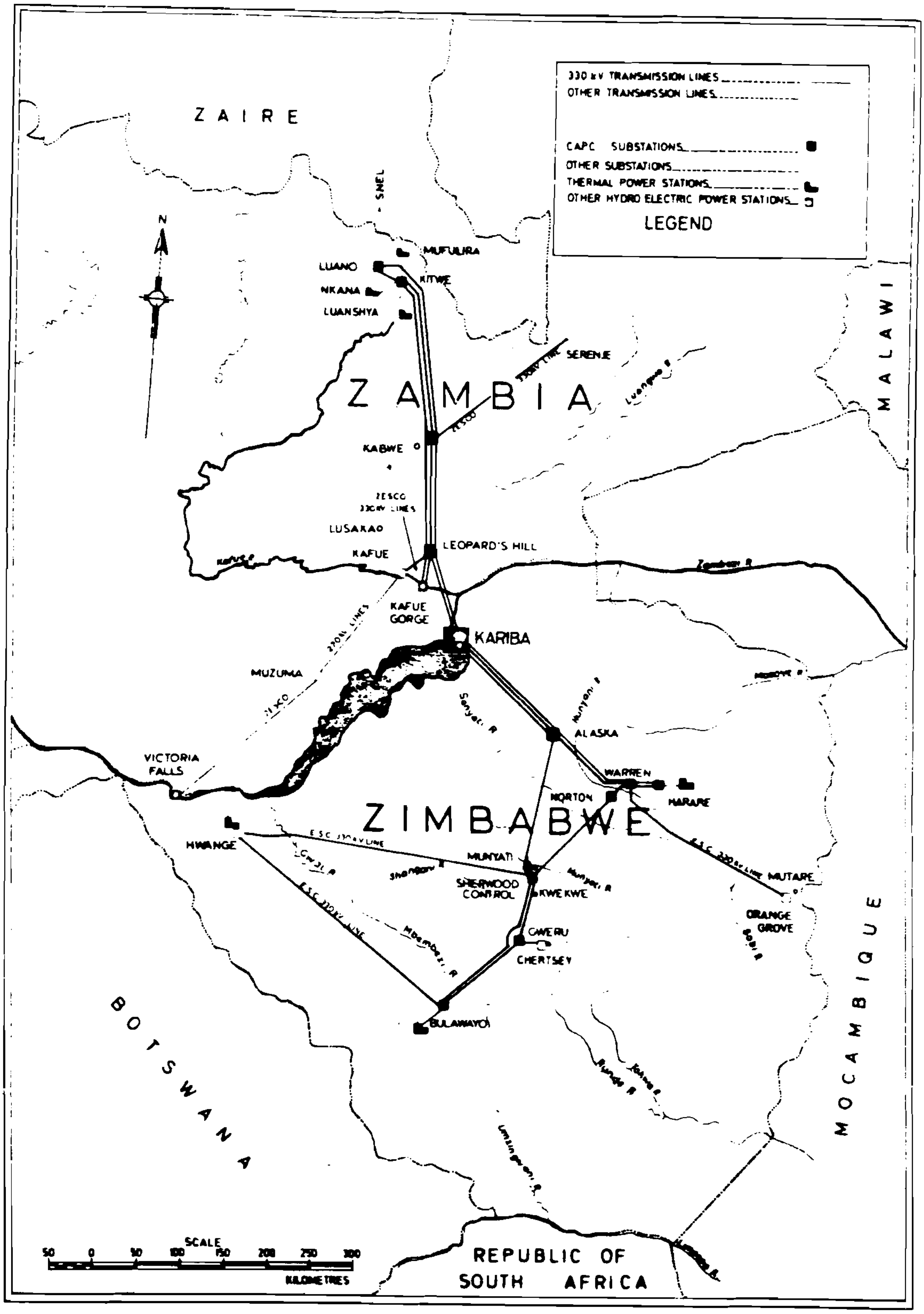


Figure 20. Interconnected system between Zambia and Zimbabwe (CAPC 1984).

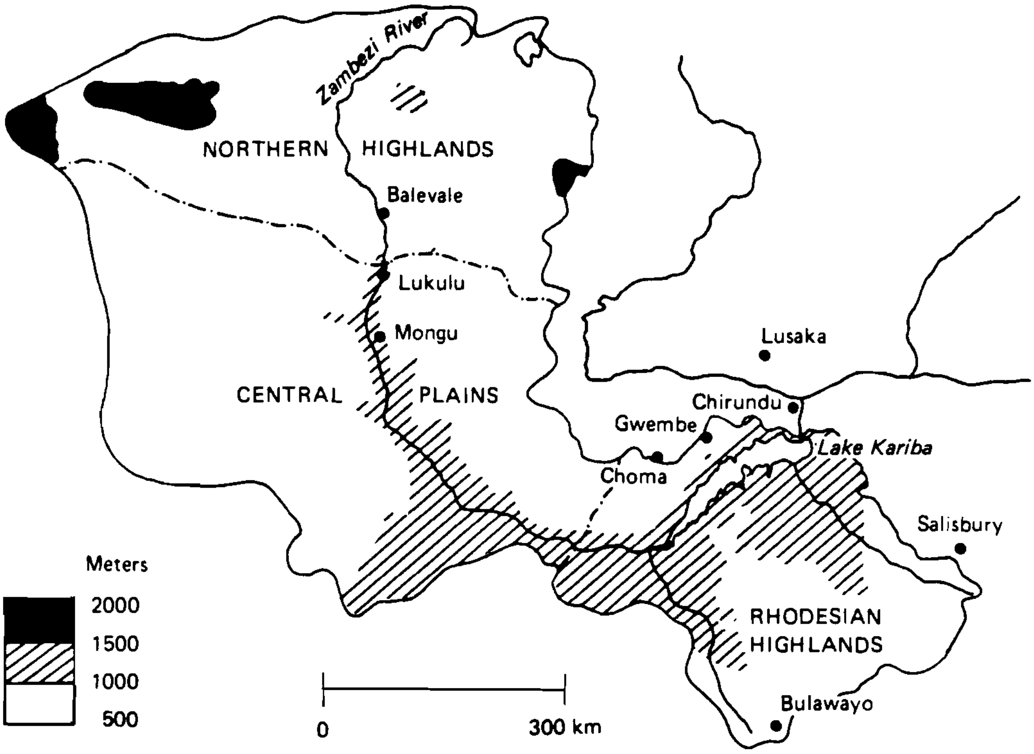


Figure 21. Drainage basin of the Zambezi river upstream from the Kariba Dam (Balon and Coche, 1974).

Table 25. General characteristics of Kariba reservoir (Jackson and Davies 1976).

Feature		Kariba
Catchment	km^2	663,820
Geographical position:		
Longitude		26°40'E–29°3'E
Latitude		16°28'S–18°6'S
Direction of main axis		SW–NE
Direction of predominant wind		SE–NW
Number of basins		5
Height of wall	m	128
Maximum depth	m	120
Mean depth	m	29.5
Maximum drawdown	m	14
Maximum length	km	300–320
Greatest width	km	~ 40
Total area at capacity	km^2	5 250
Maximum floodgate discharge	m^{3}sec-^{1}	6 500
Power capacity per turbine	MW	100
Total power output of dam	MW	1 200
Actual filling time	years	4
Impounded water mass	m^3	15.5 x 10^{10}
Infestant aquatic macrophytes present in the system		1. *Salvinia molesta* 2. Pistia stratiotes

2.3. Hydrology

The Zambezi is the major river flowing into Lake Kariba and provides between 70 and 80 per cent of its water. The remainder is supplied by other tributaries and direct rainfall. Average inflow into the Kariba lake from the Zambezi between 1925 and 1959 was 1133 m^3s^{-1} (Balon and Coche 1974), while the total input from other tributaries was 319 m^3s^{-1}. On the basis of their individual catchment areas, the main secondary rivers are the Gwaai, Sanyati and Sengwa (Table 26, Figure 22). Altogether these rivers situated in Zimbabwe drain 63.6 percent of the lake catchment area.

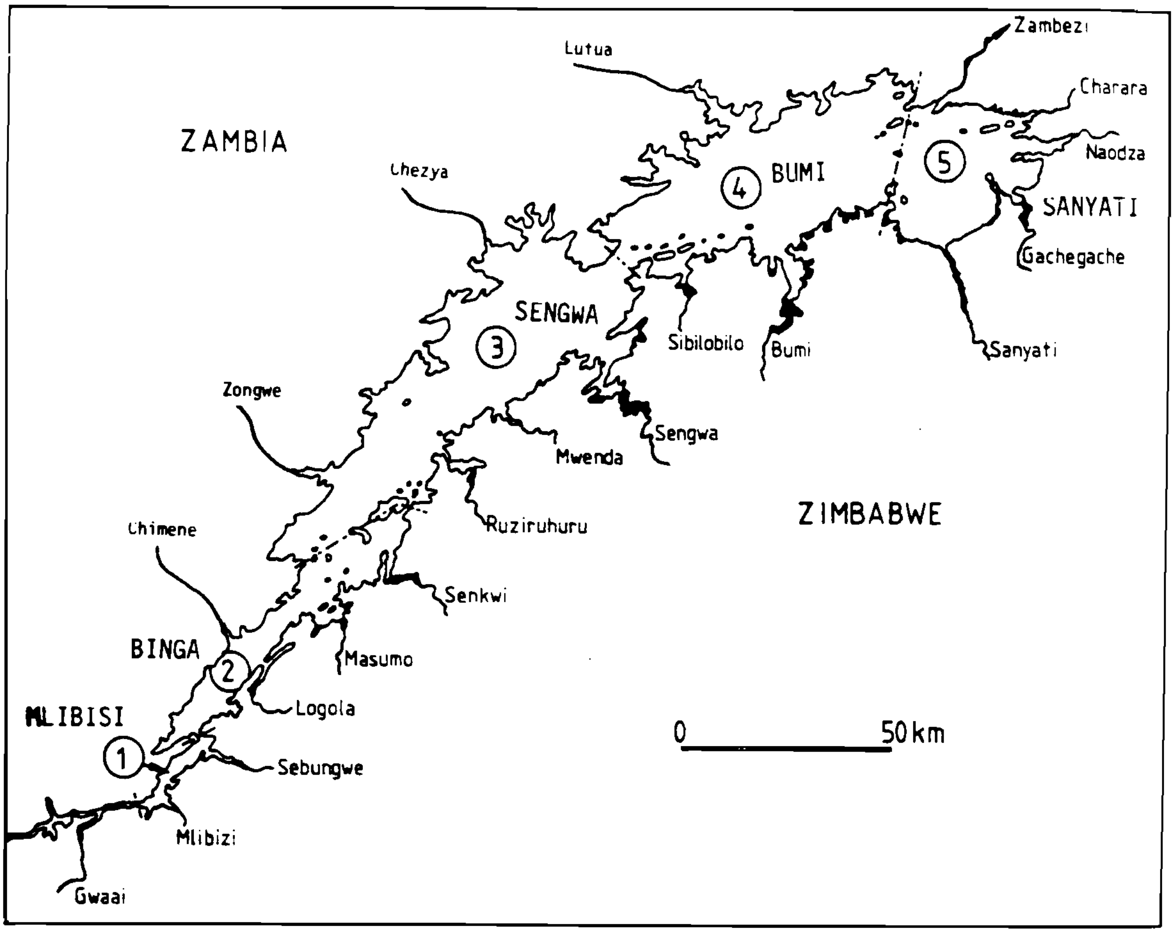


Figure 22. Man-made Lake Kariba and its main tributaries (adapted from Marshall and Junor, 1983).

Table 26. Drainage basin areas of the main secondary tributaries of Lake Kariba.

North Shore		Kariba Basins	South Shore	
Drainage basin km^2	Tributaries		Tributaries	Drainage basin km^2
		Mlibizi (1)	Gwaai	47 140
2 567	Chimene	Binga (2)		
2 290 850	Zongwe Chezya	Sengwa (3)	Mwenda Zengwa	270 5 200
2 274	Lufna	Bumi (4)		
		Sanyati (5)	43 500	

One of the characteristics of the secondary tributaries is their erratic discharge. For instance, absolute minimum and maximum average annual discharges were 75 $m^3.s^{-1}$ in 1946/47 and 852 $m^3.s^{-1}$ respectively (Balon and Coche 1974). Therefore, overall average discharge (318 $m^3.s^{-1}$) has not changed since the creation of Lake Kariba, although the average Zambezi inflow has increased from 1.999 $m^3.s^{-1}$ between 1925–1966 period to 1.517 $m^3.s^{-1}$ between 1959–1966 Concerning the hydrological cycle, the secondary tributaries feature a main flood season between January and March (about 56 per cent of the annual discharge), and constitute the Gumbura floods cited previously (Chapter I, Section 3.2). The Zambezi flood (Murorwe) occurs between March and May (Figure 11).

2.4. Reservoir Operation

The dam was closed on December 2, 1958, when the lake started to fill from its river-bed base of 391 m above sea level. The filling phase finished in 1963. During the first phase period, water level fluctuations were very important (Figure 23). Water levels rose from 420 m above sea level in 1959–1960 extremely rapidly (6 metres every 24 hours). Until the eight metres drop in 1964, conditions had been improving. Considering the Kariba lake's bathimetry (Figure 24) these drawdowns entail important variations on the waterlogged area. During this filling period, discharges from Kariba dam were much lower (annual average 258 $m^3.s^{-1}$), compared to the natural flow of the Zambezi river at Kariba station (1 423 $m^3.s^{-1}$). Table 27 gives the monthly flows from the Kariba dam during the filling phase.

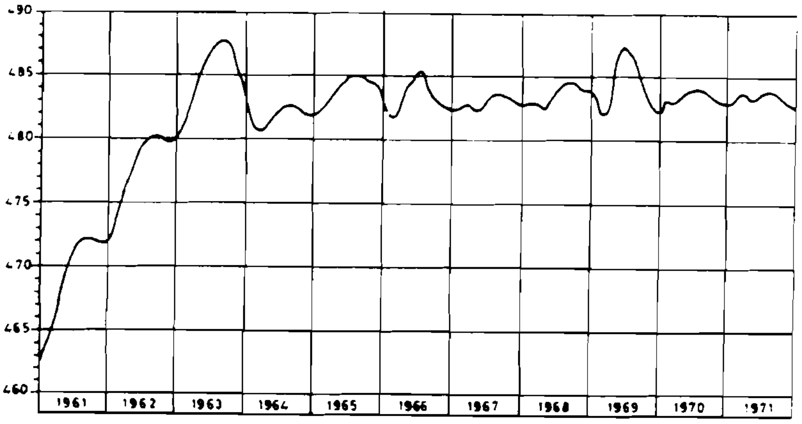


Figure 23. Lake levels on the Kariba (metres a.s.l.) recorded over the period 1961–71 (Begg, 1973).

Table 27. Lake Kariba monthly discharges in cubic metres per second (Balon and Coche 1974).

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1958–59	472	472	33	24	14	19	19	19	24	194	288	278
1959–60	283	283	142	142	142	142	142	189	189	236	283	283
1960–61	330	283	330	330	283	330	330	330	330	330	378	378
1961–62	378	378	378	378	330	378	378	378	425	425	425	378

Since the end of the filling phase, reservoir operation has managed to provide the best hydropower production. The Zambezi flow or discharge below the Kariba dam consists of two components whose importance varies greatly according to the engineering needs during the year: (a) the turbine flow released through the tail races is closely related to the electricity power requirements. The centres of the lake water intakes are situated at about 462.5 and 447.5 m.a.s.l. respectively. At an average operating water level of the reservoir (485 m.a.s.l.), the water is therefore drawn from a depth of at least 20 metres; (b) the spillage flow is released through one or more of the six sluice gates built into the dam (457–466 m) for controlling the lake water level (Balon and Coche 1974). Maximum floodgate discharge is about 6500 $m^3.s^{-1}$ but varies depending on the hydrological conditions. For instance, Table 28 gives the number of days of floodgate discharge between 1961 and 1978.

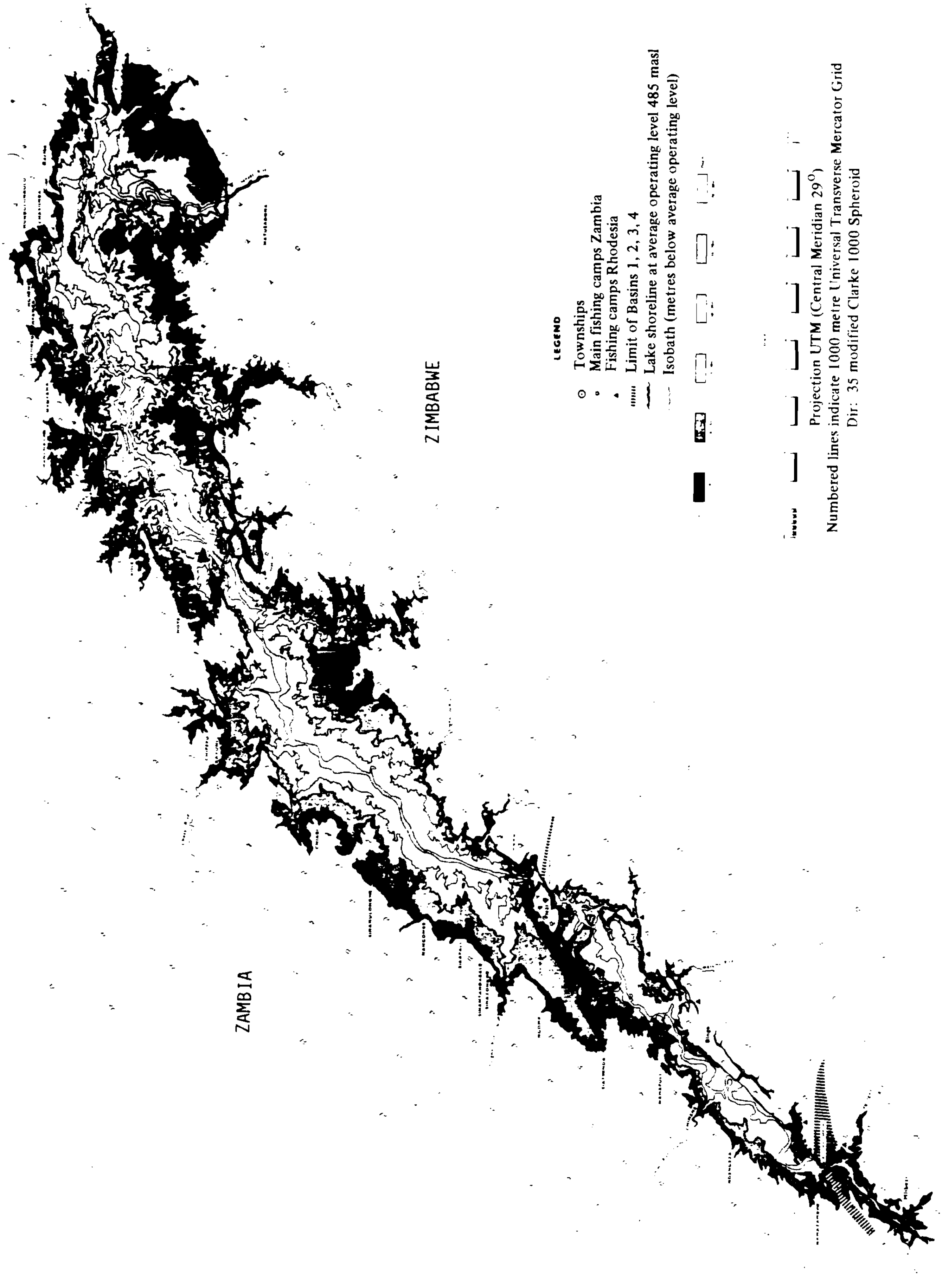


Figure 24. Bathymetry of Lake Kariba (Balon and Coche, 1974).

Table 28. **Floodgate discharge at Kariba dam in days per month between 1961–1978 (Guy 1981).**

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1961	4				1							
1962	6			29	11							
1963	22	28	31	30	12					17	30	31
1964	31	29	4									
1965		12			3							
1966	31	1	1		11		31	31	12			21
1967		9	31	30	20							
1968	17	29	31	27								16
1969	31	28	31	30	31	23	24	31	30	31	30	
1970	20	28	31	30	31	1						15
1971	31	28	31	30	2							
1972		13	15									
1973												
1974			28	30	31	1						
1975	8	28	31	27								
1976		5	31	30	31	30	29					
1977				25	31	10						
1978	5	28	31	30	31	30	31	2				

Energy demand constitutes the main parameter regulating the turbine discharge. Current monthly turbine flow releases are almost the same whatever the period considered (Figure 25). Evaporation is another kind of output from the lake. Since the creation of Lake Kariba, increased evaporation and increased rainfall over the lake have affected the downstream flow. According to Dutoit (1982), between 1975/76 and 1979/80, about 7 per cent of the total annual inflow into Lake Kariba consisted of rainfall, while 14 per cent of the total annual inflow was lost through evaporation.

In terms of total input and output from the Kariba reservoir, it seems, as mentioned previously (Chapter I, Section 3.1) that the monthly downstream flow regime was much the same as it would have been without the Kariba dam. On the other hand, Guy (1981) showed from inflow and outflow records (1966–1978 Figure 26) that seasonal differences have become more pronounced, with wet seasons being "wetter" and dry seasons "drier". This remark is in contradiction with the results of Attwell (1970) where reservoir operation of the Kariba tends to stabilize the flow. DuToit (1982) reports that the mean annual flow of the upper Zambezi was

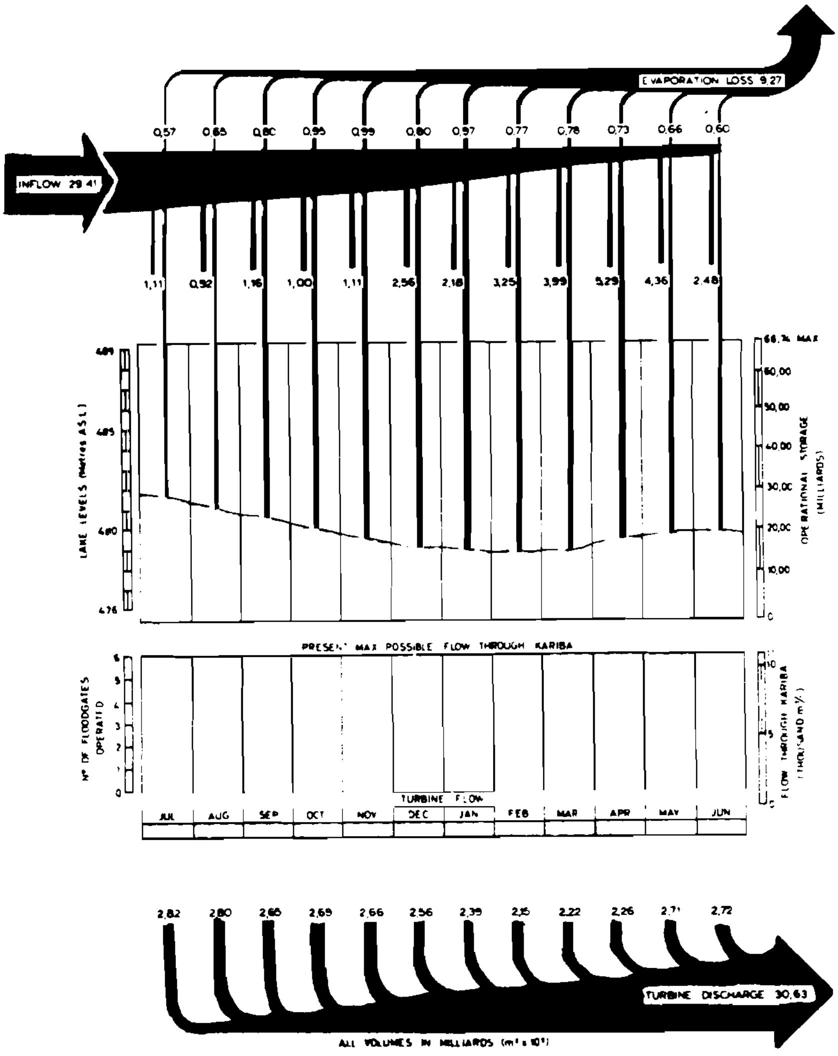
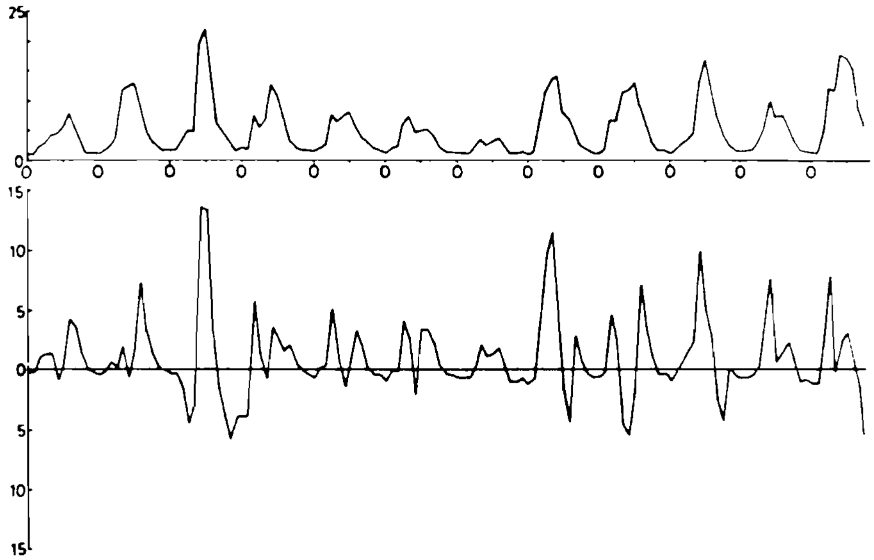


Figure 25. Turbine flow releases of the Kariba Dam. July 1983–June 1984 (CAPC, 1984).

42.5.$10^9 m^3$ with a minimum of 19.2.$10^9 m^3$ in 1958/59. Furthermore, extreme monthly flows were 23.1 $10^9 m^3$ in March 1958 and 0.37.$10^9 m^3$ in November 1924. This constitutes a ratio of 62:1. Thus, the annual and seasonal variations in the flow of the Zambezi are of major significance to the ecological dynamics of the river downstream from the dam.



The monthly differences between the amount of water flowing into and out of Lake Kariba. The units are milliards ($m^3 \times 10^9$). The upper figure indicates the normal pattern of flow for the Zambezi River based on the inflow figures for Lake Kariba. October (the start of the hydrological year) is indicated on the horizontal axis. The data are for the period October 1966 to July 1978

Figure 26. Water balance in the Kariba reservoir (Guy, 1981).

2.5. Water Level Fluctuations

Routine in the course of management of a hydroelectric power installation is the determination of discharge rates to meet power demand and flood control. These activities, in turn, affect the water levels of the lake (Magadza 1986). Thus, the lake is characterized by large fluctuations in the water level with an annual amplitude of around three metres and long-term fluctuations to extremes of more than eleven metres (Ramberg *et al.* 1987). The promising effects of drying and wetting soils are quite well known, a process that accelerates the decomposition of organics resulting in nutrient release (Chauvet 1987; Fabre (forthcoming); Pinay and Decamps 1988). It is likely that the process of drying and wetting is largely responsible for the important flushes of grass in the Kariba lake shore, the inundation of which led to the release of large quantities of materials into the water. A shore line exposed to drawdowns are characteristics of an ecotone: "the zone of transition between adjacent ecological systems, having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between adjacent ecological systems" (Clements 1905; Holland 1987). The margin of tropical man-made lakes act as man-made floodplains: lake level fluctuations add to the organic and mineral nutrient pools of both the terrestrial and aquatic components of the ecosystem through drowning during advancing and standing

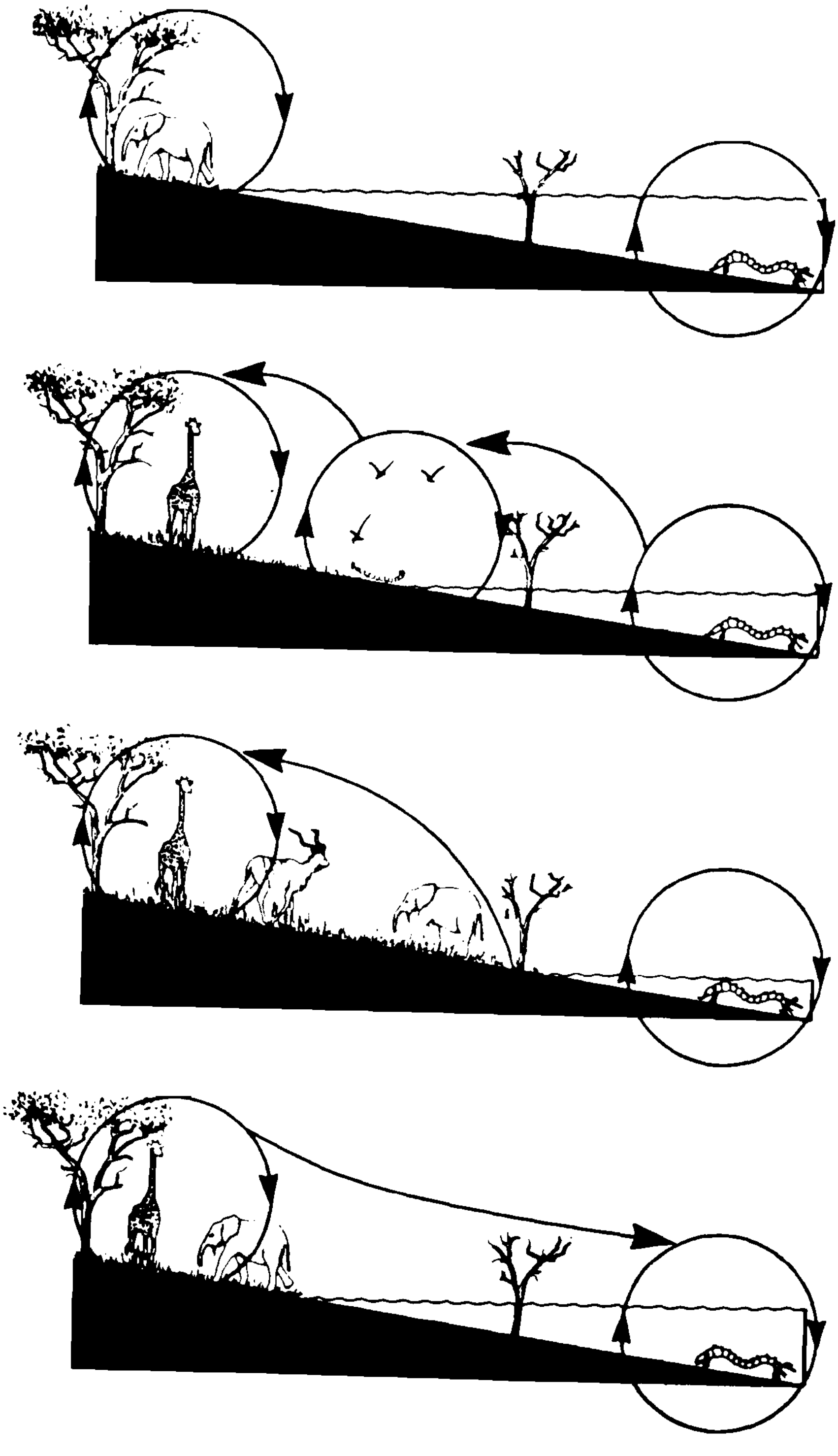
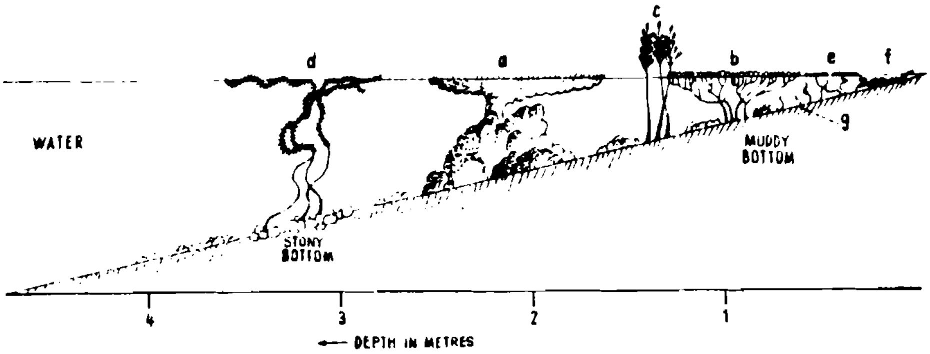


Figure 27. Interactions between terrestrial and aquatic ecosystems during water level fluctuations (Davies, 1986).

vegetation, and animal material during retreat. In addition, migratory terrestrial herbivorous interactions take place in this ecotone (McLachlan 1974; Davies 1986) (Figure 27). These interactions are beneficial for game pastures and lake productivity.

Thus, nutrient enrichment is a positive effect on submerged plants. Figure 28 gives an example of the depth distribution of an aquatic plant community. This entire community forms an important source of consumer food as well as a protective canopy for invertebrates and fish (McLachlan 1969; 1970a,b). If the water level fluctuations have a positive reciprocal effect for terrestrial as well as for aquatic life, it is important that the pattern of water level variation in Lake Kariba is controlled to resemble the natural cycle of the Zambezi river without artificial floods out of season. For instance, Bowmaker (1973) recommended that the half-cycle fluctuation in lake levels should not exceed 2 metres, and that the rate of change should be less than 0.6 metre/month.



Depth distribution pattern of some of the major aquatic plants recorded at Sengwa. a. *Potamogeton pusillus*. b. *Ludwigia stolonifera*. c. *Ludwigia erecta*. d. *Ceratophyllum demersum*. e. *Nymphaea* sp. f. *Alternathara sessilis*. g. *Utricularia inflexa*

Figure 28. Example of distribution pattern of some of the major aquatic plants on the Kariba shoreline (McLachlan, 1969).

2.6. Water Chemistry

Since the Kariba reservoir has reached its post-filling phase, the Zambezi provides about 70 per cent of inflow water and contributes most of the input of dissolved and suspended materials in the lake. Therefore, the Zambezi upstream from the Kariba has a relatively low nutrient level compared to other rivers (Mitchell 1973). The electric conductivity of water has been found to be a useful index for estimating the degree of mineralization of waters. In the case of the Kariba reservoir, strong relationships exist between conductivity on the one hand, and total solids content, salinity, total ionic concentrations and total alkalinity on the other (Balon and Coche 1974). Thus, the mineral content increases from Basin 1 to Basin

5. The proximity to the Zambezi dictates the physico-chemical characteristics of Basins 1 and 2; but these riverine features change to lacustrine features in the other basins. Since the closure of the Kariba dam, four phases of chemical evolution may be distinguished in the most lacustrine part of the reservoir on the basis of the pattern of variation of the water content in dissolved substances (Figure 29).

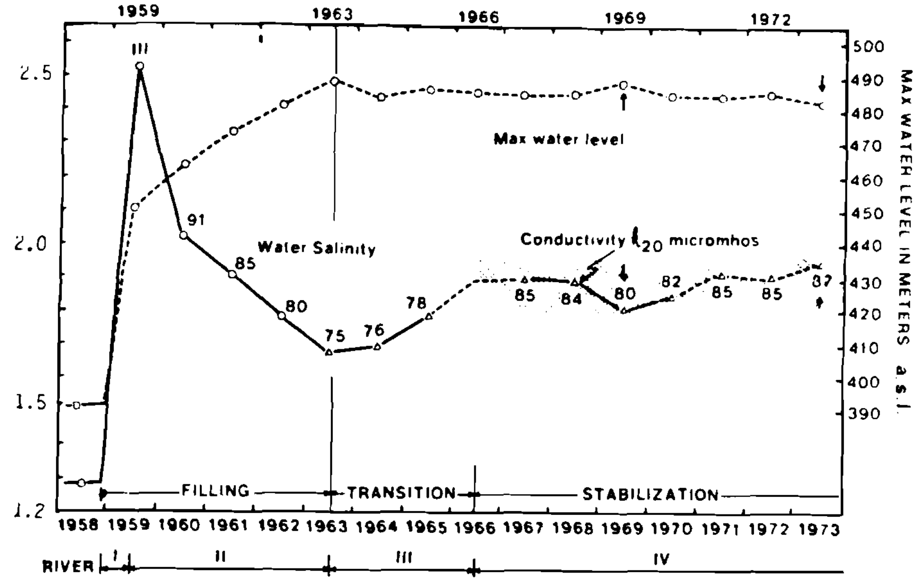


Figure 29. The phases of chemical evolution in Sanyati basin of Lake Kariba (Balon and Coche, 1974).

Phase I corresponds to the first year of rapid flooding of the valley soils, adding large quantities of organic and inorganic matter to the solution. During phase II, the rate of flooding decreases, and the newly flooded soils are less rich than those flooded earlier. Phase III started at the completion of the filling phase – lacustrine conditions develop and salinity increases. During Phase IV, chemical characteristics vary according to the storage level of the reservoir and within a narrow range. On the basis of its total mineral content, the Kariba lake contains waters of low total ionic concentrations (Balon and Coche 1974). Table 29 gives the main chemical nature of the Zambezi river upstream and downstream from the reservoir as well as in the lake.

Although the Zambezi river must be considered as the most important factor in determining the lake's chemical character, particularly for the two upper basins, the local importance of the other inflowing rivers cannot be ignored. Secondary rivers are important in terms of the chemical nature of their waters. Begg (1969)

Table 29. Main chemical characteristics on the Zambezi river flowing through Kariba lake (Davies 1986).

Variable	Units	Zambezi at Kariba Inflow^2	Station Lake Kariba Basin 5$^{(2)}$	Lake Kariba Outflow^2
Water temperature	°C		Homothermy establishes at 22m	
pH		7.6	8.4(0.44)	7.1(0.2)
Dissolved oxygen	mgl^{-1}			
Transparency-Secchi	cm	629(151)$^{(3)}$	537(220)	
Total alkalinity	mgl^{-1} $CaCO_3$	33(12.1)	41.7(1.49)	40.5(5.45)
Chloride	mgl^{-1} Cl			
Calcium hardness	mgl^{-1} Ca			
Total hardness	mgl^{-1} $CaCO_3$	31.6(9.96)	S 33.41(1.21) B 33.37(1.2)	35.2(5.64)
Colour	(Pt-Co)Units			
Conductivity	$\mu S\ cm^{-1}$	74.6(23.2) 55–75(Basin 1)^4	94.7	(92.7(5.03)
Ammonia	mgl^{-1}			
Nitrite	mgl^{-1} N	0.0017(0.0015)	S 0.002(0.0008) B 0.002(0.0013)	0.0005(0.001)
Nitrate	mgl^{-1} N	0.0103(0.0056)	S 0.017 (0.01) B 0.034(0.005)	0.027(0.021)
Orthophosphate	mgl^{-1} PO_4^{3-}	0.041(0.047)	S 0.022(0.015) B 0.034(0.017)	0.019(0.013)
Silica	mgl^{-1} SiO^{2-}			
Sulphate	mgl^{-1} SiO_4			
Magnesium	mgl^{-1}	2.56(1.3)	S 2.21(0.39) B 2.06(0.81)	1.85(0.81)
Sodium	mgl^{-1}	3.08(1.1)	S 4.15(0.19) B 4.03(0.21)	3.96(0.07)
Potassium	mgl^{-1}	0.73(0.67)	S 1.32(0.26) B 1.2(0.19)	1.15(0.15)
Calcium	mgl^{-1}	7.72(2.7)	S 9.8(0.55) B 10.44(1.42)	10.71(1.8)
Iron	mgl^{-1}			
Manganese	mgl^{-1}			

$^{(1)}$Hall *et al.* (1977)

$^{(2)}$Calculated from Coche (1968) and Balon & Coche (1974).

$^{(3)}$Calculated from Coche (1968) as mean of annual cycle from the eastern section of Basin 4 (the equivalent of Basin 5 of Begg (1970), close to the dam wall).

$^{(4)}$Calculated from Begg (1970).

S Surface measurements (Kariba).

B Bottom measurements (Kariba).

suggests that Lake Kariba receives the major part of its supply of dissolved salts from secondary rivers. In fact they mostly influence the lake's chemical content in the vicinity of their entry (Balon and Coche 1974). The chemical contribution of the Zimbabwean input waters is particularly important due to their large drainage basin (Table 26) (King and Lee 1974; Bowmaker 1976; King and Thomas 1985). The Sanyati river, for instance, has great influence on the limnological characteristics of Basin 5 at the eastern end of Lake Kariba.

Concerning the reservoir itself, the establishment of a thermocline during the warm season entails a separation of deep water from surface ones. This hypolimnion (below the thermocline) is richer in mineral content than the epilimnion. Furthermore, mineralization processes that occur in the lower layers entail a depletion in dissolved oxygen, which could, in turn, lead to a solution of ferrous iron and hydrogen sulfide (H_2S). These processes reflect oxido-reduction potentials in the hypolimnion. This was the case during filling and post filling phases. Nowadays, reduced conditions still occur until the water mixes in the cooler season. These reduced conditions hinder fish settlement in the hypolimnion. On the other hand, when deoxygenated water is discharged into the river, either by floodgate spillage or via the tailraces from the lowest turbines, the dissolved oxygen concentrations in the river downstream from the dam are liable to drop.

2.7. Sediment Deposition

The area of the drainage basin of Lake Kariba is about $650.10^3 km^2$. Of this, $40.10^3 km^2$ lies upstream from the Victoria Falls. The Barotse plain and Chobe swamps in the upper Zambezi catchment act as a sediment trap for virtually all the sediment from this part of the basin. Thus, the silt load of the river water as it reaches the lake is relatively light. Tributaries downstream from the Victoria Falls drain the remaining $170.10^3 km^2$ of Lake Kariba's drainage basin; $140.10^3 km^2$ lie in Zimbabwe, and $30.10^3 km^2$ lie in Zambia. Finally, it appears that the bulk of the sediment deposited in Lake Kariba originates from the tributaries. It is estimated (Stocking and Elwell 1973; Bolton 1984) that the sediment yields of the drainage basin of Lake Kariba downstream from the Victoria Falls lies in the range 40–400 $t/km^2/year$. Figure 30 gives as an example, the potential erosion hazard in the Zimbabwean part of the Kariba drainage basin.

On the basis of these estimations, the mean annual input of sediment to Lake Kariba lies in the range of 7 to $70.10^6 t$ (Bolton 1984). In the case of Lake Kariba, the long time scale involved suggests that most of the sediment will reach a high

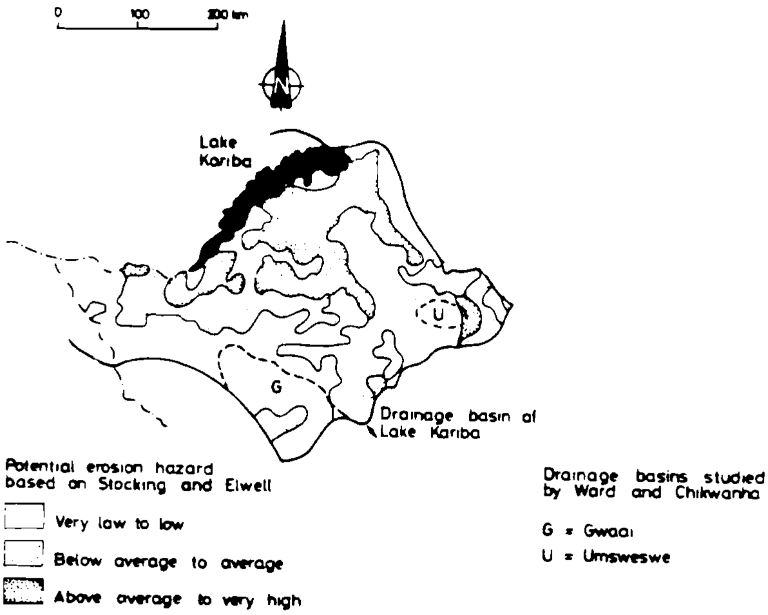
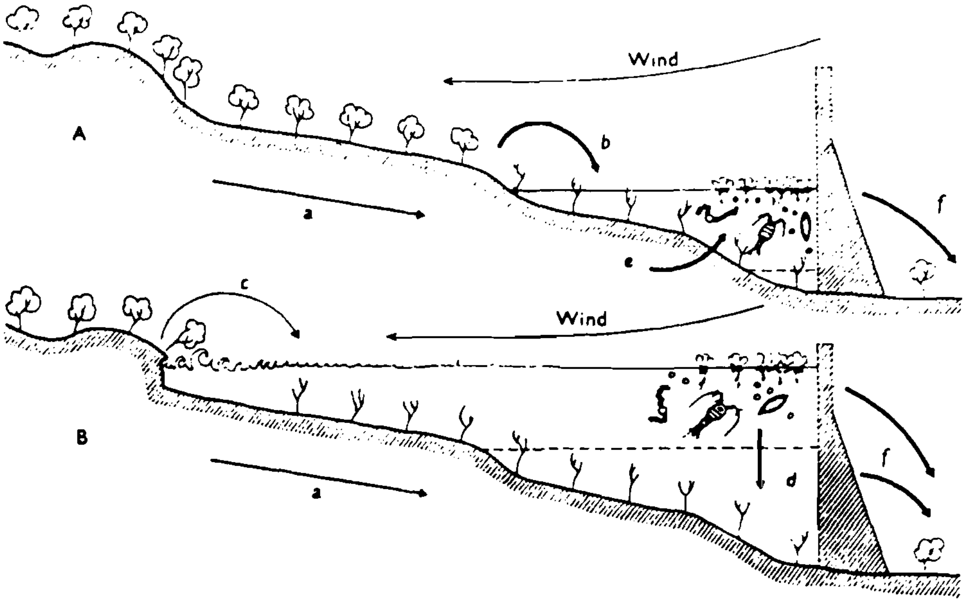


Figure 30. Potential erosion hazard in Zimbabwe (Stocking and Elwell, 1973; Bolton, 1984).

degree of consolidation, and Bolton (1984) assumes that the annual rate of loss in storage capacity of Lake Kariba lies between 7 and $70.10^6.m^3$. The dead storage capacity of Lake Kariba is about 116.10^9m^3, representing over 60 per cent of total reservoir capacity. At the present rate of input, this storage would be filled in 1600–16000 years. Bolton (1984) concludes that the effect of sediment on the operation of the project is small. Nevertheless, such siltation should occur near secondary tributary inlets, and would be appreciable at this small scale with respect to navigation or fisheries.

2.8. Ecological Aspects

The formation of a lake provides a changed habitat for the development of a new ecosystem. Immediately after the river is dammed, three phenomena appear simultaneously: (a) the normal flow of the river is stopped, (b) there is a continuous increase in the area of the new habitat as the lake fills up; (c) expanding lake margins drown the surrounding land. Initially the resulting environment is initially extremely unstable, but after a few years reaches an "equilibrium". The major factor in the filling phase is the continuous increase in the size of the lake, and the major input is derived from the newly inundated materials at the advancing shoreline. During this phase, the contributions of rivers is relatively minor. Thus, the nutrients leached from the flooded terrestrial habitats and the rising lake waters enable an increased productivity. During the filling phase, the floating fern *Salvinia molesta* showed an explosive growth, and with the help of the available nutrients, this aquatic weed covered 22 per cent of the lake's surface by 1962, but later (1970) declined to 15 per cent. Coverage declined again to about 1 per cent of the lake in 1980 (Marshall and Junor 1981). This well-known natural phenomenon of increased production in newly created lakes is also noticeable in fish production. When filling is completed (Figure 31) the extraneous input from rivers naturally remains the same, while the now almost static shoreline is relatively small (McLachlan 1974).



Some possible pathways by means of which materials enter and leave the lake ecosystem during the filling phase (A) and the post-filling phase (B). The probable relative importance of each pathway is indicated by the thickness of the arrow. Input from (*a*) affluent river, (*b*) decomposition of flooded biota and leaching of soil, (*c*) eroding shore-lines, (*d*) decomposition of aquatic biota. Uptake by (*e*) exploding animal and plant populations. Loss (*f*) in effluent. Position of thermocline is indicated by a broken line. Living terrestrial woodland, drowned forests, aquatic biota and the dam wall are shown in both transects.

Figure 31. Relative importance of input and output of materials during the filling and post-filling phases of Kariba reservoir (McLachlan, 1974).

Another important feature of large reservoirs, such as the Kariba, is the thermal stratification of water during the hot season from November to March. Thus, a thermocline lies at about 25 metres below the surface, and rarely goes below 35 metres (Coche 1968; McLachlan 1970a). The establishment of such a thermocline separates the oxygenated epilimnion and the cooler deoxygenated hypolimnion. As stratification occurs, a chemocline simultaneously develops at the depth of maximum density change, coinciding with the thermocline and the oxycline.

2.9. Fish and Fisheries

The natural fish population in the middle stretch of the Zambezi before impoundment is described as a property of the fauna referring largely to the mainstream where, since no "reservoir" swamps occur (as on the upper Zambezi), river flow dwindles almost to a trickle between sandy pools during the dry season (Bell Cross 1972; Jackson 1986). From 156 species recorded in the Zambezi river system, only 27 have been recorded in the Gwembe valley before it was flooded by Lake Kariba (Balon 1978). With the formation of Lake Kariba, an area of 5 250 km^2 of static water was suddenly imposed on the fish. As the rising waters gradually moved to the floor of the Zambezi valley, there was more space, more floods occurred each year, and many species of fish flourished. Balon quoted, for instance, that in less than two years the native species *Brachyalestes imberi*, very successful during the filling phase was entirely displaced by an invader from the upper Zambezi: *Alestes lateralis* more adapted to the new conditions. Dispersal of fish species according to conditions existing in the five basins of the Lake

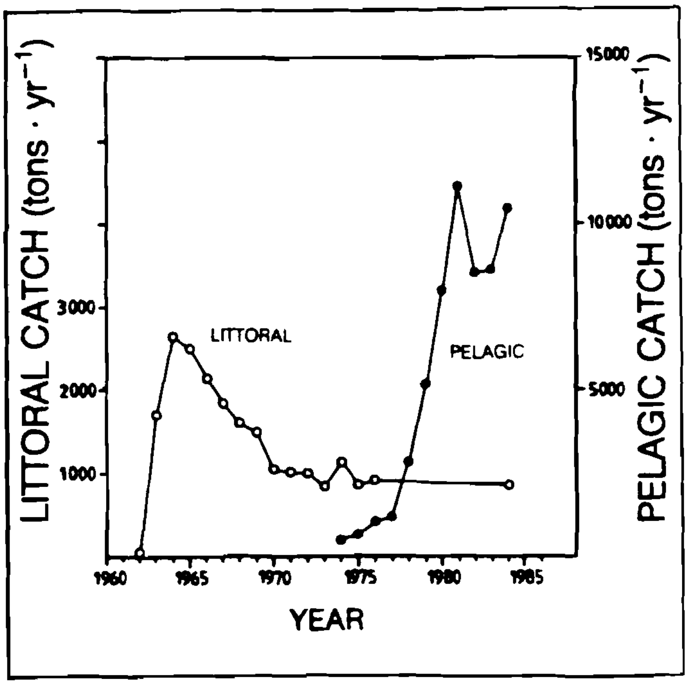


Figure 32. Evolution of littoral and pelogic catches in the Zimbabwean part of Lake Kariba (Ramberg *et al.*, 1987).

Kariba is dictated by a marked gradation from fluviatile to partly lacustrine, to lacustrine conditions, when passing from Basin 1 (Mlibizi) through Basin 5 (Sanyati) (Begg 1974). Thus, the Cyprinidae family, represented by *Labeo congoro* and *Labeo altivelis* in the commercial catch is dominant in riverine basins (1 and 2) and in the vicinity of affluent rivers while the Cichlidae family composed mainly of *Tilapia mortimeri*, *Tilapia rendalli* and *Sargochromis codringtoni* has adapted to the lacustrine conditions. For example, the total littoral catch on the Zimbabwean side of Lake Kariba was at its highest in 1964 (Figure 32), when 2600 tons were landed, after which it declined to between 800–1000 tons per year (Ramberg *et al.* 1987) caused mainly by the development of the initial high leaching of nutrients from the submerged land. As a result, after a sharp increase in production it went down due to the fact that all the dominant littoral fish species were present in the middle of the tributaries of the Zambezi before the lake was formed, and many of them are typical riverine species. Concerning the pelagic fishes, *Limnothrissa miodon* was introduced from lake Tanganyika in 1968. This small sized clupeid sardine locally called "kapenta" propagated rapidly and commercial fishing started in 1974 on the Zimbabwean side. At present, most of the catch in Lake Kariba (some 8000 of 10000 tons in 1980), consists of the sardine *Limnothrissa miodon*. This is partly because this fish is short-lived with a rapid breeding potential (reaching catchable size 4–5 cm in length, after five to six months) and because it is situated at the end of a short food-chain (phytoplankton, zooplankton, *L. miodon*), it is able to respond to periods of transient food abundance (Marshall *et al.* 1982). Thus, the tigerfish (*hydrocynus vittatus*) has switched from a diet of littoral fish to the pelagic *L. miodon*. Prediction models on Lake Kariba's sardine yields are above real catches (Machena and Fair 1986). Total annual catch in Lake Kariba was about 24000 tons in 1985, with 15000 tons for Zimbabwe representing 80 per cent of its production), and 9000 tons for Zambia (Magadza 1986; Ramberg *et al.* 1987). It appears that fish production as a source of protein for the population is one of the main targets of riparian countries, and especially for Zimbabwe (Kenmuir 1982).

Nevertheless, there are limitations on fish production: (a) the feeble primary production, due to small input from the Zambezi; (b) rapid turnover (less than four years) of the water in the reservoir which prevents accumulation of energy; (c) thermal stratification hindering nutrient exchange within water layers (Mtada 1987); (d) large drawdowns out of season which limit fish spawn. Another feature to be taken into account is the significance of tributaries in fish yields. Owing to

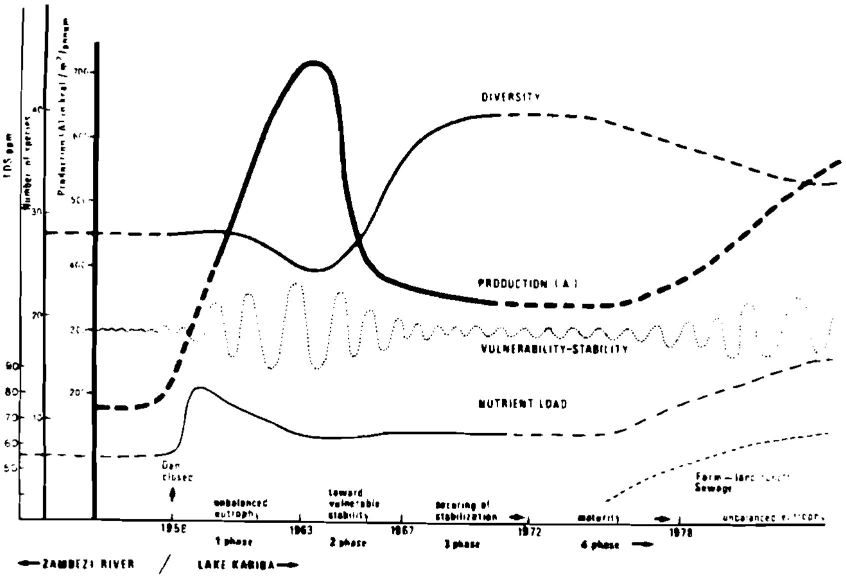


Figure 33. Evolution of Lake Kariba in terms of ecological variables (Balon, 1978).

their nutrient richness compared to the Zambezi, they sustain a large proportion of the lake's primary production. Hence, nearly 30 000 tons of fish were caught between 1976 and 1981, of which some 80 per cent was taken from the Sanyati basin drained by one of the main secondary tributaries of the Kariba lake (Kennmuir 1984). The evolution of the fish population is similar to that of most African man-made lakes showing a transition in time of riverine type of fish to lacustrine-adapted cichlids, but also shows a species cline from one end of the lake (Mlibizi) to the other (Sanyati). This confirms Rzoska's statement (Rzoska 1966) that the successive changes in a newly created lake occur over a period of the order of ten to twenty years. Figure 33 summarizes the evolution of Lake Kariba in terms of ecological variables. The new lake underwent the eutrophic phase after which it stabilized into the oligotrophic phase, and will probably return to a state of eutrophy under additional man-made influences in the future.

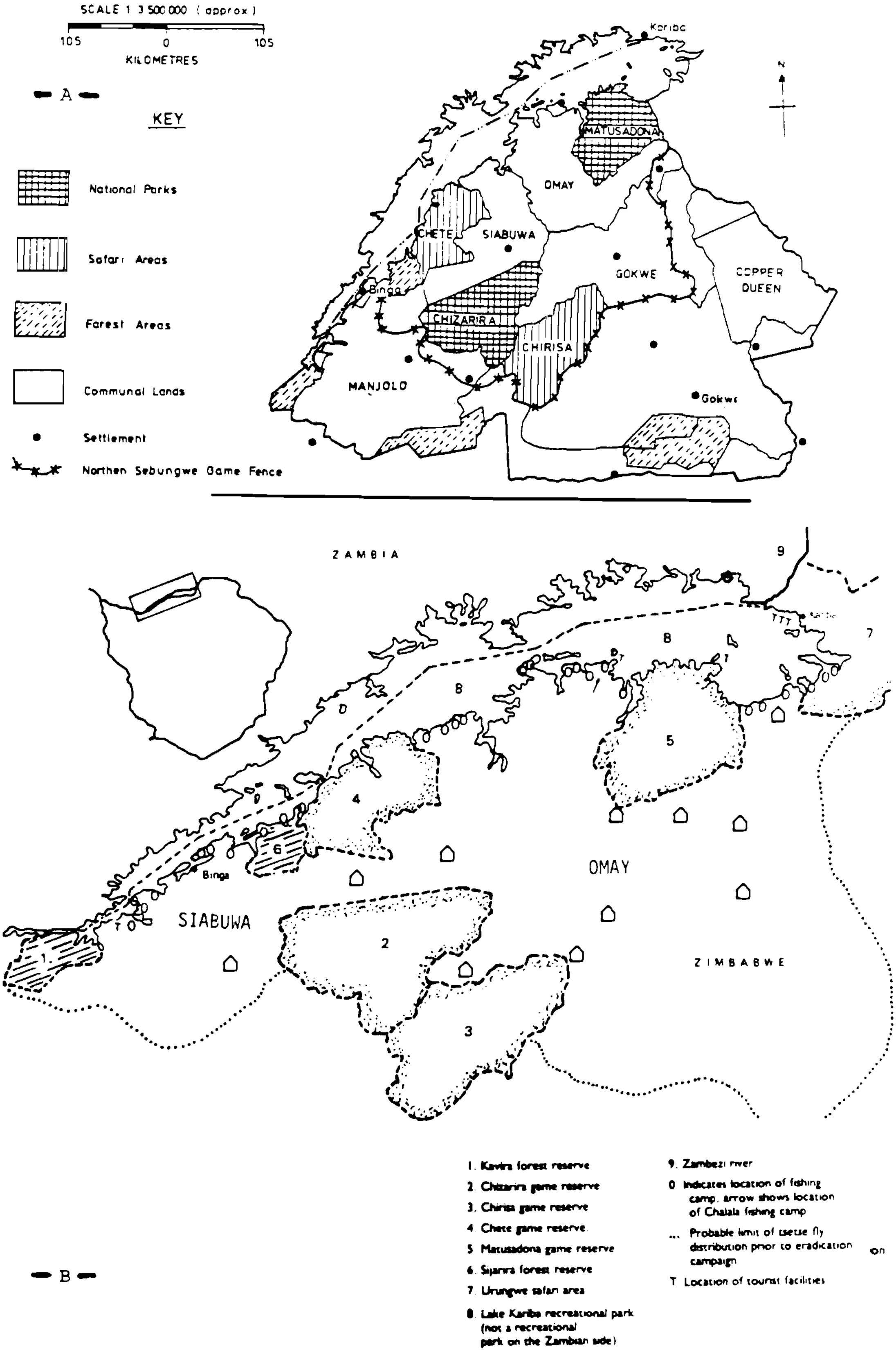


Figure 34. A. The Sebungwe region and land-use (Taylor, 1982); B. Detailed map of vicinity districts of Lake Kariba and land-use (Magadza, 1986).

2.10. Other Uses of the Lake Kariba Environs

The surroundings of the Zimbabwean part of Lake Kariba belong to the Sebungwe region, an area of about 40 000 km^2 constituting 10 per cent of Zimbabwe (Figure 34). Approximately 15 000 km^2 in the north of the region is infested with the tsetse fly. Low rainfall, unsuitable soils and marked slopes make this region a marginal agricultural land (Taylor 1982). The fly front is demarcated by the northern Sebungwe game fence. The region is divided between game reserves, agricultural, and pasture areas (Figure 34). Although this region is still sparsely populated, man's influence over the past hundred years has been considerable. The spectacular rural population change in the sixties was the result of the resettlement of the Tonga population, who initially lived in the Gwende valley, prior to the filling of the Kariba in the southern Sebungwe (Figure 35). Rural development and wildlife conservation entail cohabitation problems due to their different requirements. This conflict is sharpened by the fact that Zimbabwe earns considerable foreign currency from the tourist industry. Lake Kariba is one of the major attractions and nowadays there are large investments in hotel accomodation and other related tourist facilities (Magadza 1986). The present population of the Kariba town is 13 000. The majority of the employed are engaged in natural resources and wildlife related activities, such as fisheries, hunting, tourism, and crocodile farming.

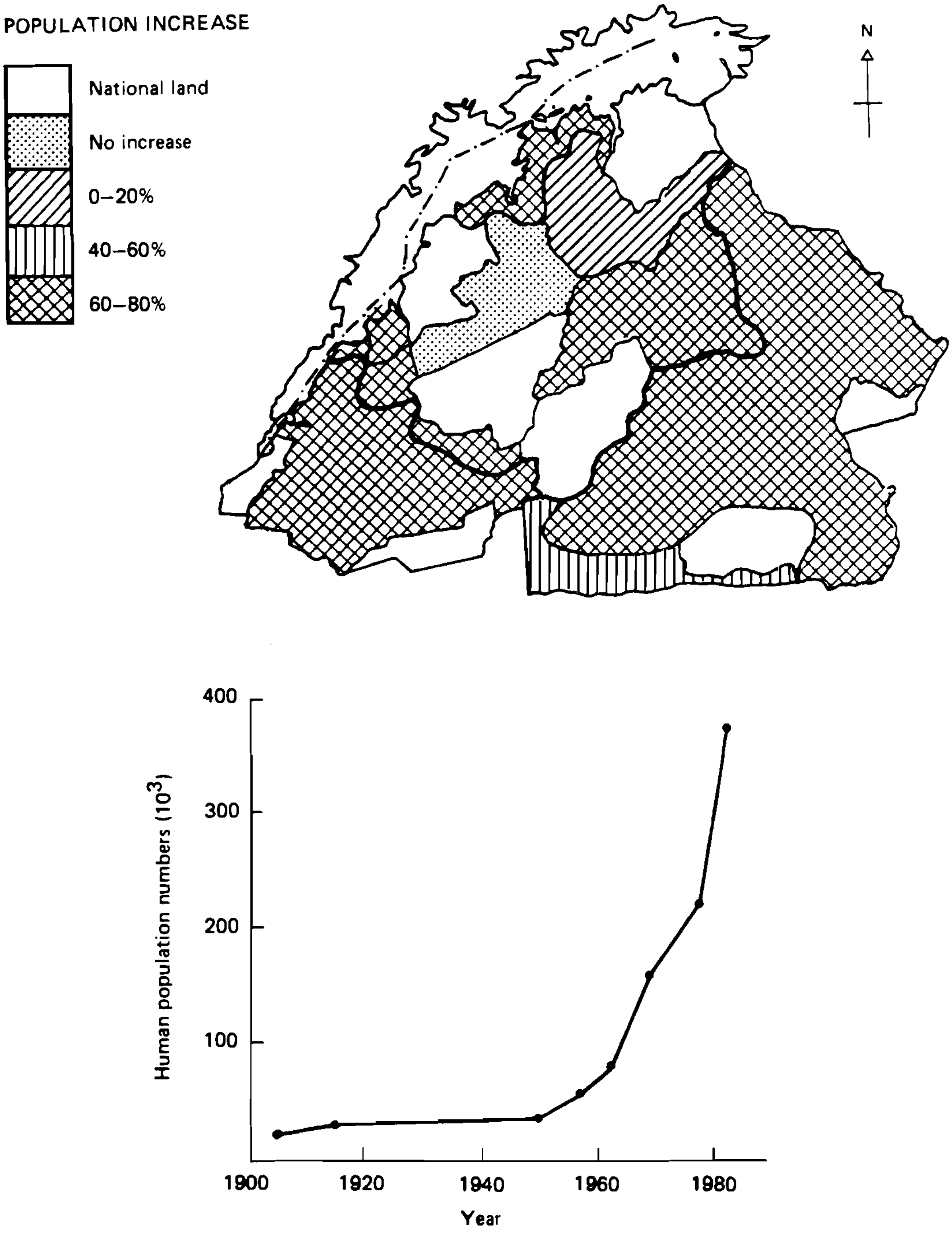


Figure 35. Rural population change in the Sebungwe region (Taylor, 1982).

3. Cahora Bassa Impoundment

3.1. Historical Aspects

The idea of constructing a dam at Cahora Bassa was suggested a hundred years ago, although first direct measures were taken to implement the idea not earlier than 1956. The site of the dam, three hundred kilometres from the mouth of the river is called "Kebra-Bassa", meaning "where the work stops" by slaves who came over 450 years ago with the Portuguese expeditions, where they were confronted with falls and rapids that stopped them in their upstream progression (Gaster 1974). Construction of the second dam in the middle Zambezi commenced in the Cahora Bassa Gorge in 1969. The resulting lake began to fill on December 5, 1974. The impoundment of Cahora Bassa lake began six months before the independence of Mozambique in 1975. Political arguments developed in Portuguese publications in order to point out the benefits that the region would receive from the large impoundment, mainly as a driving force behind economic development taking into account the richness of the tete region in coal, iron, chromium, nickel, manganese, copper and aluminium (Hall and Davies 1974; Davies *et al.* 1975). At independence, the vast sums of foreign capital invested in the project were safeguarded by a Portuguese administrative company with the authority to operate the dam, sell the power and pay outstanding financial obligations (Bolton 1986). Thus, the sharing of the Cahora Bassa dam between Portugal and Mozambique is 82 and 18 per cent, respectively. On August 2, 1984, an agreement was signed by Portugal, Mozambique and South Africa stipulating that two-thirds of the hydroelectricity produced at Cahora Bassa should be sold to South Africa. In fact, since October 1983, almost no energy has been produced due to sabbotage of the overhead transmission lines leading from the dam to the only major consumer of the Republic of South Africa.

3.2. Main Features of the Man-Made Lake of Cahora Bassa

The two main rivers flowing into the Cahora-Bassa reservoir at Zumbo are the Zambezi and the Huangwa. The catchment area of the Zambezi river above Cahora Bassa lake consists of low hydrological subcatchments: (a) the Kariba catchment (see Chapter 3, Section 2), from which the releases from Kariba dam range between 26 and 97 km^3 per year, with an average of 51.5 km^3; this represents almost 75 per cent of the total inflow into the Cahora Bassa reservoir; (b) Kafue catchment (see Chapter 3, Section 4) with a mean annual discharge of 10.3 km^3

(range 2–30 km^3); (c) Chongwe and Recomenche catchments along the north shore; and (d) Chewore catchment along the south shore of the Zambezi river between the Kafue confluence and the Zumbo basin. Each of these catchments has an area of 15 000 km^2. The other main river reaching the Cahora Bassa lake in Zumbo basin is the Huangwa river. It has a drainage basin of 147 500 km^2 in Zambia. The average annual discharge is about 13 km^3, but as the river is unregulated, floods peak rapidly. About 90 per cent of the flow into Cahora Bassa reservoir is regulated (Kariba, Kafue river). Regarding the lateral inflows along the reservoir shores, the total north shore catchment is 16 000 km^2, while the south shore is 40 966 km^2 (Bernacsek and Lopes 1984).

The Cahora Bassa reservoir was formed with a 176-metre high wall and an area of about 2 700 km^2, with an average depth of 26 metres. The lake consists of seven basins (Figure 36). Its length and width are approximately 250 km and 38 km, respectively. Table 30 and Annexes I and II give the main features of the Cahora Bassa reservoir.

Table 30. Main characteristics of the Cabora Bassa reservoir (Jackson and Davies 1976).

Feature		Cabora Bassa
Catchment	km^2	200 000
Geographical position:		
longitude		30°25'E–32°44'E
latitude		15°29'S–26°00'S
Direction of main axis		W–E
Direction of predominant wind		SE–NW
Number of basins		5
Height of wall	m	176
Maximum depth	m	151
Mean depth	m	26
Maximum drawdown	m	36
Maximum length	km	~ 250
Greatest width	km	~ 38
Total area at capacity	km^2	2 739
Maximum floodgate discharge	m^{3}sec$-^1$	13 600
Power capacity per turbine	MW	430
Total power output of dam	MW	3 870
Actual filling time	years	1
Impounded water mass	m^3	7 x 10^{10}
Infestant aquatic macrophytes present in the system		1. *S. molesta* 2. *P. stratiotes* 3. *Azolla nilotica* 4. *Eichhornia crassipes*

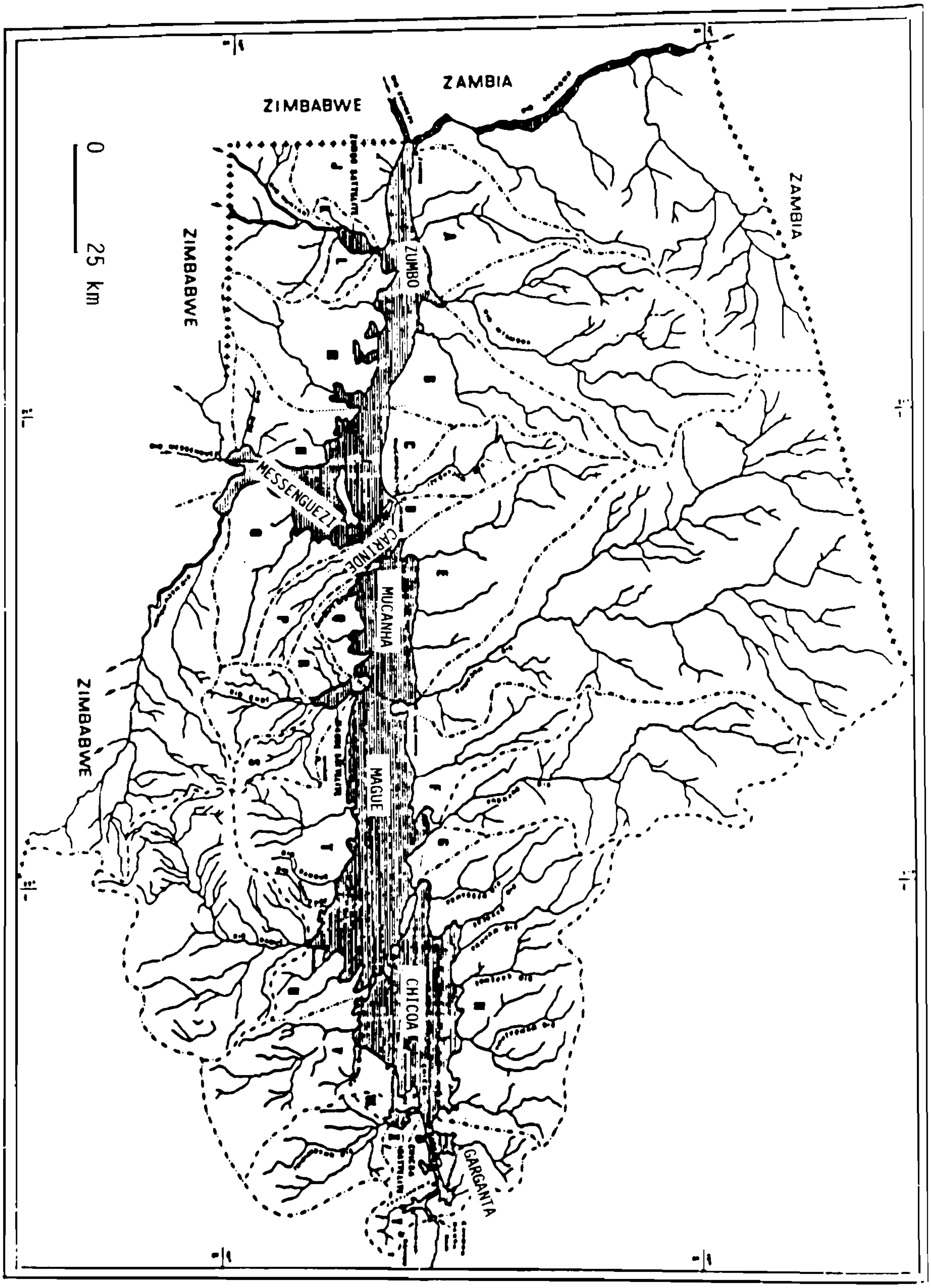


Figure 36. Cahora Bassa man-made lake (Bernacesk and Lopes, 1984).

The impounded water mass of $7.10^{10}m^3$ is intended for the production of 2150 Mw from five tributaries. Another four are planned for future installation bringing a total potential power production of Cahora Bassa to 3870 Mw (Chapter 3, Section 3.4).

3.3. Hydrology

The Cahora Bassa lake lies entirely in Mozambique, but the bulk of the 1000000 km^2 drainage basin lies in other countries, mainly Angola, Zambia and Zimbabwe. The reservoir consists of seven basins from upstream to downstream: they are Zumbo, Messenguezi, Carinde, Mucanha, Mague, Chicoa and Garganta (Figure 36). Surfaces of these basins as well as the catchment areas they drain are indicated in Table 31.

Table 31. Cahora Bassa reservoir basin surface areas with waterlevel at 326000 a.s.l. and affluent catchment areas (Bernacsek and Lopes 1984).

North Shore catchment (km^2)	Basin surface (km^2)	South Shore catchment (km^2)
3598	Zumbo 330.5	25215
639	Messenguezi 469	9760
86	Carinde 82.6	275
6682	Mucanha 335.8	164
2536	Mague 839.5	3654
2132	Chicoa 546.3	1657
333	Garganta 61.3	241
16006	Total	40966

None of the 20 rivers draining the total north shore catchment into the reservoir is perennial. The total south shore catchment is larger than the north. Thirty-six rivers enter the lake including two perennials constituting 71.9 per cent of the south shore drainage basin. These are the Hunyani, with a drainage basin of 23 897 km^2 entering the Zumbo basin and Messenguezi with a catchment area of 5 556 km^2, which enters the lake in the Messenguezi basin. Table 32 gives the morphometry of the Cahora Bassa basins.

Table 32. Morphometry of the Cahora Bassa basins (Bernacsek and Lopes 1984).

Basins	Extreme length km	Mean breadth km	Surface km^2	Catchment basin area
Zumbo	57.5	5.75	330.5	87.18
Messenguezi	38.4	12.21	469.0	22.17
Carinde	17.6	4.69	82.6	4.37
Mucanha	39.5	8.50	335.8	20.39
Mague	71.5	11.74	839.5	7.37
Chicoa	55.7	9.81	546.3	6.94
Garganta	24.5	2.50	61.3	9.36

Concerning inflows into the Cahora Bassa lake, three main parameters must be taken into account: inflow of the two main tributaries (Zambezi and Huangwa rivers), inflow of lateral rivers, and precipitation over the reservoir area. Rainfall in the vicinity of the reservoir area has been calculated as 650 mm per year and almost all rainfall occurs between November and March. Evaporation from the lake surface has a bimodal distribution peaking in April, and again more strongly in October. It has been estimated at 4.73 km^3/year (Bernacsek and Lopes 1984). Inflows for lateral affluents are almost unknown but, taking into account the small total catchment area (only 6.7 per cent of the total Cahora Bassa drainage basin) their contribution is minor. Assuming a runoff coefficient of 0.20, and the annual rainfall over the region, the total lateral inflow volume affluents is estimated at 7.41 km^3/year. Inflow at Zumbo basin is the sum of flows of the two main inflow streams, the Zambezi and Huangwa rivers (Figure 37). Due to the fact that inflow in Cahora Bassa is 90 per cent regulated (Kariba, Kafue), the flood pattern has changed since these impoundments. The pre-Kariba river showed a regular annual cycle, usually peaking in February or March (5000–20000 m^3/s) and falling in October–November to 200–800 m^3/s. The Kariba dam has resulted in an increase in dry season flows and a delay in the timing of floods during the wet season. Thus, the flood magnitude is decreased by an average of 24 per cent during the 1970–80 period, while before the Kariba dam was built, the average ratio between the maximum and minimum flow of the Zambezi at Cahora Bassa Gorge was roughly 40:1.

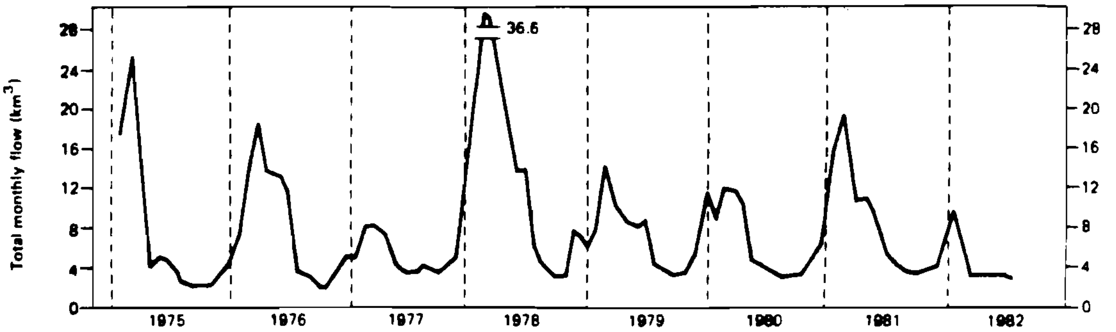


Figure 37. Total monthly inflow in Zumba basin of Cahora Bassa lake (Bernacsek and Lopes, 1984).

3.4. Reservoir Operation

The main purpose of the Cahora Bassa reservoir is energy power generation; dam operation seeks to maximize electricity generation. The dam possesses eight rectangular flood gates and five hydraulic turbine-alternators (Annex II). The total discharge capacity of the Cahora Bassa is about 16250 m^3/s. Considering the morphology of the Cahora Bassa reservoir and its inflows and outflows, the lake has a very high output per unit reservoir area (1.4 Mw/km^2) compared to the Kariba (0.3 Mw/km^2). The storage ratio, which is the total reservoir capacity divided by the mean annual inflow is 0.86 for the Cahora Bassa while it is 3.5 for Kariba. From the point of view of electricity generation, dam operating procedures seek to maintain a rather constant water level of the lake, and depend on the characteristics of the dam (Figure 38): the water level cannot exceed 330.5 m.a.s.l. and cannot drop below 295 m.a.s.l. This gives a maximum working water level range of 35.5 metres. Nevertheless, the water level should remain as close to the maximum permissible level as possible in order to maximize the head to the turbines. However, because of the reservoir capacity there is no alternative

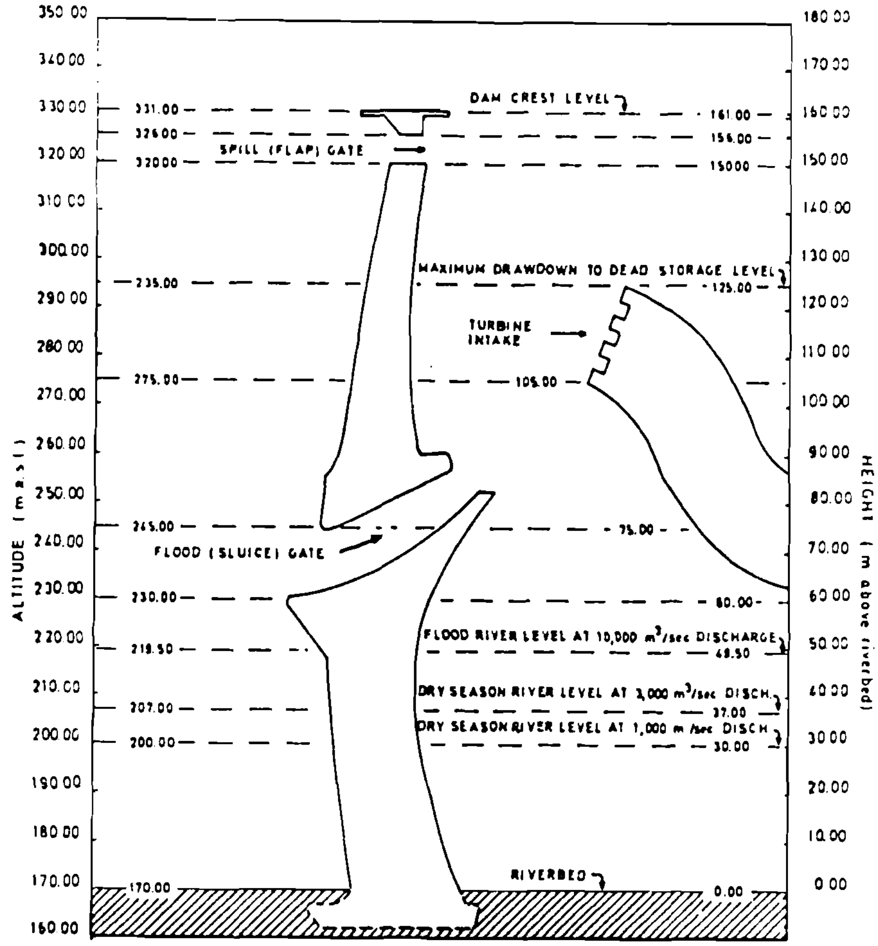


Figure 38. Morphometric characteristics of Cahora Bassa dam (Bernacsek and Lopes, 1984).

other than to release water from the reservoir before each rainy season to accomodate, and temporarily store, incoming flood waters which are then released during the following dry season. This entails important drawdowns as will be shown below (Chapter III, Section 3.5).

Since the construction of the Cahora Bassa dam in 1974, only two years (1980 and to a lesser extent 1979) can be considered to have been "normal" hydrologically and operationally. A combination of natural (hydrological) and socio-political events have led to erratic behaviour. Furthermore, almost no electricity has been produced at the Cahora Bassa power plant since October 1983 due to sabbotage of the transmission lines. The effect on the flow of the Lower Zambezi downstream from the Cahora Bassa dam is important (Figure 39).

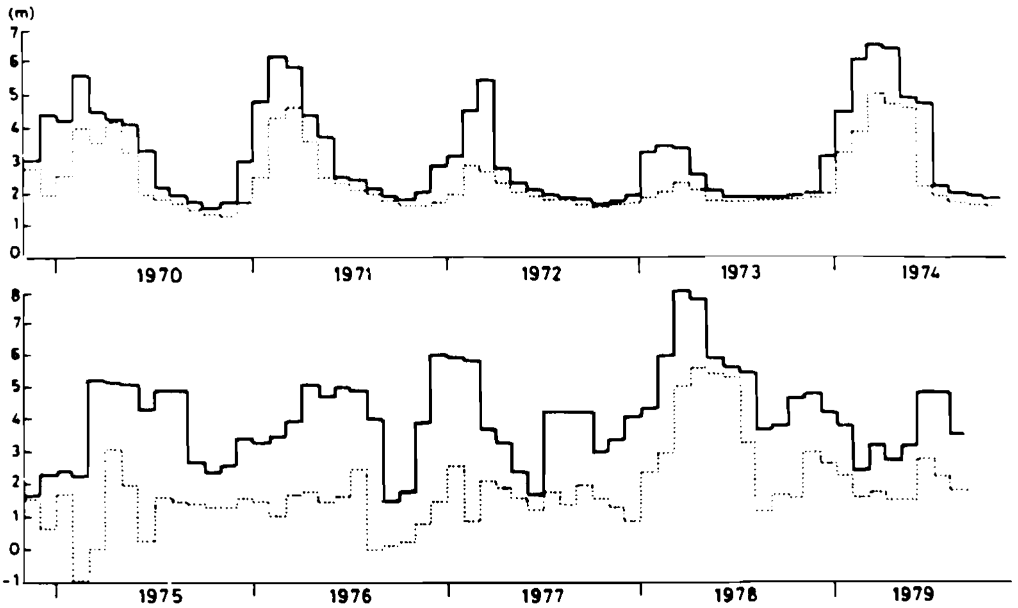


Figure 39. Monthly maximum and minimum of the Zambezi at Tete below Cahora Bassa impoundment (Bolton 1986).

After 1974, when the impoundment was completed, the river levels became far more erratic and unseasonal. This can be attributed to the poor hydrological operation of Cahora Bassa dam. Even if such problems may be of a "relatively short term" nature, their effects from the ecological point of view are highly disruptive. As an example of "normal management", the pattern of annual fluctuation in water level, water gain and loss are illustrated in Figure 40. Mainstream inflows peak in March. Then floodgate discharge occurs from May to July, but the peak is in December–January. Turbine discharges should be virtually constant throughout the year and are roughly comparable to floodgate releases. Consequently, the reservoir level peaks in June and then falls to a minimum drawdown in January. Water level, water gain and loss data for the period 1975–1982 are given in Annex II, Sections 3.1–3.4.

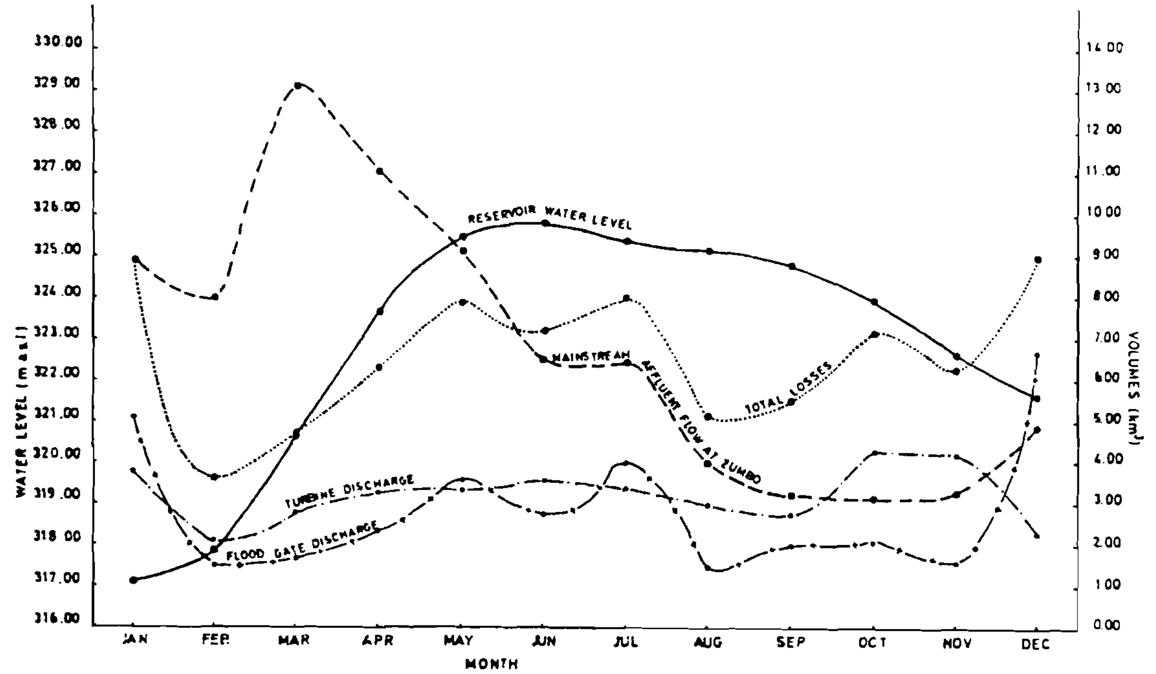


Figure 40. Mean monthly water level, water gains and water losses from Cahora Bassa reservoir, averages for 1979 and 1980 (Bernacsek and Lopes, 1984).

3.5. Water Level Fluctuations

Reservoirs with a high output per unit reservoir area like the Cahora Bassa maximize power output for a given level of environmental disruption, but with important consequences on reservoir storage ratio and drawdown. Thus, the maximum drawdown in normal operation is 34 metres which entails a less stable aquatic environment and also poses more difficulties for shoreline habitation, fisheries and navigation (Bolton 1986). For water level at the maximum permissible level of 330.50 metres above sea-level, the Cahora Bassa lake has an area of 3014 km^2. For the minimum operational water level, which is 295.0 m.a.s.l, the lake has an area of 838 km^2. Thus, actual drawdown of 34 metres entails tremendous variations in the area of lake water surface. Figure 41 gives the relationship between lake waterlevel and surface area and the proof. These curves have been plotted from data given in Annex II, Section 4. Due to the fact that the predictability of flood timing and size is poor, drawdowns must be of sufficiently high magnitude to

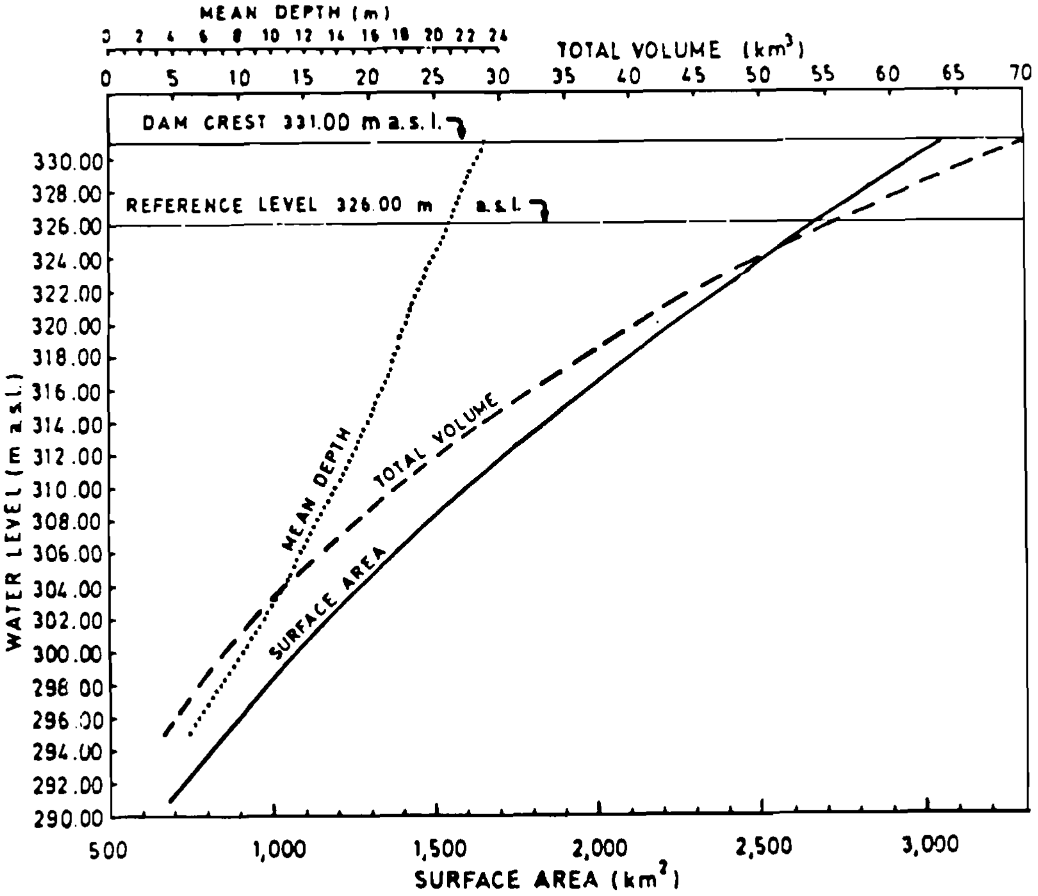


Figure 41. Cahora Bassa reservoir surface area at water levels 295.00 to 331.000 m.a.s.l. (Bernacsek and Lopes, 1984).

incorporate a significant safety margin. They must allow sufficient storage capacity for incoming floods as well as retain sufficient water in order to maximize hydropower production. The theoretical design for water level fluctuations for the Cahora Bassa is given in Table 33.

Table 33. **Maximum permissible water level at the end of each month on the Cahora Bassa reservoir (Bernacsek and Lopes 1984).**

Month	Maximum water level m.a.s.l.	Month	Maximum water level m.a.s.l.
January	316	July	324.7
February	321	August	323.4
March	326	September	322
April	326	October	320.6
May	326	November	319.1
June	326	December	317.6

Theoretically, the water level should fluctuate around a median of 321 m.a.s.l. within a ten-metre range, which is significantly higher than the median of 312.75 m.a.s.l. between dead storage (295 m.a.s.l.) and maximum permissible level (330.5 m.a.s.l.). A 10-metre fluctuation is excessive from a fishery perspective (Chapter III, Section 3.9). It is clear that flood prediction must include close and continual liaison with the power plant managers and hydrologists of the Kariba, Kafue and Itezhi-Tezhi dams, permitting the reshaping of the design curve. It appears that it would be possible to reduce the magnitude of annual fluctuations to 3 or 4 metres and raise the median level to 324 m.a.s.l. (Bernacsek and Lopes 1984). Variations in reservoir water level from 1975–1982 are plotted in Figure 42. The observed changes in water level are far from the design operation curve and show the seasonal floods as well as drastic drawdowns.

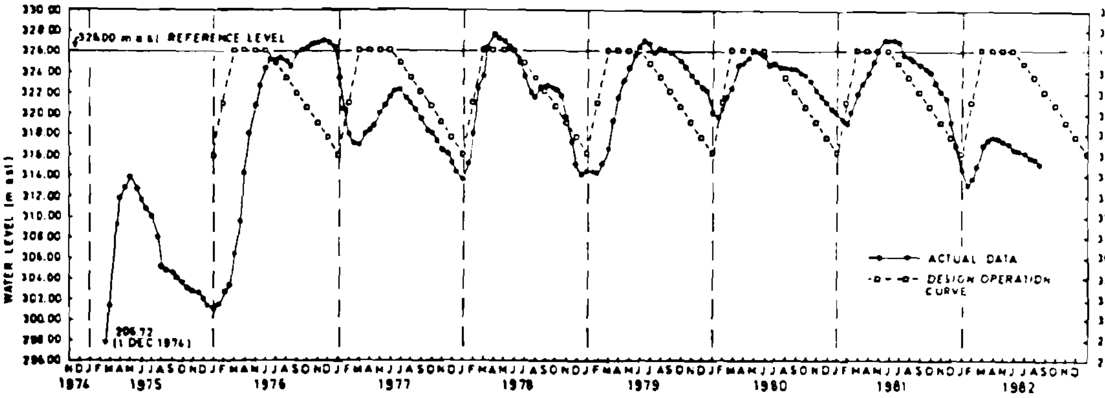


Figure 42. Variations of water level in Cahora Bassa reservoir (Bernacsek and Lopes, 1984).

3.6. Water Chemistry

Physico-chemical assessments of the Zambezi river prior to the closure of the Cahora Bassa dam (Hall *et al.* 1977) showed that the water quality of the Zambezi river entering Mozambique was mainly determined by outflows of the Kariba and the Kafue dams. Since the closure of the dam, it has been noticed that there is a substantial increase in dissolved substances between Kariba dam and the Zumbo basin for during the passage of water through the Cahora Bassa reservoir, there is an increase by a factor of 1.24 for total dissolved solids (97.47 to 120.67 mg/l) and of 1.03 for conductivity (114 to 117 μS). This increase in conductivity is small

Table 34. Main physico-chemical characteristics of the Cahora Bassa lake (Bernacsek and Lopes 1984).

Parameter	Unit	Mean	Range
Cations			
Na	mg/l	6.08	2.97–11.3
Ca	mg/l	16.08	6.81–25.65
Mg	mg/l	4.16	1.94–5.72
Anions			
Cl	mg/l	8.66	4.06–17.04
HCO_3	mg/l	70.54	39.66–97.63
SO_4	mg/l	6.69	2.30–16.62
SiO_2	mg/l	5.07	5.00–6.08
Organic matter	mg/l	3.39	2.60–5.63
Dissolved solids	mg/l	120.67	
Dissolved gases			
O_2	mg/l	6.73	6.00–7.05
CO_2	mg/l	3.70	0.00–6.00
pH	pH units	7.60	7.00–8.20
Turbidity	Jackson turbidity unit	9.5	5–21

Species	Mean concentration (mg/l)	Milliequivalent
Cations:		
Calcium	16.08	0.401
Sodium	6.08	0.264
Magnesium	4.16	0.171
Totals	26.32	0.836
Anions:		
Bicarbonate	70.54	0.578
Chloride	8.66	0.244
Sulphate	6.69	0.070
Totals	85.89	0.892

compared to the value obtained in Kariba (1.36) (Bernacsek and Lopes 1984). Table 34 gives the main physico-chemical characteristics of the Cahora Bassa reservoir.

Table 35. Average values (and standard deviation) of middle and lower Zambezi (Hall *et al*. 1977).

Parameters	Units	Stations			
		Huangwa	Shire	Hunyani	Messenguezi
Water temperature	°C	24(4)	24(4)	19	19
pH	7.93(0.24)	7.54(0.36)	8.20	7.70	
Dissolved oxygen	mg $l^{-}O_2$	8.00(0.89)	5.50(2.01)		
Transparency	cm	38(31)	30(31)		
Total alkalinity	mg l^{-1} $CaCO_3$	57(25)	110(17)	100	45
Chloride	mg l^{-1} Cl	6(7.7)	10.0(3.5)	10	5
Calcium hardness	mg l^{-1} $CaCO_3$	37(27)	39(13)	62	180
Total hardness	mg l^{-1} $CaCO_3$	56(31)	67(13)	105	
Colour	(Pt-Co)U	9(14)	29(27)	15	15
Conductivity	$\mu S\ cm^{-1}$	147(86)	315(61)	350	506
Ammonia	mg l^{-1} N	0.13(0.22)	0.24(0.22)	0.20	0.30
Nitrites	mg l^{-1} N	0.004(0.001)	0.006(0.009)	0.003	0.002
Nitrates	mg l^{-1} N	0.15(0.12)	0.18(0.13)	0.34	0.14
Orthophosphates	mg l^{-1} PO_4	0.24(0.19)	0.21(0.09)	0.08	0.20
Silica	mg l^{-1} SiO_2	16.9(4.8)	6.3(1.5)	30.0	30.0
Sulphates	mg l^{-1} SO_4	9(6)	6(3)	4	8
Suspended solids	mg % (p/v)	36.9(47.1)	10.6(5.8)	25.3	35.8
Na	mg l^{-1}	6.7(2.0)	17.7(4.8)	10.6	8.0
K	mg l^{-1}	2.7(1.0)	6.2(1.8)	1.9	5.9
Ca	mg l^{-1}	11.6(4.6)	15.2(1.9)	13.6	42.5
Mg	mg l^{-1}	4.2(2.6)	8.0(1.2)	13.3	20.5
Fe	mg l^{-1}	0.24(0.26)	0.20(0.20)	0.18	0.04
Mn	mg l^{-1}	0.01(0.04)	0.01(0.02)	0.01	0.02

On the other hand, the influence of the main tributaries on the water quality of the Cahora Bassa reservoir is quite important, mainly in the vicinity of their confluence. Their importance is enhanced due to the high concentration of dissolved matter (Table 35).

The influence of the Shire on the water quality of the Zambezi river downstream Cahora Bassa dam has been discussed by Hall *et al*. (1977). Due to the short residence time of water in the Cahora Bassa reservoir (0.61 year), the effect of latent heat of impounded water mass in the reservoir does not exert as great an effect as in the Kariba reservoir, which has a longer residence time (4.0 years). Thus, Bernacsek and Lopes (1984) consider three phases of thermal evolution of impounded water in the Cahora Bassa reservoir: (a) filling phase – the peak inflow at Zumbo basin takes place in March–April during which time almost 24.26 km^3 (representing 43.5% of the total reservoir volume) enter the reservoir. This incoming mass of relatively warm water (25°C from the Kariba metaliminion) would replace the resident water mass of the four western basins (from Zumbo to Mucanha). High wind velocities mainly from the southeast in March tend to keep the new water mass well mixed, which makes stratification in these shallow basins difficult; (b) cooling phase – by the middle of the year, the air temperature and water inflow reach minima. Increased discharge through Cahora Bassa dam from May to July (22.15 km^3 or 39.7% of the total reservoir volume at 326.00 m.a.s.l.) would draw the cooled and well mixed mass of water into the eastern basins; (c) heating phase – air temperatures reach their maximum in the later months of the year resulting in heating of the surface layer of the reservoir. Wind may prevent the development of severe stratification, and tend to increase the depth of the heated upper layer through mixing. In the deeper eastern basins, stratification should be better developed.

Another characteristic of the Cahora Bassa reservoir is the intense olive green colour of the water (Gliwicz 1982) that persists through the year reducing light penetration dramatically and preventing growth of phytoplankton. Regarding the dissolved gases, Bond *et al.* (1978) detected oxyclines in the latter part of the year in eastern basins which corresponds to the thermal stratification. Meanwhile, the western basins do not develop oxyclines due to the well oxygenated Zambezi inflow and wind-induced mixing. In order to deduce water quality in the Cahora Bassa reservoir, it appears that the short residence time of the water entails a weaker influence of the impoundment on the physico-chemical evolution than in the case of the Kariba, for instance.

3.7. Sediment Deposition

No quantitative estimate of the rate of sediment accumulation in the Cahora Bassa has been published. However, some estimates have been published including one reported by Bolton (1984). Regarding the input of sediment to the reservoir, a large part of the catchment area of the Cahora Bassa reservoir can be neglected: the Kariba dam regulates almost 65% of the drainage basin trapping all its incoming sediment, while the Kafue dam regulates a further 15 per cent of the entire basin of the Cahora Bassa lake. Three different subcatchments should be considered to have an impact on the sediment input in the lake: (a) the basins of tributaries in Zimbabwe (42.10^3km^2), (b) the basins of minor tributaries in Zambia and Mozambique (35.10^3km^2), and (c) the Huangwa basin (148.10^3km^2). The Huangwa basin in Zambia is the principal source of sediment to the Cahora Bassa. Erosion rates have been accelerated by changes in land use since the turn of the century. It is reported that sediment concentration in the river rarely falls below 1 000 mg/l. Thus, it is believed that sediment from the Huangwa river to the Cahora Bassa ranges between 15 and 150.10^6 t/year. Concerning the basins of minor tributaries in Zambia and Mozambique, Bolton (1984) suggests that sediment is of the order of

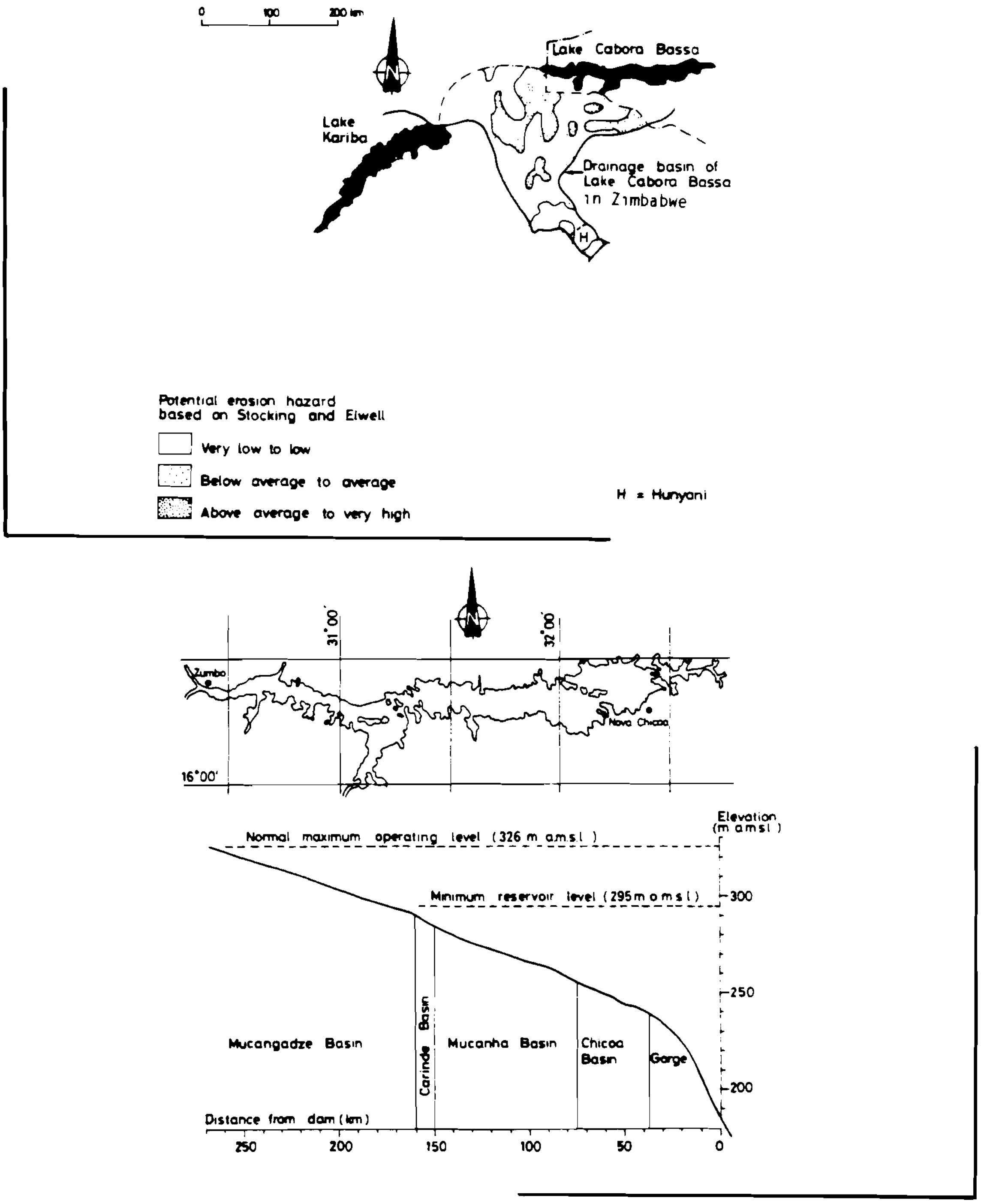


Figure 43. Potential erosion hazard in Cahora Bassa tributary basins in Zimbabwe and longitudinal profile of Cahora Bassa reservoir (Bolton, 1984).

200 t/km^2, and sediment input rate from these tributaries into the Cahora Bassa should range between 3 and 30.10^6 t/year. Finally, taking into account the results of Stocking and Elwell (1973), it appears that the Cahora Bassa's tributaries in Zimbabwe (Figure 43) should provide total sediment discharge which ranges between 2 and 20.10^6 t/year.

Making the same assumptions for the consolidation of deposits as for the Kariba, the loss of storage capacity lies in the range of 20 and 200.10^6 t/year. The sediment input rate to the Cahora Bassa reservoir appears to be a factor three times greater than that of Lake Kariba. Its storage capacity is considerably smaller. Considering the design of the Cahora Bassa project a minimum drawdown level of the reservoir is taken to be 295 m.a.s.l., and the "dead" storage below this level is almost $12.5.10^9$ m^3. This would be filled in a period of 60–600 years if all sediment would be deposited in the dead storage, although due to the particular shape of the Cahora Bassa lake (Figure 43), a significant proportion of the incoming sediment will accumulate within the "line" storage of the reservoir. The bulk of the incoming sediment passes through a broad shallow basin (Mucangadze basin) which is separated from the deeper parts by a narrow reach constricted by islands. Thus, sediment deposit in the Cahora Bassa reservoir should affect its operation much sooner than expected.

3.8. Ecological Aspects

The Cahora Bassa reservoir has, as mentioned above, a high output per unit reservoir area for it is a kind of a "riverine" reservoir as compared to a relatively stable "lacustrine" one such as the Kariba. The riverine influence is more accentuated within the lake, especially in the western basins. Furthermore, its short water mass turnover cannot lead to lacustrine conditions except in the eastern basins. During the filling phase of the Cahora Bassa reservoir between December 1974 and March 1975, downstream flow of the Zambezi river has been reduced from an average discharge of 3000 to 60 m^3/sec (Davies 1975a,b). This flow shortage certainly has had ecological consequences that persisted beyond the only filling period. On the other hand, the duration of the initial "productive phase" has been shorter than the Kariba, certainly due to a more rapid lake water exchange (Bond *et al.* 1978). So no special massive release of minerals from drowned terrestrial habitat have taken place during the first year of the life of the Cahora Bassa. The brief duration of maximum flooding probably did not allow sufficient time for decomposition of plant matter to occur. Thus, expected aquatic macrophyte infestation (Davies *et al.* 1975) as seen in the case of the Kariba did not occur. Only 0.32 per cent of the entire reservoir surface was covered with water hyacinth (*Eichhornia crassipes*). It seems that the small release of minerals from flooded terrestrial environments, wind-wave action as well as important drawdown have hindered a large infestation of the lake surface with aquatic macrophytes (Bond and Roberts 1978). A marked hydrological heterogeneity along the east-west and the north-south axes of the Cahora Bassa lake is apparent. The east-west heterogeneity concerns transition from riverine to lacustrine environmental conditions within subbasins, while the north-south heterogeneity is due to the prevailing wind (NW-SE and N-S, respectively, 35 and 20% of frequency) causing differences in temperature and oxygenation within the reservoir.

3.9. Fish Population

A total of 58 fish species was recognized from the middle Zambezi before the closure of the Cahora Bassa. Among them almost 43 per cent, or, nearly half of the total number consisted of two species of the family Charicidae, the small carnivorous *Alestes imberi* and the piscivorous *Hydrocynus vittatis* (Jackson and Rogers 1976). The closure of Cahora Bassa dam in December coincided with the seasonal spawning migration up inflowing rivers, of many cyprinid, characid, siluroid and other non-cichlid fish species, and consequently a very high survival of the newly spawned juveniles accused in these newly flooded area where they could find better protection from predators and more abundant food than in the old confined river (Jackson and Davies 1976). Nowadays 33 species of fish have been recognized in the Cahora Bassa reservoir, representing many zoological levels (25 genera and 13 families) (Bernacsek and Lopes 1984). Among these families Characidae are still well represented with *Hydrocynus vittatus* (tiger fish) and *Alestes* species. From the Dishtichodotridae family, *Distihodus scheuga* is most common. In the Chicoa basin for instance it is the dominant consumer of primary production and forms a major proportion of the gillnet catch. Among the Cyprinidae family, four species of *Labeo* exist in the Cahora Bassa basin. They are a common component of commercial catch, especially in the western basins. Concerning the Clupeidae family, *Limnothrissa miodon* species introduced from Lake Tanganiika to the Kariba is now well established in the Cahora Bassa reservoir. It is assumed that the introduction was natural. Prior to the impoundment at Cahora Bassa there were speculations as to whether or not *Limnothrissa* was capable of establishing itself by travelling down the Zambezi river from the Kariba (210 km) (Kenmuir 1975; Jackson and Davies 1976). Thus *Limnothrissa* is now well established at least in the eastern lacustrine basins of the Cahora Bassa (Bernacsek and Lopes 1984). The basic infrastructure of commercial fisheries on the Cahora Bassa is very limited in comparison to other major African reservoirs. This is due mainly to two factors: (a) an extended period of warfare in the area, and (b) other government priorities (marine fisheries). Nevertheless, a total yield of 4 343 tons of the fish has been estimated for Cahora Bassa in 1982, while a total annual yield of sardines could be approximately 6 000 tons (Bernacsek and Lopes 1984). It is also estimated that the potential yield for Cahora Bassa could be 6 700 tons of table fish and 8 000 tons of sardines per year. These estimates seem to be close to calculations based on the Morpho Edaphic Index (MEI) developed for other man-made lakes in Africa (Figure 44). This index estimates an annual yield from water conductivity of the reservoir and its mean depth according to the following equation: yield = 23.3956 $MEI^{0.4215}$ expressed in kg/ha/year; MEI = conductivity in µS divided by mean depth (metres).

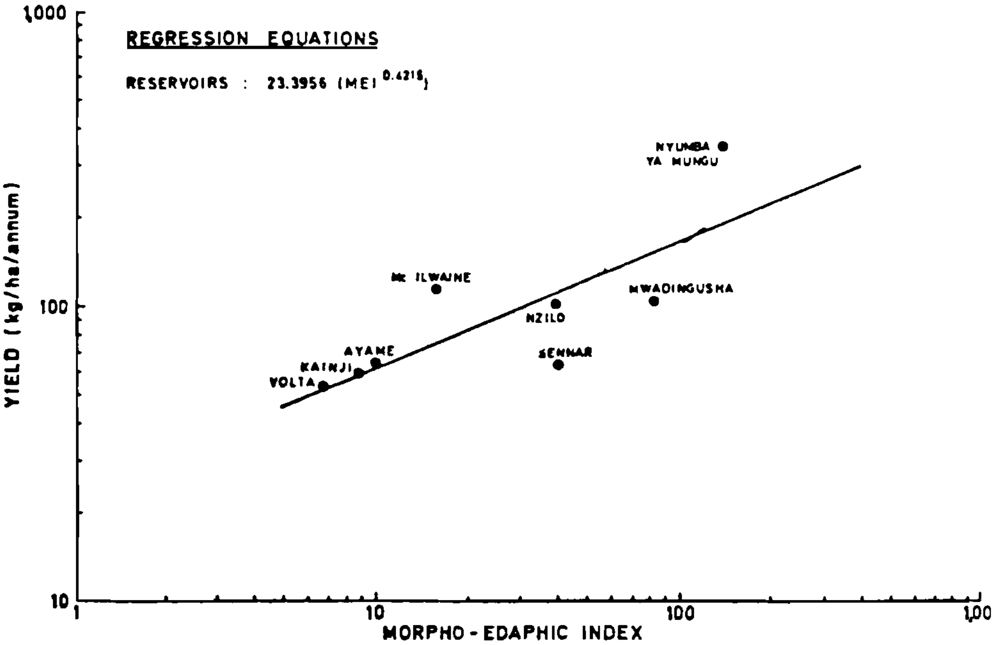


Figure 44. Relationship between morpho-edaphic index (MEI) and annual fish yield for African reservoirs (Bernacsek and Lopes, 1984).

The conductivity of Cahora Bassa is 117 µS and the mean depth is 20.92 m at reference level 326 m.a.s.l. This gives an MEI of 5.59. The yield calculated according to this formula is 48.32 kg/ha/year equivalent to an annual catch of 12877 tons. This is quite in accordance with estimates from Bernacsek and Lopes (1984). The MEI Index is an interesting tool for generating estimates of reservoir yields and total catch at different water levels. Figure 45 gives the relationship between water level and total annual catch in Cahora Bassa reservoir. It can be noticed that within the range of 310.0–330.5 m.a.s.l., the relationship is approximately linear. An increase in mean water level from, for instance, 322 to 325 m would theoretically increase the catch by 709 tons. Thus, it is clear that from the fishery perspective, the design water level fluctuations of over 10 metres is unacceptable. The best interests of the fisheries are served by the highest possible mean operating level 324 metres a.s.l. with a small annual fluctuation (3 or 4 metres).

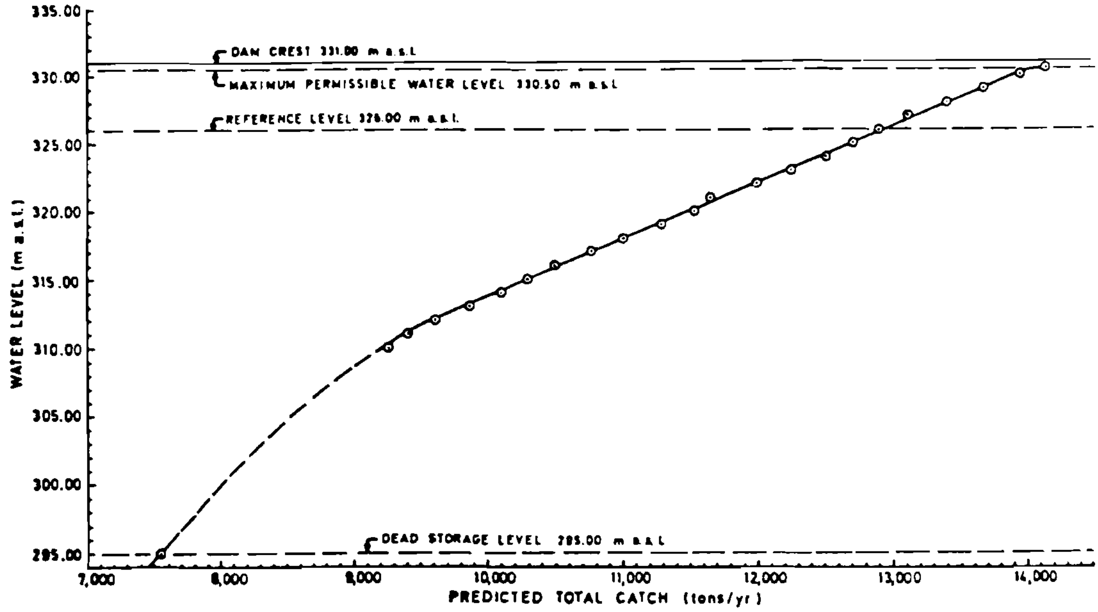


Figure 45. Relationship between water level of Cahora Bassa lake and total potential annual catch predicted by MEI equation for African reservoirs (Bernacsek and Lopes, 1984).

3.10. Other Purposes

The Cahora Bassa project's potential to transform the region remains high, and once the unique short-term political and economic situation improves, benefits could be substantial (Bolton 1984). As yet, however, the far-reaching multiple purpose benefits (i.e. energy power, mining, irrigation, tourism) envisaged by the planners have not materialized. Even concerning the main purpose of the Cahora Bassa impoundment, electrical power generation, the output is very small. Practically the only present use is the artisanal fishery. Nevertheless, if the estimate of fish yield is high, the real harvest is far from the existing potential.

4. Impoundments on the Kafue River

4.1. Historical Aspects

The Republic of Zambia is one of the most industrialized countries of the Zambezi drainage basin. Copper mining dominates the economy of Zambia and adequate supplies of low-cost electricity are vital to the country, of which the copper industry is an extensive user. Copper mines are located mainly in the upper part of the Kafue drainage basin. Until 1972, electricity produced in Zambia came from the Victoria Falls power plant and from the Kariba dam from which hydropower output was shared with Rhodesia (now Zimbabwe). Thus, Zambia's requirements of power were met from sources outside the country shared with others. As a consequence of reducing its supplies caused by conflicting interests, Zambia started to plan for self-sufficiency. The Kafue river is in fact a very attractive system from the energy power production point of view. As the river belongs entirely to the Republic of Zambia, its drainage basin includes the copper belt area and there is a rapid drop of the river in the gorge to give a good impoundment zone, Zambia decided to construct a power plant on the Kafue Gorge. The first dam was completed on the Kafue Gorge below the Kafue swamps in 1972. Later on, in order to get sufficient storage without a great increase in surface area, a second dam was built at Itezhi-Tezhi at the upper end of the flats in 1977.

4.2. Main Features of the Kafue Impoundments

The Kafue river is almost 1 500 km in length up to its confluence with the Zambezi river, with a catchment area of about 155 000 km^2 up to that point (Chapter 1, Section 2.3; Figure 46). The Kafue river is one of the major tributaries of the Zambezi river. Its drainage basin can be subdivided into three subbasins: (a) the upper half of the catchment area in the wetter northern part of Zambia, roughly north of Itezhitezhi, (b) the middle, area referred to as the "Kafue flats" from Itezhitezhi to the Kafue Gorge, and (c) the lower part of the river, the Gorge where the river drops steeply from the plateau to the level of the Zambezi river (Figure 46 and 47). Taking advantage of this geomorphological feature, the first dam was built in the Kafue Gorge. Water from the reservoir is carried through a headrace tunnel of 10 km, and then falls vertically for 410 metres to the power plant just above the river (Sheppe 1985).

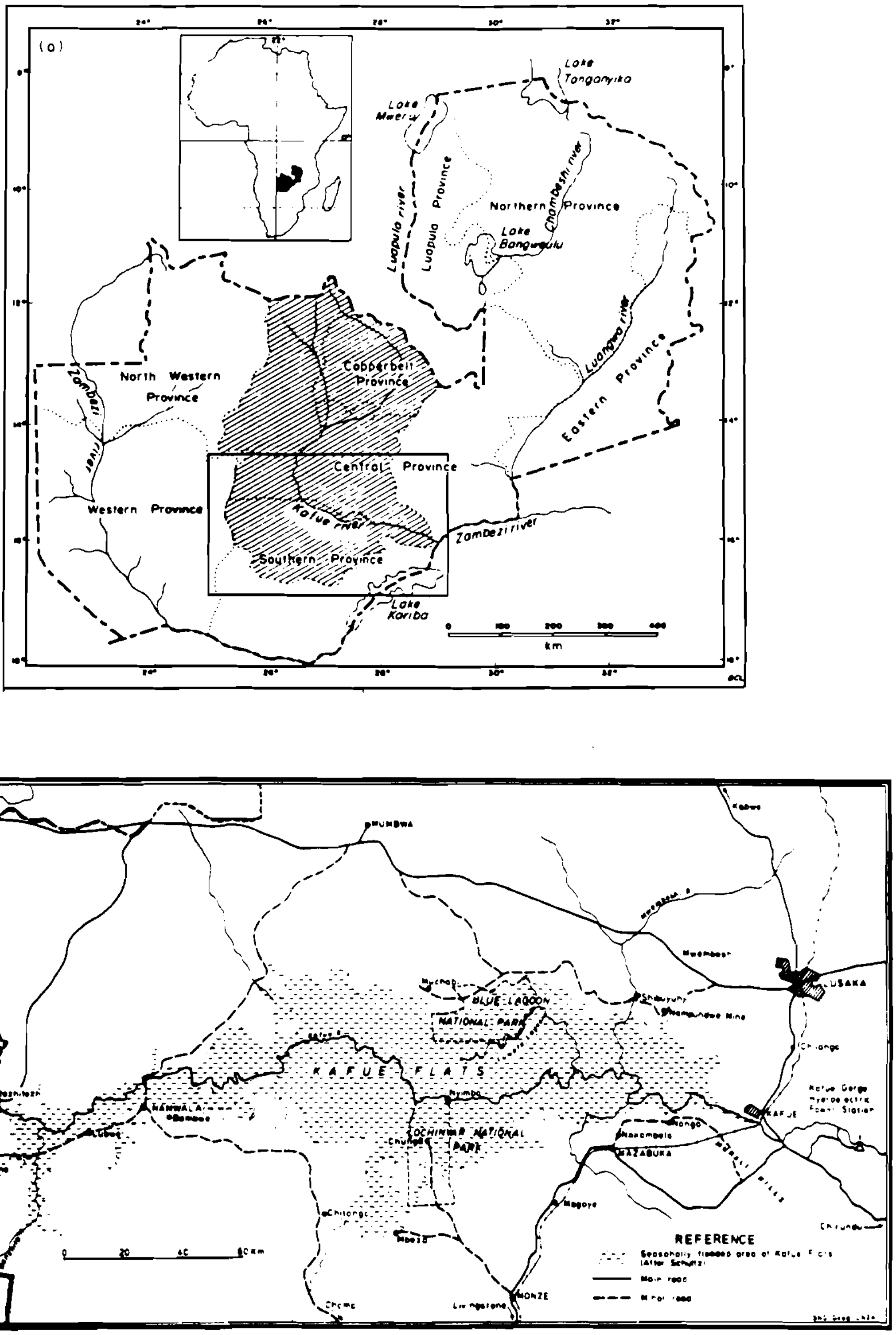


Figure 46. Kafue drainage basin and Kafue flats (Rees 1978b and Handlos 1982).

The catchment area above the dam is about 150 000 km^2, providing a mean annual inflow of 10.3.10^9.m^3. This impoundment generates power with four turbines with a maximum discharge capacity of 200 m^3/sec (Annex I). As most of the reservoir is in the Kafue flats, the storage capacity is low and the surface area is large, resulting in great water loss through evapotranspiration. Then, in order to provide sufficient storage without a great increase in surface area and water losses, a second dam was built at Itezhitezhi (Figure 46) in 1977. It forms a large reservoir with 8.5.10^6 m^3 capacity which provides most of the storage capacity for the Kafue Gorge power plant (Annex I).

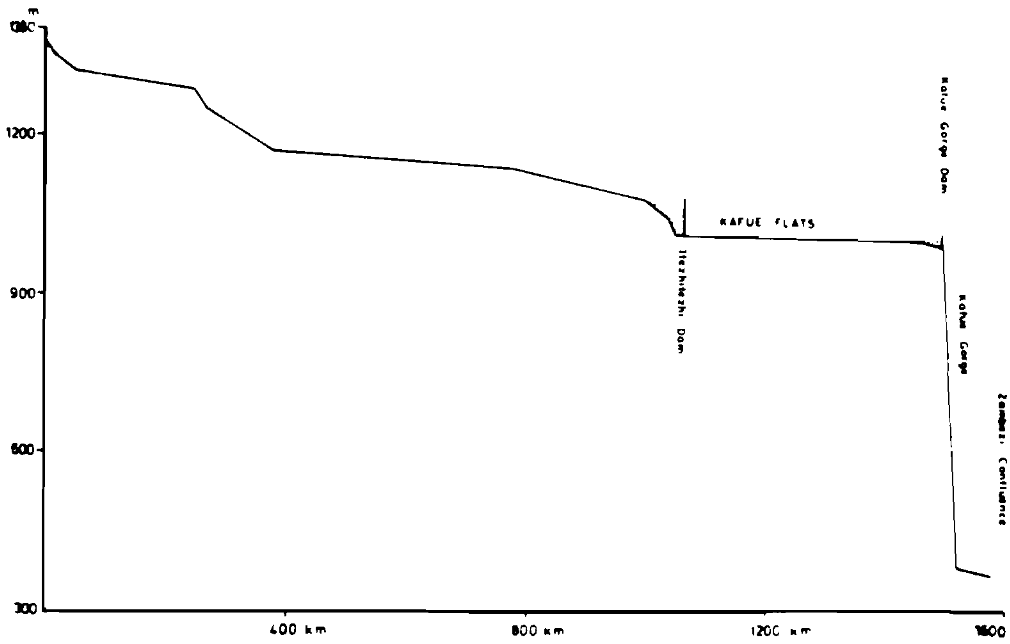


Figure 47. Longitudinal profile of the Kafue river (Handlos, 1982).

4.3. Hydrology

In view of the drainage basin of the Kafue river, there is a great difference in the runoff contribution between the upper part of the catchment (upstream Kafue Hook) and the lower part. The rainfall in the upper parts of the catchment is more than in the lower part; hence the contribution to the runoff in the river is more from the upper regions. Thus, 93 240 km^2 covering the upper part of the catchment area provide an annual average runoff of about 10.10^9 m^3, while the drainage basin lying between Itezhitezhi and the Kafue Gorge (59 569 km^2) provide only an average runoff of 1.1.10^{9}m^3. Differences in precipitation amounts between these two parts of the Kafue drainage basin as well as the important evapotranspiration which occurs in the Kafue flats increase the differences in runoff contribution by them. Thus, it is reported that in the upper drainage basin, the average rainfall is close to 1400 mm/m^2 annually, while in the flats, rainfall averages 800 mm/m^2. Estimates of evapotranspiration in the Kafue flats are about 2700 mm/m^2 per annum. The balance between precipitation and evapotranspiration is negative within the Kafue flats.

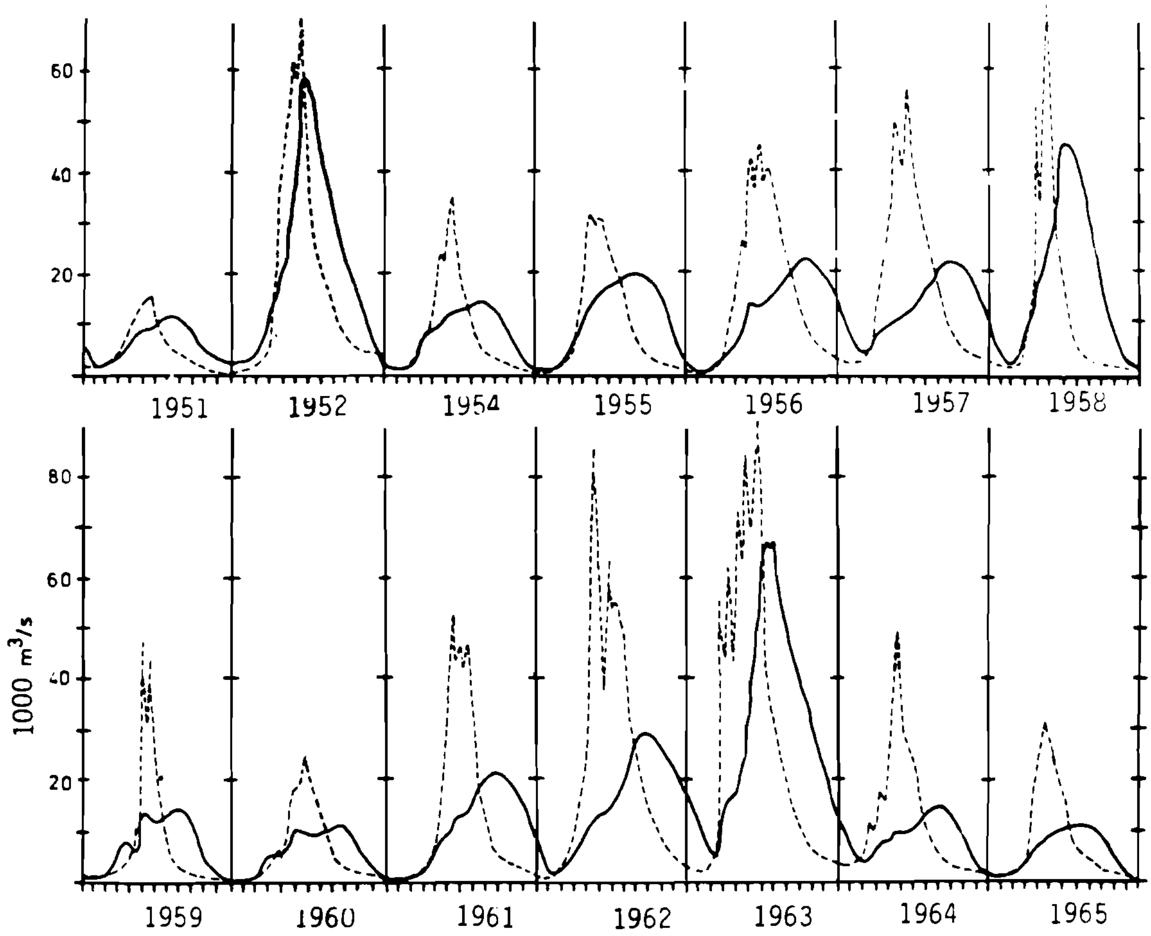


Figure 48. Discharge at Itezhitezhi (broken line) and Kasaka (solid line) from 1950 to 1965 (1952–53 missing). Each hydrological year begins in October (Handlos, 1982).

On average, significant amounts of rain in the flats begin about mid-November and continue until about the middle of March. Rainfall and runoff from the local tributaries account for the initial flooding and waterlogging of the Kafue flats between December and February (Handlos 1982). Rainfall from the northern catchment runoff to Itezhitezhi and peak in March, and then flows slowly southwards, finally reaching a peak at Kafue Gorge in May, often well after the local rains in the flats have ended. The rains in the northern part of the catchment continue until mid-April, thus continuing to feed water into the Kafue river for almost a month after the local rains in the Kafue flats have ended (Hutchinson 1974). As a result, high water levels are maintained on the Kafue flats for 6–7 months (December to June). Therefore, much of the flooding between March and June is due to the runoff from the northern part of the Kafue drainage basin. The Kafue river meanders for a distance of 410 km as it traverses the 250 km distance across the Kafue flats. The normal channel of the river is estimated to be able to carry 170 m^3/s of water, but during the height of the flood (2500 m^3/s before the Itezhitezhi impoundment), the water spills into the Kafue flats area and floods the flats if they have not already been inundated by local rainfall and runoff, or maintains the already occurring flood. Figure 48 gives discharges at Itezhitezhi and Kasaka (Kafue Gorge) before the Kafue impoundments.

4.4. Reservoir Operation

The main purpose of these two impoundments on the Kafue river is power generation, even if planned reservoir operation try to take into account some other secondary goals (Howard and Williams 1982). Among the factors favouring Itezhitezhi as the site for the main backup storage for the gorge power station, is the fact that it is able to control practically the entire yield of the river (almost 90 per cent of the flow). However, one of the major disadvantages of the Itezhitezhi site is that the travel time to the Kafue Gorge for water released from Itezhitezhi is about two months, a factor that adds to the complexity of reservoir operation. From the point of view of power generation, production of 600 Mw in the gorge power station needs a regulated flow corresponding to 170 m^3/sec at the gorge (Balasubrahmanyam and Abou-Zeid 1982a). A storage of $4200.10^6 m^3$ in Itezhitezhi reservoir was decided as the base amount for power production in the Kafue Gorge power plant. To this was added a storage of $750.10^6 m^3$ for flooding the flats even in the dry years in response to ecological dictates. Together with a dead storage of $750.10^6 m^3$, the gross storage works out to be $5700.10^6 m^3$. During a "normal" year before the Itezhitezhi dam was built, the flow in the western flats ranged from 30 to 1400m^3/sec with recorded extremes of 10 and 2700 m^3/sec. For normal operation, it was stipulated that the Itezhitezhi reservoir should reach its full retention level of 1023.5 m in January or February depending on the hydrological conditions in the year (Balasubrahmanyam and Abou-Zeid 1982b). Once the reservoir reached its full retention level, practically all the inflow into Itezhitezhi should be released downstream (Figure 49). During drier years the flow pattern would be as in Figure 49.

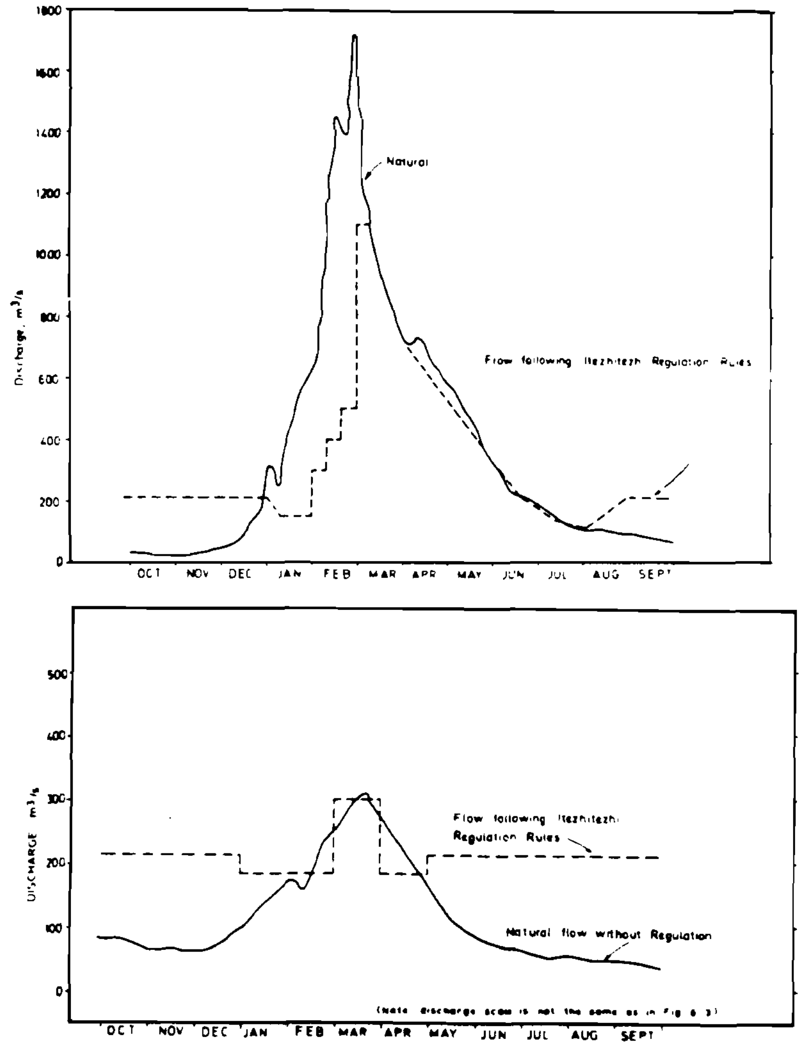


Figure 49. The Kafue hydrograph for an average year at Itezhitezhi (above) and during a dry year (below) (Balasubrahmanyan and Abou-Zeid, 1982b).

Only regulated releases to meet power generation requirements, plus the 15 m^3/sec stipulated for other uses are made monthly, except in March when 300 m^3/sec is released to maintain at least partial flooding of the flats (White 1973; Balasubrahmanyam and Abou-Zeid 1982b). However, it appears that in most years, reservoir operation follows the second pattern (Sheppe 1985). Nevertheless, Itezhitezhi reservoir operation should provide optimum water to the Kafue Gorge power plant (Figure 50).

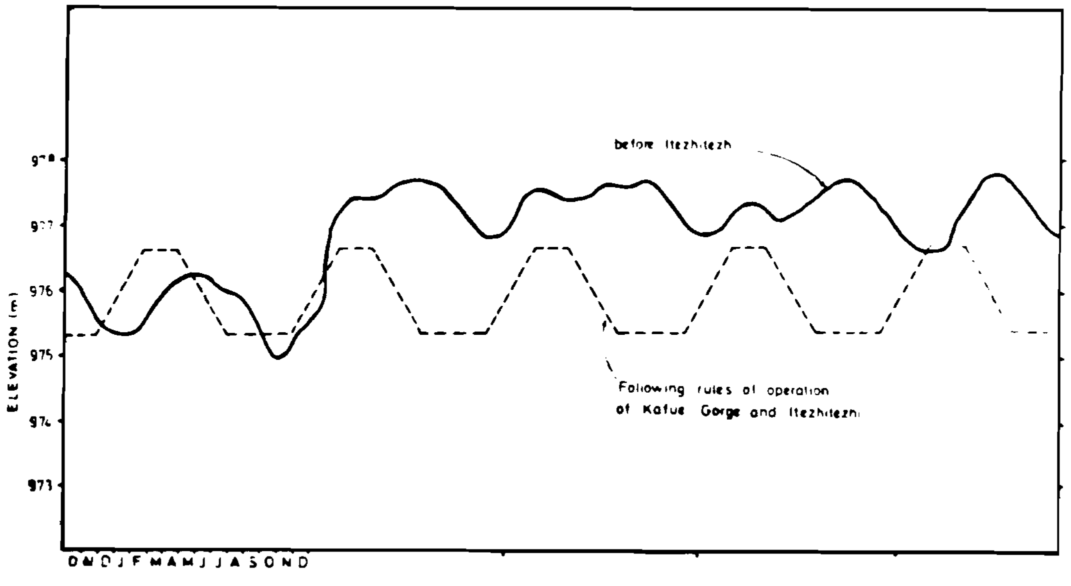


Figure 50. Water surface elevation at the Kafue Gorge dam (Balasubrahmanyan and Abou-Zeid, 1982b).

4.5. Water Level Fluctuations

The Kafue flats can be divided into two main parts, from Namwala to Nyimba and from Nyimba to the Kafue Gorge. The second (eastern) section is affected by the fluctuation of the Kafue Gorge reservoir. Normal operation of the dam envisages maintenance of the Kafue Gorge reservoir at the 975.3 m level from August to November, rising to the full retention level of 976.6 m in December, maintaining this level until the following March. Thus, inundation of areas in the section Nyimba to Kafue Gorge vary each year between 600 and 1600 km^2, which implies that at least 600 km^2 is always inundated. In the reach between Namwala and Nyimba, fluctuation of levels in the Kafue Gorge have no effect, but this reach is under the influence of regulation from the Itezhitezhi dam. Another effect of these impoundments on the floodplain has been to greatly reduce the amount of land that is seasonally flooded. According to Lagler *et al.* (1971), before impoundments total area of flats liable to flooding was 6604 km^2, while the mean maximum area inundated by high water from 1954 to 1964 was 4820 km^2 and estimated mean area flooded annually for a 4-month period was 2833 km^2. Nowadays, Itezhitezhi dam releases water at a relatively constant rate to assure a continuous supply to the gorge power plant, thus reducing the height and extent of the floods in the flats. Consequently, the western part of the Kafue flats is no longer flooded (Sheppe 1985). In order to preserve some semblance of the floodplain ecosystems, it would be necessary to assure release of sufficient water and at the right time from Itezhitezhi but this goal is in conflict with the demand for electric power, and the power agency wants to minimize flooding in order to reduce water loss by evapotranspiration.

4.6. Water chemistry

The relationships between the Kafue river and its floodplain are numerous and reciprocal. Thus, river floods markedly influence biogeochemical cycles which occur in floodplain soils, while in turn these processes (respiration, mineralization, etc.) influence the water quality of the river. The average conductivity, which is a good indicator of variations of river load, was measured at 172 μS with a range of 110 to 260 μS (Salter 1985). Seasonal variation of conductivity presents two maxima, one between August and October (230 μS) and one between January and June (260 μS). The former should be due to slow leaching of ions from soils during the dry season, while the latter should be the result of the flushing of terrestrial nutrients into aquatic systems during flood periods. The average annual pH is 7.9 but its values range between 6.7 to 9.3 depending on the hydrological cycle. A shortage of dissolved oxygen can occur during floods due to high biochemical demand in oxygen by decomposition processes (Salter 1979).

4.7. Sediment Deposition

Sediment deposition in Kafue reservoirs is not an important problem because the Kafue river flows through several floodplains (Lukanga, Busanga, Kafue flats) which act as sediment traps. One of the consequences on the Kafue river downstream from the Kafue Gorge dam is its low concentrations of suspended matter. On the other hand, its ionic composition (dissolved matter) is very high.

4.8. Ecological Aspects

The aquatic and terrestrial ecosystems of the Kafue flats are closely interrelated. The annual cycle of flooding and drying exerts a profound influence on life in the two biological systems. Processes are quite common to those described for the Kariba (Chapter III, Section 2.8), but at a really broader scale since it concerns an area of about 5600 km^2. Furthermore, the particular hydrological cycle of the Kafue river influences these processes. Thus, as the floodwaters recede and the flood plain dries up (May–September), the vast quantity of aquatic vegetation is heavily grazed by herbivorous animals or burned down (Figure 51). For instance, the Kafue lechwre (***Kobus leche kafuensis***), an endemic antilope well studied by Rees (Rees 1978a–e), feeds on this stranded vegetation. When floods occur, usually in December, the aquatic vegetation begins a period of rapid growth. It coincides with the reproduction period of most fish species (Lagler *et al.* 1971).

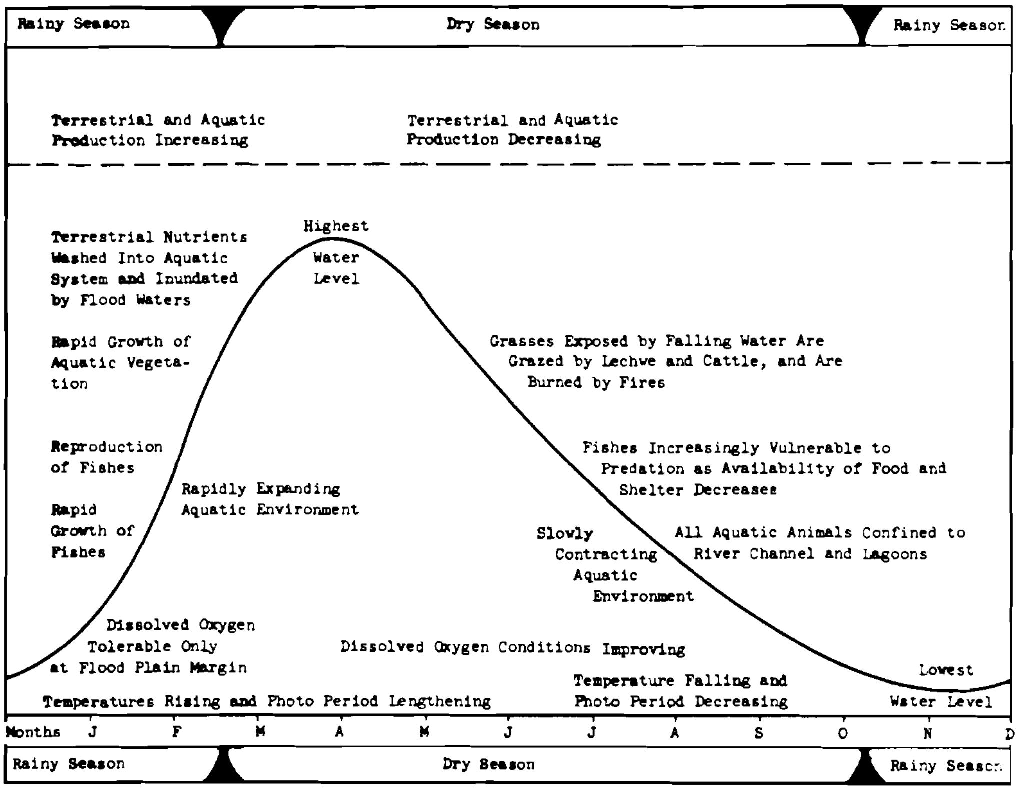


Figure 51. Generalized annual ecological cycle of the Kafue flats (Lagler *et al.*, 1971).

The resultant young fishes find food and shelter in the vegetation in the fringe zone of the floodplain margin. As the flood crest begins to move downstream from the flats, decomposition of organic matter inundated by the flood or washed in by runoff deoxygenates the waters from place to place. After the maximum flood is reached, the aquatic ecosystem starts a period of slow contraction while primary production decreases along with the falling temperature and diminishing photo period (Lagler *et al.* 1971). By July or August the floodplain is dry and the surviving aquatic animals are concentrated in the lagoons and the river. This rough description of an average annual cycle in the Kafue flats must not disguise one of the most important properties of any ecosystem, which is its variability from year to year. Occasional extreme conditions may exclude long-lived species that cannot tolerate even one unfavourable year, but on the other hand, variability of habitats may permit an increased variety of species to live in one area (Sheppe 1985). The effect of the dams is to reduce the amount of year to year variations, but variation will not be eliminated altogether, because of variation in local rainfall; the Itezhi-tezhi reservoir is not large enough to buffer all variations in runoff from the upper drainage basin.

4.9. Fish and Fisheries

The Kafue fishery is one of the most productive in Zambia. Of the 67 fish species known to occur in the Kafue fishery, 21 are of some commercial significance. Of these ten are more preferable to others. They belong to a *Sarotherodon* sp, *Tilapia* sp *Lapeo* sp, *Clarias* sp, *Serronochromis* sp, *Schilbe* sp and *Hepsetus* sp (Chipungu 1981; Muyanga and Chipungu 1982). Pre- and post-impoundment studies have been carried out in order to assess the effect of water regulation on fish populations (Dudley 1974; 1979; Dudley and Scully 1980). It is clear that seasonal flooding of the Kafue flats provides an extension to fish habitats for about six months of the year. Thus, the life cycle of fish is closely related to the flooding regime (Williams 1971).

As is shown in Figure 52, the high production of fish on the Kafue flats, and in turn, commercial fishery, are dependent on the flooding regime. There has long been a major fish industry on the flats, supported by high fish productivity in the floodplain. The fishermen operate largely from small villages situated along the river using gill-nets. Few villages on the river banks or mounds are sufficiently elevated to be habitable during the high water period. As floods recede, fishermen and their families migrate along the river and adjacent lagoons in temporary camps (Lagler *et al.* 1971). Table 36 gives the evolution of the fish yield on the Kafue flats from 1969 to 1978.

The slight increase in fish yield in the Kafue flats is due to a significant increase in fishing effort. In fact, the catch per boat per night has dropped in contrast to the predicted increase in ichthyomass. Also, there have been a few noticeable changes in relative abundance and weight of the commercially important species. The most significant change was the decline in catches of *Sarotherodon macrochir*, *Tilapia rendalli*, and *Tilapia sparrmanii* (Muyanga and Chipungu 1982). Fish yield in the Kafue flats was and still remains an important part of the

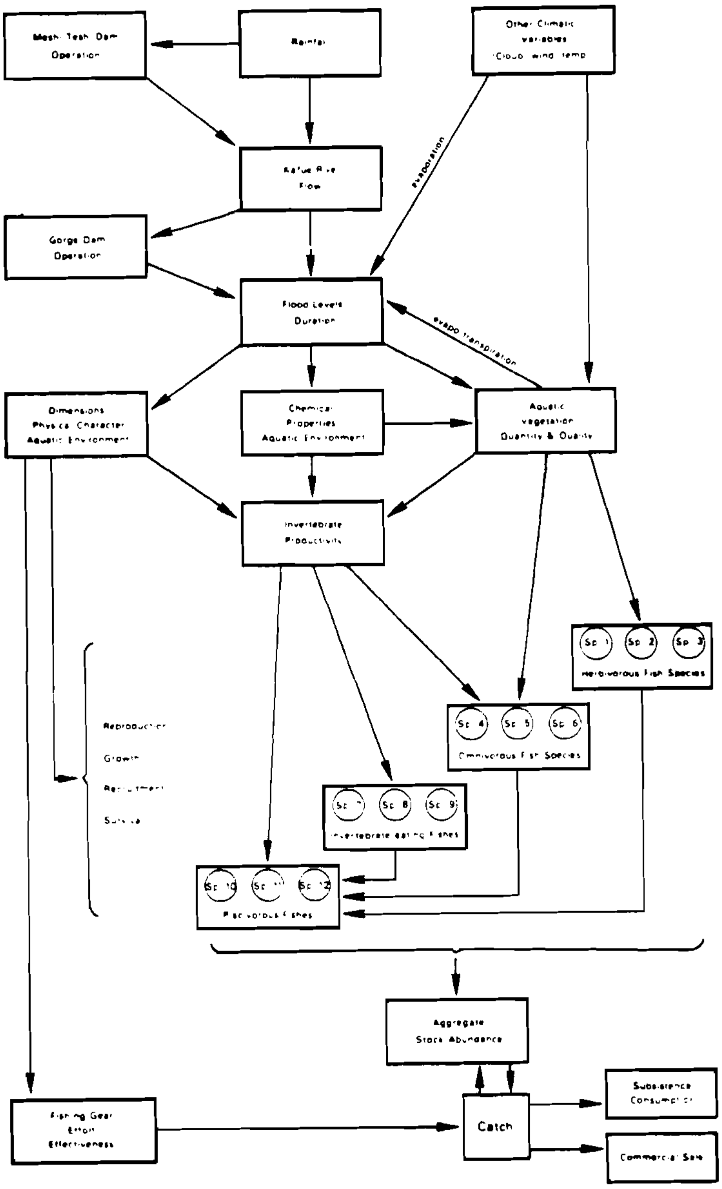


Figure 52. Some interrelationships of factors of fish production in the Kafue flats (Lagler *et al.*, 1971).

Table 36. Evolution of fish yield in Kafue flats (Chipungu 1981).

Year	1969	1970	1971	1972	1973
Fish yield(t)	5728	5558	8247	7874	6289
	1974	1975	1976	1977	1978
Fish yield(t)	5177	7226	9306	9829	8634

fish production of the Republic of Zambia. The fish industry is actually one of the main reasons why the Kafue flats seems to be an attractive area for the population (Sheppe 1985). Considering that fish is a staple food in Zambia and that the fishery provides many jobs, this activity should be seen as an important feature in the region.

4.10. Other Uses

Other uses are actually developed or being developed in the Kafue flats. As shown previously, about 15 m^3/s are available from the Itezhitezhi for other uses. It appears that irrigation requires one litre per second and per hectare. This means that given the present restrictions, only 15 000 ha can be irrigated in the Kafue flats. In Zambia, the most important crops grown under irrigation are wheat and sugar cane, potatoes and vegetables. Table 37 gives a seasonal cropwater requirement for irrigated crops.

Table 37. Seasonal crop water requirement for irrigated crops in Zambia (Kiele 1982).

Crop	Seasonal water (mm)
Sugar cane	700–900
Wheat	400–450
Citrus	600–900
Potatoes	300–500
Vegetable	250–450

Among others, the most important agricultural project in the Kafue flats is the Nakambala sugar estate in the southeast edge of the flats just off the floodplains. It occupies some 10 300 ha and depends largely on irrigation (Sheppe 1985). From planting to cutting the cane plant, it requires about 2 000 mm of water for its optimum growth (Pike 1982). Of this, 750 mm is assumed to be normally provided by rainfall and the remaining 1 250 mm must be supplied by the irrigation system on the Kafue river itself.

Concerning the livestock in the Kafue flats, Bingham (1982) reported that about 250 000 cattle depend on the flats for dry season grazing between August and November. The rise of water level with the rains in December forces the cattle off the flats. These herds belong to the Tonga people to the south and the Ila in the west.

Both numbers and distribution of large mammals in the flats have been greatly reduced during this century, especially the lechwre, but also buffalo, zebra and eland among others. In order to stop this disappearance of mammals, Lochinvar Ranch was declared a National Park in 1972, and the Blue Lagoon Ranch achieved the same status in 1973 (Mwenya and Kaweche 1982). Wildlife utilization in the Kafue flats has encouraged tourism as well as subsistence and recreation hunting. The small amount of accomodation available and the lack of catering are the major limiting factors for tourism in the Kafue flats.

Chapter IV: Consequences of Impoundments on the Zambezi Drainage Basin

The preceding description of the impoundments on the Zambezi basin are mainly about man-made lakes. The Zambezi river system has gradually changed due to human interferences, and has reached the second stage of anthropic development according to David (1985). Here, the natural runoff system gradually changes to become more regulated. Thus, it has been said that almost 570 km of the Zambezi is regulated by man-made lakes. Moreover, the storage capacity along the river system has increased tremendously. These reservoirs were built for the sole purpose of generating hydropower. Nevertheless, they affect many different substances of the fluvial ecosystem. In the previous chapter, the consequences of dam impoundments on the reservoirs themselves, particularly with respect to limiting secondary uses have been described. However, downstream effects on these huge reservoirs must also be considered. Thus, a quick overview of the main challenges that have emerged will be given in the following sections.

1. Consequences Downstream from the Kariba Dam

1.1. Mana Pools Wildlife Reserve

Within Zimbabwe, there is a wildlife estate covering virtually all of the valley between the eastern end of Lake Kariba and the Mozambique border, occupying some 12000 km^2 (Figure 53). The Government of Zambia has declared a large area on its side of the Zambezi river as a national park, which together with the Zimbabwean part cover 16800 km^2. This area is particularly rich in large mammals (Du Toit 1984, 1985) that feed on vegetation growing on the Zambezi floodplains, an area providing food, shade and water for game animals and birds during the dry season. Both the hydrologic and the biological cycles of the floodplain are similar to that of the Kafue swamps (Chapter III, Section 8).

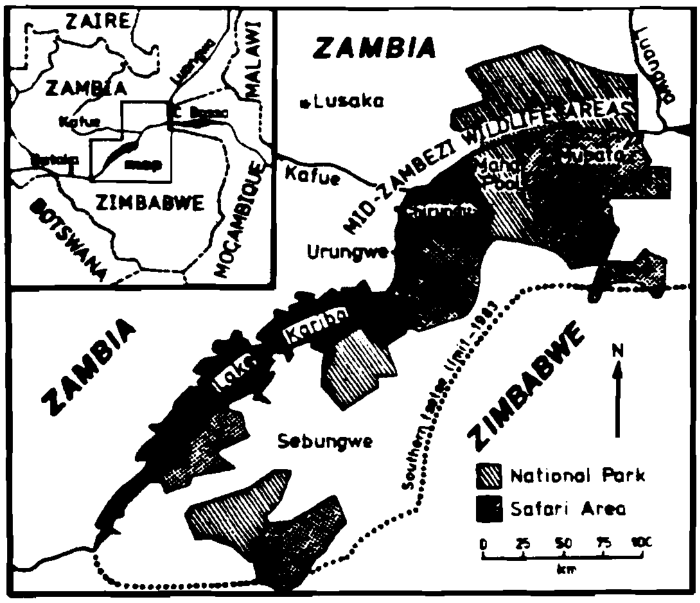


Figure 53. Mid Zambezi wildlife area (DuToit, 1985).

The Kariba impoundment has disrupted the ecological equilibrium, and this may be attributed to different reasons (Figure 54).

– Decrease in flood peaks in the flow and duration, and out-of-season floods affect the richness and biomass of the vegetation. This decrease in flood duration causes game animals to pasture on the floodplain, which in turn also affects the vegetation biomass.

– The trapping of sediment in the Kariba reservoir provides a silt-free outlet for water which causes an increase in bank erosion.

– The overpasture by game on riparian vegetation influences the effectiveness of the plants on the banks in reducing erosion.

For instance, according to Guy (1981) between 1954 and 1973, 1 030 hectares were lost to erosion over a distance of about 40 km. This stretch represents only 10 per cent of the total length of the bank downstream from Lake Kariba to the Zimbabwe–Mozambique border. It may therefore be assumed that many more hectares of soil were eroded outside this area, particularly downstream from Mana Pools.

This wildlife area is an important source of foreign currency for Zimbabwe, and conservation is of utmost ecological and economic interest that must be considered from the point of view of reservoir operation management.

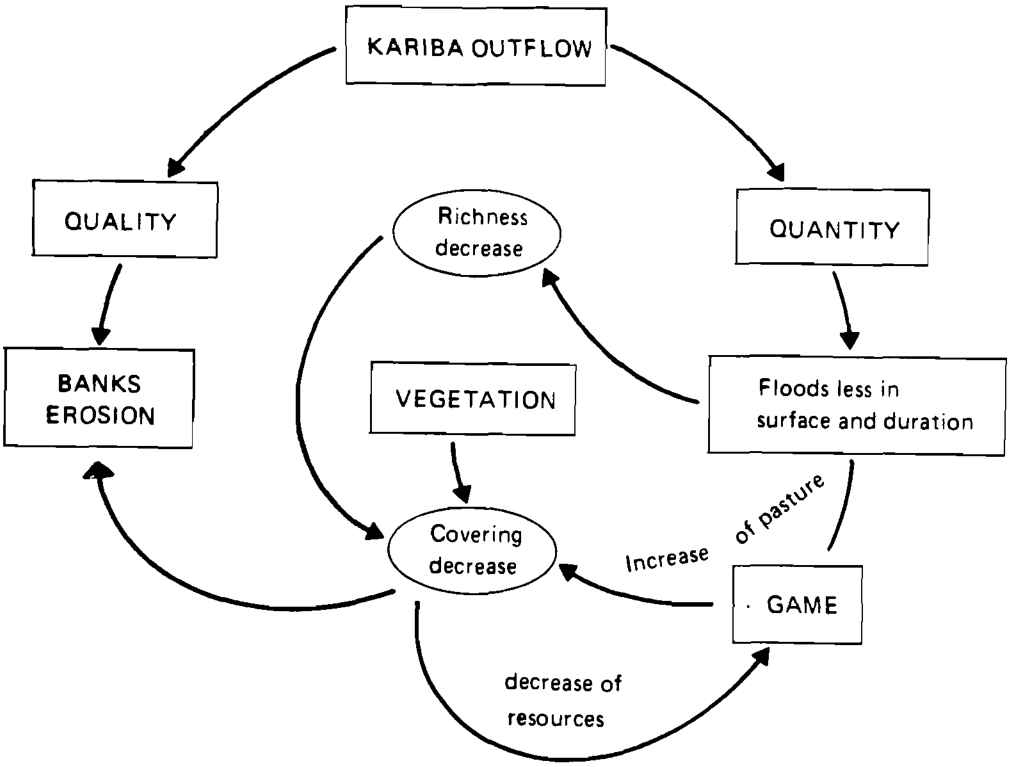


Figure 54. Consequences of Kariba outflow on the ecological equilibrium of Mana Pools floodplain.

1.2. Inflow at Cahora Bassa

The Kariba outflows constitute about 75 per cent of the total inflow into the Cahora Bassa reservoir. The discharge capabilities of the Cahora Bassa dam and its storage capacity are too small to protect the dam from overtopping even floods below the design flood magnitude. On the other hand, flood generation within the Cahora Bassa drainage basin is extremely intricate and difficult to predict accurately. Accordingly, the water level in the Cahora Bassa reservoir must be drawn down heavily each year during the dry season in anticipation of the next flood in the rainy season. Moreover, the presence of three major impoundments within the catchment, each with its own specific operating rules, is an additional complication. In fact, the Kariba reservoir operations seem to have considerable influence on that of the Cahora Bassa. The upstream regulation affects the flood discharges downstream. In the driest years, regulation is likely to reduce the annual maximum three month floods since natural floods will be stored in the upstream reservoirs to provide electricity at a later date. In the wettest years, assuming the reservoirs are operated according to a reliable flood rule curve procedure, the annual maximum three-month floods will also be reduced, the amount being equal to the total storage capacity of the reservoirs (or flood control – Bolton, 1983). Between these extremes, the effect will depend on the operating policy adopted for the upstream reservoirs. For instance, the Kariba project was not yet operated consistently according to flood rule curve procedures between 1971 and 1980, as shown in Table 38.

Table 38. Reservoir levels at Kariba on February 1 (Bolton, 1983).

Year	Reservoir level (m.a.s.l.)	Flood storage provided (10^3m^3)
1971	484.2	27.6
1972	483.7	30.3
1973	483.3	32.2
1974	484.6	25.4
1975	486.6	14.9
1976	484.7	25.0
1977	485.0	23.4
1978	487.3	11.1
1979	486.1	17.6
1980	484.7	25.0

It has been suggested by Rendel, Palmer and Tritton (Bolton, 1983) that $30.8.10^9m^3$ should be the flood storage on February 1 (reservoir level at 483.6 m.a.s.l.) and $13.7.10^9m^3$ (reservoir level at 486.8 m.a.s.l.) on March 1. It appears that a joint operating policy is necessary in order to optimize hydroelectric power generation by each power plant as well as to sustain ecological equilibrium in the valleys.

2. The Consequences Downstream from the Kafue Gorge Dam

The consequences downstream from the Itezhitezhi dam have already been elaborated in the previous chapter. Concerning the Kafue Gorge dam, the consequences downstream from the impoundment seem to be similar to that of the Kariba. Thus, it is essential that a joint operating policy which should involve managers of the Kariba, Itezhitezhi, Kafue Gorge and Cahora Bassa reservoirs as well as the wildlife conservationist be developed in order to sustain the several purposes at stake on this particular reach of the Zambezi.

3. The Consequences Downstream from the Cahora Bassa Dam

3.1. Ecological Consequences

The shortage of flow downstream from the dam during the filling phase has already been mentioned (Davies 1975a,b). Moreover, erratic management until now has not allowed any kind of ecological restoration in the fluvial system downstream from the reservoir. The annual floods before the Cahora Bassa impoundment rejuvenated the entire riverine and floodplain system with water, fresh silt and nutrients. At present, floods that are buffered are even worse, for they occur out of season disrupting the whole natural cycle of flood and ebb, even if a fresh discharge of $7.10^9 m^3$ over a period of 12 days in February each year is planned. On the other hand, sediment trapped in the reservoir is no longer available to sustain the maintenance of the Zambezi delta, a triangular area of 18 000 km^2 with a sea frontage 120 km long. The Marromeu Buffalo Reserve covers 1 600 km^2 of the delta. The evolution of this area is very close to that of the Mana Pools (Section 1.1): decrease of flood peak, overgrazing, less input of silt from the river, and erosion. In addition, this decrease in sediment deposition as well as the decrease in river flow no longer hinder intrusion and salinization by sea water in the alluvial soils devoted mainly to sugar cane agriculture. This decrease of the suspended matter load in the Zambezi river could also have a negative effect on the fish yield along the coast.

3.2. Navigation and Irrigation

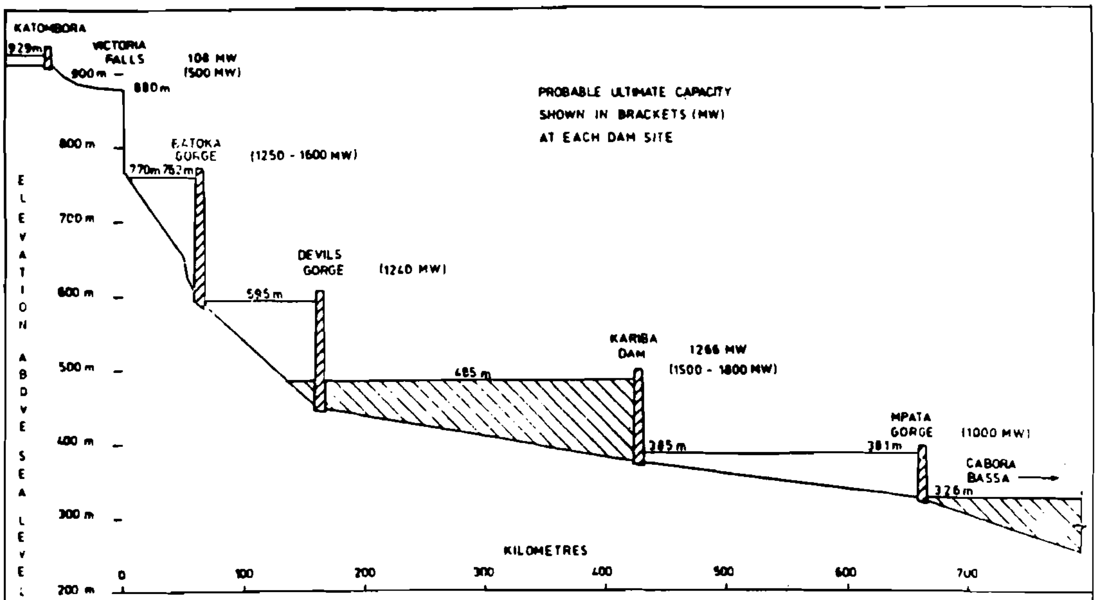
It was assumed that the Cahora Bassa project should not only provide hydroelectricity but also water for agricultural purposes downstream from the reservoir and a 500 km long navigable stretch. At present, navigation on the lower Zambezi is restricted to a few ferries. Prospects of future expansion of navigation depends partly on the minimum guaranteed flow of the river (1 600 m^3/s from Cahora Bassa), but more on the morphological characteristics of the channel (Bolton, 1983).

Today very little water is extracted from the Zambezi for irrigation. In fact, for the foreseeable future, water is unlikely to be a limiting factor in the possible expansion of irrigated agriculture.

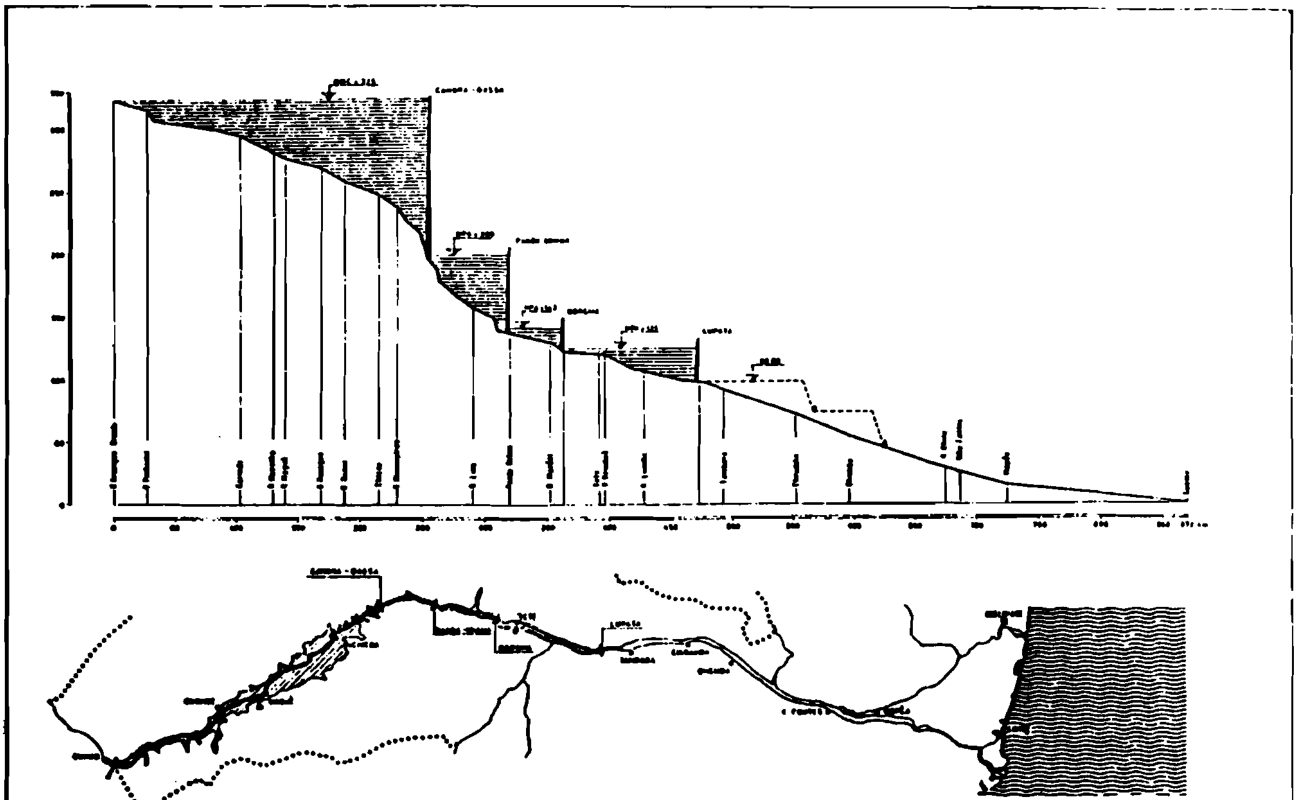
Chapter V. Conclusions

In this report, the Zambezi drainage basin constitutes one entity, and it is only for the sake of presentation that it is separated into different topics. It is shown that there are many interrelationships amongst the river system components, such as hydrological, biological, chemical, and anthropogenic, whatever the perceived scale may be. In a large international river basin such as the Zambezi, the prospects of long-term integrated development may appear attractive, but given the available resources and the complexity of the issues, short term expediency and narrowly defined objectives are likely to dominate policy formulation in the foreseeable future.

The proposed new impoundments on the Zambezi river concern mainly power plants (Figure 55). Taking into account the actual power generation capacity and the actual demand for it, it seems more reasonable even from the hydroelectricity generation perspective to try to optimize energy output from the already existing hydropower plants. In such circumstances, there is an urgent need for further studies of existing projects to focus attention on the impacts of large dam projects and to enable more realistic estimates of the true costs and benefits.



Source G.F. Allison, Address to The Economic Resources Conf., Zimbabwe, Sep. 1980.



Source: Falcão (1963)

Figure 55. Proposed hydroelectric development on the Zambezi river (Bolton, 1983).

REFERENCES

Attwell, R.J. (1970) Some effects of Lake Kariba on the ecology of a floodplain on the mid-Zambezi valley of Rhodesia. *Biol. Conserv.* **2**(3)189–196.

Austin, R.H.F. (1968) International legal aspects of the Kariba project. In: N. Rubin and W.M. Warren (Eds.) "Dams in Africa", 146–157.

Bailey, R.G. (1985) The factor of scale in ecosystem mapping. *Environ. Manag.*, **9**(4)271–276.

Balasubrahmanyam, S. and Abou-Zeid, S.M. (1982a) The Kafue river hydro-electric development. *Proc. Nat. Sem. on Environment and Change: the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, University of Zambia, Lusaka, 1978, 31–33.

Balasubrahmanyam, S. and Abou-Zeid, S.M. (1982b) Post-Itezhitezhi flow pattern of the Kafue in the Kafue flats region. *Proc. Nat. Sem. on Environment and Change: the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, University of Zambia, Lusaka, 1978, 63–67.

Balek, J. (1977) Hydrology and water resources in tropical Africa. *Development in Water Science*, 8, Elsevier, Amsterdam, 208p.

Balon, E.K. and Coche, A.G. (1974) Lake Kariba: on man-made tropical ecosystem in central Africa. *Monographiae Biologicae*, 24, W. Junk Publisher, 767p.

Balon, E.K. (1978) Kariba: the dubious benefits of large dams. *Ambio*, **7**(2)40–48.

Baxter, R.M. (1977) Environmental effects of dams and impoundments. *Ann. Rev. Ecol. and Syst.*, Vol. 8, 255–283.

Beadle, L.C. (1932) Scientific Results of the Cambridge Expedition to East African Lakes in 1930–1 IV. The Waters of Some East African Lakes in Relation to their Fauna and Flora. *J. Limn. Soc. (Zool.)*, 38, 157–211.

Begg, G.W. (1969) Observations on the water quality and nature of the affluent rivers of Lake Kariba with reference to their biological significance. *Limn. Soc. S. Afr. Newsl. (Suppl.)*, 13, 26–33.

Begg, G.W. (1970) Limnological observations on Lake Kariba during 1967 with emphasis on the special features. *Limnol. Oceanogr.*, 15, 776–788.

Begg, G.W. (1973) The biological consequences of discharge above and below Kariba Dam. In: "Congr. Comm. Int. Grandes Barrages", Madrid, 421–430.

Begg, G.W. (1974) The distribution of fishes of riverine origin in relation to the limnological characteristics of the five basins of Lake Kariba. *Hydrobiologia*, 44, 272–285.

Bell-Cross, (1972) The fish fauna of the Zambezi River system. *Arnoldia (Rhodesia)*, **5**(29)1–19.

Bernacsek, G.M. and Lopes, S. (1984) Investigations into the fisheries and limnology of Cahora Bassa reservoir seven years after dam closure. FAO/GCP/MOZ006/SWE Field doc., 149p.

Bhagavan, M.R. (1985) The energy sector in SADCC countries. *Ambio*, **14**(4–5)214–219.

Bingham, M.G. (1982) The livestock potential of the Kafue flats. *Proc. Nat. Sem. on Environment and Change: the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, University of Zambia, Lusaka, 1978, 95–103.

Bolton, P. (1983) The regulation of the Zambezi in Mozambique: a study of the origins and impact of the Cahora Bassa project. PhD. thesis, University of Edinburgh, 571p.

Bolton, P. (1984) Sediment deposition in major reservoirs in the Zambezi basin. In: "Challenges in African Hydrology and Water Resources", *Proc. Harare Sym.*, IAHS Publications 144, 559–567.

Bolton, P. (1986) Mozambique's Cahora Bassa project: an environmental assessment. In: E. Goldsmith, N. Hildyan (Eds.) "The Social and Environmental Effects of Large Dams", Wodebridge Ecological Centre, Vol. II Case Studies, 156–166.

Bond, W.J. and Roberts, M.G. (1978) The colonization of Cahora Bassa, a man-made lake by floating aquatic macrophytes. *Hydrobiologia*, 60, 243–254.

Bond, W.J. Coe, N., Jackson, P.B.N. and Rogers, K.H. (1978) The limnology of Cahora Bassa, Mozambique, during its first year. *Freshwater Biology*, 8, 433–447.

Bowmaker, A.P. (1973) Hydrophyte dynamics in Mwenda Bay, Lake Kariba. *Kariba Stud.*, 3, 42–59.

Bowmaker, A.P. (1976) The physico-chemical limnology of the Mwenda river mouth, Lake Kariba. *Arch. Hydrobiol.*, 77, 66–108.

Burgis, M.J. and Symoens, J.J. (1987) African wetlands and shallow water bodies. Directory. *Editions de l'ORSTOM, travaux et documents* No. 211, 650p.

CAPC (1984) Annual reports and accounts. Central African Power Corporation, 32p.

Carey, T.B. (1971) Hydrological survey of the Kafue floodplain. *Fish. Res. Bull. Zambia*, 5, 245–295.

Chauvet, E. (1987) Changes in the chemical composition of alder, poplar and willow leaves during decomposition in a river. *Hydrobiologia*, 148, 35–44.

Chipungu, P.M. (1981) The impacts of the Kafue dam on the Kafue floodplain fishery Zambia. FAO Fisheries Dept., Report No. FAO-FI-CIFA/T8 No. 8, 120–129.

Clements, F.E. (1905) Research Methods in Ecology. University Publishing Co., Lincoln, Nebraska (USA).

Coche, A.G. (1968) Description of physico-chemical aspects of Lake Kariba, an impoundment, in Zambia Rhodesia. *Fish. Res. Bull. Zambia*, 5, 200–267.

David, L. (1985) Water transfer in a small country: Hungarian experiences and perspectives. In: G.N. Golubev and A.K. Biswas (Eds.) "Large-Scale Water Transfers: Emerging Environmental and Social Experiences", 135–156.

Davies, B.R. (1975a) They pulled the plug out of the lower Zambezi. *African Wildlife*, **29**(2)26–27.

Davies, B.R. (1975b) Cahora Bassa hazards. *Nature*, 254, 477–478.

Davies, B.R., Hall, A. and Jackson, P.B.N. (1975) Some ecological aspects of the Cahora Bassa dam. *Biol. Conserv.*, 8, 189–201.

Davies, B.R. (1979) Stream regulation in Africa: a review. In: J.V. Ward and J.A. Stanford (Eds.) "The Ecology of Regulated Streams", 113–142.

Davies, B.R. (1986) The Zambezi River System. In: B.R. Davies and K.F. Walker (Eds.) "The Ecology of River Systems", 225–267.

Davies, B.R. and Walker, K.F. (1986) River systems as ecological units. An introduction to the ecology of river systems. In: B.R. Davies and K.F. Walker (Eds.) "The Ecology of River Systems", 1–8.

Dudley, R.G. (1974) Growth of Tilapia of the Kafue floodplain, Zambia: predicted effects of the Kafue gorge dam. *Trans. Amer. Fish. Soc.*, No. 2, 281–291.

Dudley, R.G. (1979) Changes in growth and size distribution of *Sarotherodon-macrochir* and *Sarotherodon-andersoni* from the Kafue floodplain, Zambia since construction of the Kafue gorge dam. *J. Fish Biol.*, **14**(2)205–223.

Dudley, R.G. and Scully, R.J. (1980) Changes in experimental gillnet catches from the Kafue floodplain, Zambia since construction of the Kafue gorge dam. *J. Fish Biol.*, **16**(5)521–537.

Du Toit, R.F. (1982) A preliminary assessment of the likely environmental impacts of two proposed hydroelectric schemes on the Zambezi river, Zimbabwe. *M. Env. Stud. Proj. Rep.*, Dept. Environmental Studies, University of Cape Town, 199p.

Du Toit, R.F. (1983) Hydrological changes in the middle-Zambezi system. *The Zimbabwe Science News*, **17**(7–8)121–125.

Du Toit, R.F. (1984) Some environmental aspects of proposed hydroelectric schemes on the Zambezi river, Zimbabwe. *Biol. Conserv.*, 28, 73–87.

Du Toit, R.F. (1985) A middle way for wildlife parks. *New Scient.*, 105, 33–36.

Ellis, M.M. (1941) Freshwater impoundments. *Trans. Am. Fish. Soc.*, 71, 80–93.

Elwell, H.A. (1978) Modelling soil losses in Southern Africa. *J. Agric. Engin. Res.*, 23, 117–127.

Elwell, H.A. (1984) Sheet erosion from arable lands in Zimbabwe: prediction and control. In: "Challenges in African Hydrology and Water Resources", IAHS Publications No. 144, 429–438.

Elwell, H.A. and Stocking, M.A. (1982) Developing a simple yet practical method of soil loss estimation. *Trop. Agric.*, **59**(1)43–48.

Fabre, A. (Forthcoming) Experimental studies on some factors influencing phosphorus solibilization in connexion with the drawdown of a reservoir. *Hydrobiologia*.

FAO (1975) Yearbook of Forest Products 1974. FAO Statistics Series.

FAO (1977) Production Yearbook 1976. FAO Statistics Series, No. 7, Vol. 30, 296p.

FAO (1981) FAO Fertilizer Yearbook 1980. FAO Statistics Series 30.

FAO (1986) FAO Fertilizer Yearbook 1985. FAO Statistics Series 36.

FAO (1986) Yearbook of Forest Products 1985. FAO Statistics Series.

FAO (1987) Production Yearbook 1986. FAO Statistics Series 76, Vol. 40, 306p.

FAO-UN (1969) Report to the Government of Zambia on Fishery Development in the Central Barotse Floodplain. Second Phase. FAO/UNDP (TA) (2638), 80p.

Gaster, P. (1974) Cahora Bassa. *Ecologist*, **4**(3)109.

Gliwicz, Z.M. (1982) Report prepared after first three months of work in Songo. FAO MONAP GCP MOZ (006), 8p.

Guy, P.R. (1981) River bank erosion in the mid-Zambezi valley downstream of Lake Kariba. *Biol. Conserv.*, 19, 199–212.

Hall, A. and Davies, B.R. (1974) Cahora Bassa: Apreciacao global do sen impacto no Vale do Zambeze. *Rev. Econ. Mozambique*, **11**(7)15–25.

Hall, A. Davies, B.R. and Valente, I. (1976). Cahora Bassa: some preliminary physico-chemical and zooplankton pre-impoundment survey results. *Hydrobiologia*, 50, 17–25.

Hall, A., Valente, I.M.C.B. and Burholt, M.S. (1977) The Zambezi river in Mozambique: the suspended solids regime and composition of the middle and lower Zambezi: prior to the closure of the Cahora Bassa Dam. Departmento da Quimica, Univ. Aveiro, Mimeo, Portugal, 12p.

Handlos, W.L. (1982) Introduction to the ecology of the Kafue flats. In: *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, p. 5–29.

Holland, M.M. (1987) Technical consultation on ecotones. *SCOPE/MABS UNESCO.*

Hosier, R.H. (1986) Energy planning in Zimbabwe: an integrated approach. *Ambio*, **15**(2)90–96.

Howard, G.W. and Williams, G.J. (1982) The consequences of hydroelectric power development on the utilization of the Kafue flats. In: *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, 159p.

Howard-Williams, C. and Gaudet, J.J. (1979) Structure and function of swamps. Document prepared for Societas Internationales Limnologiae, UNEP Workshop, University of Nairobi, December 1979.

Hutchinson P. (1974) The climate of Zambia. *Occasional Study*, No. 7, Zambia Geographical Association, Lusaka, 95p.

Jackson, P.B.N. (1961) Ichthyology. The fish of the middle-Zambezi. Kariba Studies. Manchester University Press, 36p.

Jackson, P.B.N. (1986) Fish of the Zambezi system. In: B.R. Davies and K.F. Walker (Eds.), 269–288.

Jackson, P.B.N. and Davies, B.R. (1976) Cahora Bassa in its first year. Some ecological aspects and comparisons. *The Rhodesia Science News*, **10**(5)128–133.

Jackson, P.B.N. and Rogers, K.H. (1976) Cahora Bassa fish populations before and during the first filling phase. *Zoologica Africana*, **11**(2)373–397.

Kabell, T.C. (1984) Sediment storage requirements for reservoirs. In: "Challenges in African Hydrology and Water Resources", IAHS Publications, No. 144, 569–576.

Kenmuir, D.H.S. (1975) Sardines in Cabora Bassa lake? *New Scientist*, 65, 379–380.

Kenmuir, D.H.S. (1982) Fish production prospects in Zimbabwe. *Zimbabwe Agric. J.*, 79, 11–17.

Kenmuir, D.H.S. (1984) Fish population changes in the Sanyati basin, Lake Kariba, Zimbabwe. *South African J. Zool.*, **19**(3)194–209.

Kiele, A.C. (1982) Irrigation development and the Kafue flats. In: *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, 69–73.

King, R.D. and Lee, R.E. (1974) The effect of river flooding on the Mwenda River mouth, Lake Kariba, Rhodesia. *Arch. Hydrobiol.*, 74, 32–38.

King, R.D. and Thomas, D.P. (1985) Environmental conditions and phytoplankton in the Mwenda River, a small intermittent river flowing into lake Kariba. *Hydrobiologia*, **126**(1)81–89.

Kovacs, I. and David, L. (1977) Joint use of international water resources. *Ambio*, **6**(1)87–90.

Lagler, K.F., Kapetsky, J.M. and Stewart, D.J. (1971) The Fisheries of the Kafue River Flats, Zambia, in Relation to the Kafue Gorge Dam. FAO-UN, University of Michigan, 161p.

Machena, C. and Fair, P. (1986) Comparison of fish yields from prediction models between lakes Tanganyika and Kariba. *Hydrobiologia*, 137, 29–32.

Magadza, C.H.D. (1986) Conflicts of resource use on the Lake Kariba environs. *Nature and Resources*, **XXII**(4)2–12.

Marshall, B.E. and Falconer, A.C. (1973a) Physico-chemical aspects of lake McIlwaine (Rhodesia), a eutrophic tropical impoundment. *Hydrobiologia*, 42, 45–62.

Marshall, B.E. and Falconer, A.C. (1973b) Eutrophication of a tropical African impoundment (Lake McIlwaine, Rhodesia). *Hydrobiologia*, 43, 109–123.

Marshall, B.E. and Junor, F.J.R. (1981) The decline of *Salvinia molesta* on Lake Kariba. *Hydrobiologia*, (83)477–484.

Marshall, B.E., Junor, F.J.R. and Langerman, J.D. (1982) Fisheries and fish production on the Zimbabwean side of Lake Kariba. *Kariba Studies*, 10, 175–231.

McLachlan, A.J. (1969) The effect of aquatic macrophytes on the variety and abundance of benthic fauna in the newly created lake in the tropics (Lake Kariba). *Arch. Hydrobiol.*, 66, 212–231.

McLachlan, A.J. (1970a) Some effects on the annual fluctuations of water level on the larval chironomid communities of Lake Kariba. *J. Anim. Ecol.*, 39, 79–90.

McLachlan, A.J. (1970b) Submerged trees as a substrata for benthic fauna in the recently-created Lake Kariba (Central Africa). *J. Appl. Ecol.*, 7, 253–266.

McLachlan, A.J. (1974) Development of some lake ecosystems in tropical Africa with special reference to the invertebrates. *Biol. Rev.*, 49, 365–397.

Mitchell, D.S. (1973) Supply of plant nutrient chemicals in Lake Kariba. In: W.C. Ackermann, G.F. White and E.B. Worthington (Eds.) "Man-made Lakes: Their Problems and Environmental Effects", 165–169.

Mitchell, D.S. and Marshall, B.E. (1974) Hydrobiological observations on three Rhodesian reservoirs. *Fresh. Biol.*, 4, 61–72.

Mtada, O.S.M. (1987) The influence of thermal stratification on pelagic fish yields in Lake Kariba, Zambia, Zimbabwe. *J. Fish Biol.*, **30**(2)127–133.

Mumeka, A. (1986) Effect of deforestation and subsistence agriculture on runoff of the Kafue river headwaters, Zambia. *Hydrol. Sci. J.*, **31**(4–12)543–554.

Muyanga, E.D. and Chipundu, P.M. (1982) A short review of the Kafue flats fishery, from 1968 to 1978. *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, 105–113.

Mwenya, A.N. and Kaweche, G.B. (1982) Wildlife conservation in the Kafue flats in the light of hydroelectric development. *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, 129–135.

Petersen, R.C. jr., Lauge Madsen, B. Wilzbach, M.A., Magadza, C.H.D., Paarlberg, A., Kullberg, A. and Cummins, K.W. (1987) Stream management: emerging global similarities. *Ambio*, **16**(4)166–179.

Pike, J.R. (1982) Nakambala and the Kafue flats. *Proc. Nat. Sem. on Environment and Change of the Consequences of Hydroelectric Power Development on the Utilization of the Kafue Flats*, Lusaka 1978, University of Zambia, 75–79.

Pinay, G. and Decamps, H. (1988) The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: a conceptual model. ***Regulated Rivers***, 2 (forthcoming).

Pinay, G., Salewicz, K.A. and Kovacs, G. (1988) An attempt to facilitate water management issues in the Zambezi river basin using decision support systems. ***Regulated Rivers*** (forthcoming).

Pitt, J.D. and Thompson, G. (1984) The impact of sediment on reservoir life. In: "Challenges in African Hydrology and Water Resources", IAHS Publications No. 144, 541–548.

Puzo, W. (1978) Patterns of man–land relations. In: M.J.A. Werger and A.C. van Bruggen (Eds.) "The Biogeography and Ecology of Southern Africa, 1049–1112.

Ramberg, L. Björkramberg, S, Kautsky, N. and Machena, C. (1987) Development and biological status of Lake Kariba. A man-made tropical lake. *Ambio*, **16**(6)314–321.

Rees, W.A. (1978a) Do the dams spell disaster for the Kafue lechwe? *Oryx*, 231–234

Rees, W.A. (1978b) Ecology of Kafue lechwe. Soils, water levels and vegetation. *J. Appl. Ecol.*, **15**(1)163–176.

Rees, W.A. (1978c) The ecology of the Kafue lechwe: the food supply. *J. Appl. Ecol.*, 15, 177–191.

Rees, W.A. (1978d) The ecology of the Kafue lechwe: its nutritional status and herbage intake. *J. Appl. Ecol.*, 15, 193–203.

Rees, W.A. (1978e) The ecology of the Kafue lechwe: as affected by the Kafue Gorge hydroelectric scheme. *J. Appl. Ecol.*, 15, 205–217.

Rzoska, J. (1966) The biology of reservoirs in the USSR. In: L. McConnel and R.M. (Eds.) "Man-Made Lakes", Academic Press, London.

Salter, L.F. (1978–79) A study of the runoff of fertilizers from agricultural land on the Kafue flats, Zambia. ***Zambian Geog.*** *J.*, 33–34, 95–103.

Salter, L.F. (1985) Preliminary study of water quality in the Kafue flats, Zambia. ***Suid Afrikaanse Tydskrif vir Wetanskap***, 81, 529–531.

Schulze, R.E. and O.S. McGee (1978) Climatic indices on classifications in relation to the biogeography of Southern Africa. In: M.J. Werger and A.C. van Bruggen (Eds.) "Biogeography and Ecology of Southern Africa", W. Junk Publishers, The Hague, 19–52.

Sheppe, W.A. (1982) Effects of human activities on Zambia's Kafue flats ecosystems. ***Environmental Conservation***, **12**(1)49–57.

Sheppe, W.A. (1985) Effects of human activities on Zambia's Kafue flats ecosystems. ***Environ. Conserv.***, **12**(1)49–57.

Simons, D.B. (1979) Effects of stream regulation on channel morphology. In: J.V. Ward and J.A. Stanford (Eds.) "The Ecology of Regulated Rivers", 95–111.

Stocking, M. and Elwell, H.A. (1973) Soil erosion hazard in Rhodesia. ***Rhodesia Agric.*** *J.*, **70**(4)93–101.

Taylor, R.D. (1982) Buffer zones? Resolving the conflict between human and wildlife interests in the Sebungwe region. ***Zimbabwe Agric.*** *J.*, 79, 179–184.

Tinley, K. (1975) Marromeu wrecked by the big dam. ***African Wildlife***, **29**(2)22–25.

UN (1972) World Survey Supplies 1961–1970. UN Statistical Papers, Series J, No. 15, 373p.

UN (1983) Yearbook of World Energy Statistics. UN Statistical Paper, Series J, No. 25, 783p.

UN (1987) Energy Statistics Yearbook. UN Statistical Paper, Series J, No. 29, 437p.

UNEP (1986a) Diagonistic study on the present state of ecology and the environmental management of the common Zambezi river system. UNEP/WG/147.2, 90p.

UNEP (1986b) Assessment of the present and future activities related to the Zambezi Action Plan. UNEP Mission of Experts to the Zambezi Countries, 115p.

Vieira, M.C. (1961) Rio Zambeze esquema para a organizacao de um sistema de aviso de cheias em Mocambique. Boletim de Sociedade des Estudos de Mocambique, 126, 1–7.

Walter, H., Harnickell, E. and Mueller-Dombois, D. (1975) Climate diagram maps of the individual continents and the ecological climatic regions of the earth. Supplement to the Vegetation Monographs, Springer-Verlag, Berlin, 36p.

Welcomme, R.L. (1977) Some factors affecting the catch of tropical river fisheries. In: "Symposium on River and Floodplain Fisheries in Africa", Bujumbwa, CIFA Technical Report, No. 5, 266–275.

Wetzel, R.G. (1975) Limnology. W.B. Saubers Co., 743p.

White, E. (1973) Zambia's Kafue hydroelectric scheme and its biological problems. In: W.C. Ackermann, G.F. White and E.B. Worthington (Eds.) "Man-Made Lakes: Their Problems and Environmental Effects", 620–628.

White, W.R. and Bettess, R. (1984) The feasibility of flushing sediments through reservoirs. In: "Challenges in African Hydrology and Water Resources", IAHS Publications, No. 144, 577–587.

Williams, R. (1971) Fish ecology of the Kafue river and floodplain environment. *Fish. Res. Bull. Zambia*, 5, 305–330.

Wilson, B.H. and Dincer, T. (1976) An introduction to the hydrology and hydrography of the Okavango delta. In: *Proc. of the Symposium on Okavango Delta and its Future Utilization*, Gaborone, Botswana, 33–47.

Annex I. Technical Details on the Main Impoundments of the Zambezi Drainage Basin (Bolton, 1983).

	Cahora Bassa	Kariba	Kafue	
			Kafue Gorge Dam	Itezhitezhi Dam
Construction commenced	Sept 1969	July 1955	1967	1973
Impounding commenced	Dec 1974	Dec 1958	1970	Dec 1976
Dam details				
Type	cupola arch	cupola arch	gravity	gravity
Material	concrete	concrete	earth-rockfill	earth-rockfill
Maximum height (m)	163	131	50	65
Crest length (m)	303	633	375	1800
Volume of dam ($m^3 \times 10^3$)	550	975	1200	8500
Rock excavation underground ($m^3 \times 10^3$)	1100	580 + 320*	--	0
Dam crest altitude (m O.D.)	331.0	489.5	981.5	1035.5
Spillway capacity (m^3/s)	13950 (at 329 m)	9500 (at 489 m)	4250	4200
Reservoir details				
Storage capacity: live	52 (295-326 m)	44	0.7	5
($m^3 \times 10^9$) dead	12.5 (< 295 m)	116	--	--
flood	8 (326-329 m)	25	--	--
total	72.5	185	0.84	5.7
Surface area, normal operation (km^2)	2700	5200	800**	370
Maximum length (km)	270	280	--	--
Maximum projected drawdown (m)	34	9	9	27

- value not known; * includes the North Bank Power Station; ** includes partial inundation of the Kafue Flats.

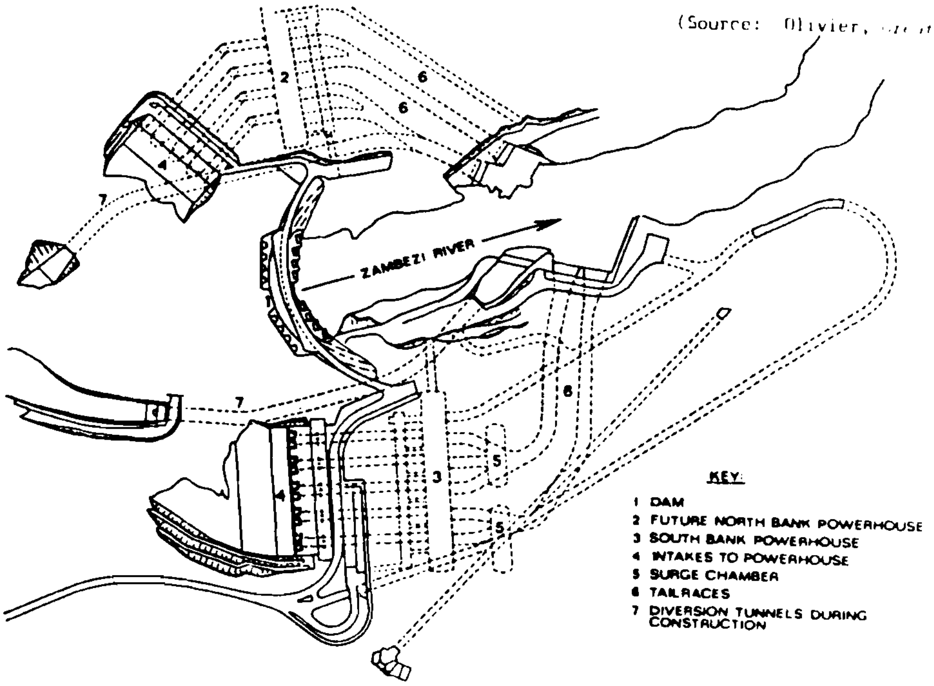
	Cabora Bassa	Kariba	Kafue	
			Kafue Gorge Dam	Itezhitezhi Dam
Hydrology				
Catchment area ($km^2 \times 10^3$)	1000	650	150	105
Approx. mean annual inflow ($m^3 \times 10^9$)	84*	52	10	10
Approx. min. regulated flow (m^3/s)	2100	1500	180	--
Maximum unregulated flow (m^3/s)	30000	16000 (in 1958)	2400	2700
Minimum unregulated flow (m^3/s)	200	200 (in 1949)	10	3

Power Generation	Cabora Bassa South	Kariba South	Kariba North	Kafue Gorge
Turbine type	Vertical Francis	Vertical Francis		Vertical Francis
Number of sets	5	6	4	4 + 2
Commercial power available	March 1977	Dec 1959	1976	Oct 1971/Apr 1977
Rated output per set (MW)	415	111**	150	150
Maximum turbine discharge (m^3/s)	452	140	200	42
Maximum gross head (m)	128	110	108	397
Generator output at 50 Hz (kV)	18	18	18	17.5
Power factor	0.85	0.9	0.9	--
Principal transmission voltage (kV)	±533 (d.c.)	330 (a.c.)		330 (a.c.)
Projected energy potential (TWh/yr)	18.5 (99% prob) 20.5 (95% prob)	over 10		9.5
Projected ultimate capacity	3800	1500 - 1800		1430

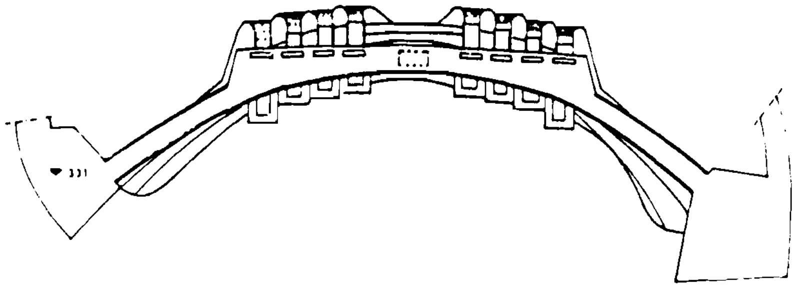
- value not known; * allowing for evaporation at Kariba; ** originally rated at 100 MW

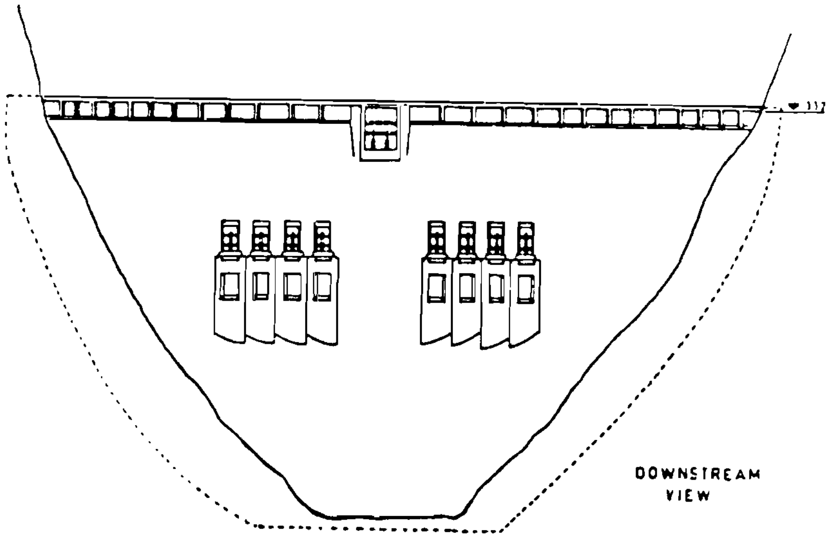
Annex II. (1) Details of the Cahora Bassa Dam (Bolton, 1983; Bernacsek and Lopes, 1984).

(Source: Olivier, [illegible])



CREST VIEW

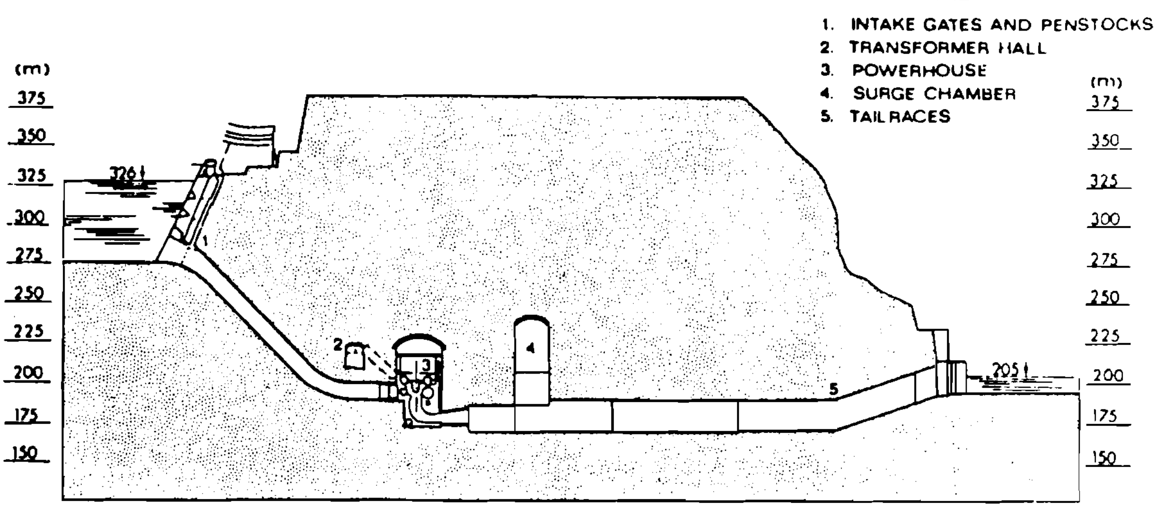




DOWNSTREAM VIEW

Annex II. (2) Hydraulic central circuit and technical details of the Cahora Bassa (Bolton, 1983; Bernacsek and Lopes, 1984).

HYDRAULIC CENTRAL CIRCUIT



TECHNICAL DATA FOR CAHORA BASSA DAM AND SOUTH SHORE POWER STATION

Geographical position	15°35'S; 32°44'E
Date of closure	5 December 1974
Dam wall	
Crest height above riverbed	161 m
Maximum thickness of foundation	21.5 m
Minimum thickness of wall (near crest)	5 m
Volume of concrete used	450 000 m³
Flood (sluice) gates	
Number	8
Discharge capacity of single sluice gate (at 326.00 m.a.s.l.)	1 700 m³/sec
Total discharge capacity of eight sluice gates (at 326.00 m.a.s.l.)	13 600 m³/sec
Spill (flap) gate	
Discharge capacity (at 326.00 m.a.s.l.)	350 m³/sec
Turbines	
Number	5 (4 operational + standby)
Generating capacity of single turbine	415 MW
Normal total generating capacity (4 turbines)	1 660 MW
Maximum total generating capacity (5 turbines)	2 075 MW
Design speed of turbine	107.1 RPM (constant)
Gross head to turbines	103.5 m
Flow to single turbine	460 m³/sec
Normal total turbinated flow (4 turbines)	1 840 m³/sec
Maximum total turbinated flow (5 turbines)	2 300 m³/sec
Total maximum discharge capacity of dam and power station (at 326.00 m.a.s.l.)	16 250 m³/sec

Annex II. (3.1) Hydrological data for the Cahora Bassa 1974–1976 (Bernacsek and Lopes, 1984).

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR December 1974 and 1975

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km^2)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							Δ Volume of reservoir (inflow-outflow) (km^3)
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m^3/sec)	Total monthly volume (km^3)	Total monthly volume (km^3)	Mean No. of turbines operating	Total monthly volume (km^3)	Mean No. of flood-gates operating	Total monthly volume (km^3)	Mean monthly rate (m^3/sec)	Total monthly volume (km^3)	
December 1974	1	206.72											
	16	252.40											
	M							4.23	4.6			4.23	
January	1	252.20											
	16	253.90											
	M							3.28	4.5		1 224	3.28	
February	1	269.20											
	16	290.50											
	M			7 314	17.70			0.26				0.26	17.44
March	1	301.70	1 148										
	16	309.20	1 550										
	M			9 662	25.49			11.27	3		4 252	11.27	14.42
April	1	311.75	1 700										
	16	312.90	1 771										
	M			6 445	16.96			13.35	3.5		5 050	13.35	3.61
May	1	313.80	1 826										
	16	313.00	1 777										
	M			1 526	4.09			7.62	3		2 844	7.62	-3.53
June	1	311.80	1 704										
	16	311.10	1 662										
	M			1 909	5.21			7.78	3		2 963	7.78	-2.57
July	1	310.25	1 611										
	16	307.95	1 679							-			
	M			1 698	4.55			11.96	3.5		4 465	11.96	-7.41
August	1	305.20	1 328										
	16	304.85	1 310										
	M			1 081	2.80			3.68	2		1 375	3.68	-0.88
September	1	304.60	1 296										
	16	304.05	1 267										
	M			911	2.36			3.63	2		1 401	3.63	-1.27
October	1	303.60	1 244										
	16	303.05	1 215										
	M			815	2.18	0.09	1	3.08	1.5		1 181	3.16	-0.98
November	1	302.80	1 203										
	16	302.60	1 193										
	M			843	2.18	0.04	0.5	3.26	2		1 275	3.30	-1.12
December	1	301.85	1 157										
	16	301.20	1 123										
	M			1 158	3.10	0.04	1	4.03	2		15.16	4.07	-0.96

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR 1976

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km^2)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							Δ Volume of reservoir (inflow-outflow) (km^3)
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m^3/sec)	Total monthly volume (km^3)	Total monthly volume (km^3)	Mean No. of turbines operating	Total monthly volume (km^3)	Mean No. of flood-gates operating	Total monthly volume (km^3)	Mean monthly rate (m^3/sec)	Total monthly volume (km^3)	
January	1	301.00	1 113										
	16	301.40	1 133										
	M			1 744	4.80	0.01		3.01	2		1 128	3.02	1.78
February	1	302.55	1 190										
	16	303.20	1 223										
	M			3 004	7.53	0.07	1	2.50	2		1 021	2.57	4.96
March	1	306.40	1 393										
	16	309.70	1 579										
	M			5 176	13.86	0.30	1.5	0.86	2		433	1.16	12.70
April	1	314.25	1 854										
	16	318.03	2 098										
	M			7 267	18.84	0.46	2	5.06	2.5		2 129	5.52	13.32
May	1	320.70	2 282										
	16	322.65	2 419										
	M			5 109	13.68	0.04	0.5	4.836	2.5	0.004	1 823	4.88	8.80
June	1	324.35	2 543										
	16	325.25	2 609										
	M			5 136	13.31	0.49	1	10.15	3	0.10	4 141	10.73	2.58
July	1	325.35	2 617										
	16	325.40	2 621										
	M			6 119	11.03	0.43	1	11.62	3	0.02	4 507	12.07	-1.04
August	1	324.95	2 587										
	16	326.35	2 543										
	M			1 366	3.66	0.78	1.5	0.52	1	0.24	575	1.54	2.12
September	1	325.76	2 647										
	16	326.19	2 680										
	M			1 257	3.26			0.95	1	0.41	524	1.36	1.90
October	1	326.47	2 700										
	16	326.70	2 718										
	M			847	2.27	0.54	1.5	0.14	1	0.75	533	1.43	0.84
November	1	326.78	2 724										
	16	326.88	2 730										
	M			775	2.01	0.59	1.5	0.44	1	0.93	754	1.96	0.05
December	1	326.80	2 726										
	16	326.42	2 697										
	M			1 644	3.17	0.40	1	11.97	4	0.71	4 881	13.08	-9.21

Annex II. (3.2) Hydrological data for the Cahora Bassa 1977–1978 (Bernacsek and Lopes, 1984).

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

1977

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood-gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	Δ Volume of reservoir (inflow-outflow) (km³)
January	1	323.25	2 462										
	16	320.40	2 402										
	M			1 917	5.14	0.05	0.5	13.78	4	3.26	6 382	17.09	-11.95
February	1	318.00	2 098										
	16	317.20	2 045										
	M			2 050	4.95	0.39	2	6.39	2		2 802	6.78	- 1.83
March	1	317.12	2 038										
	16	318.00	2 098										
	M			3 119	8.35	1.80	3	3.85	1		2 109	5.65	2.70
April	1	318.42	2 124										
	16	318.70	2 145										
	M			3 195	8.28	2.35	3.5	2.31	1		1 798	4.66	3.62
May	1	320.08	2 239										
	16	320.70	2 282										
	M			2 677	7.17	2.37	3	1.59	0.5		1 481	3.97	3.20
June	1	321.48	2 337										
	16	322.20	2 387										
	M			1 659	4.30	2.23	3			0.03	873	2.26	2.04
July	1	322.34	2 398										
	16	321.50	2 338										
	M			1 272	3.41	2.35	3	4.01	1.5	0.03	2 387	6.39	- 2.98
August	1	321.07	2 308										
	16	320.52	2 269										
	M			1 288	3.45	2.50	3	4.62	1		2 659	7.12	- 3.67
September	1	319.44	2 195										
	16	318.19	2 110										
	M			1 535	3.99	2.53	3	4.82	1.5		2 835	7.35	- 3.37
October	1	317.87	2 089										
	16	317.24	2 047										
	M			1 329	3.56	0.16	1.5	6.10	2		2 337	6.26	- 2.70
November	1	316.55	2 002										
	16	316.02	1 967										
	M			1 315	3.41	0.37	1.5	5.68	2		2 335	6.05	- 2.69
December	1	315.20	1 915										
	16	314.34	1 854										
	M			1 777	4.76	1.14	2	6.16	1.5		2 728	7.31	- 2.55

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

1978

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood-gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	Δ Volume of reservoir (inflow-outflow) (km³)
January	1	313.84	1 879										
	16	315.22	1 916										
	M			5 031	13.48	1.24	2	3.78	1		1 875	5.02	8.46
February	1	318.14	2 107										
	16	322.42	2 403										
	M			9 422	22.79	1.04	2	8.88	2		4 098	9.91	12.88
March	1	323.74	2 498										
	16	326.24	2 683										
	M			13 679	36.64	1.84	3	23.73	5.5	0.77	9 831	26.33	10.31
April	1	327.64	2 790										
	16	327.07	2 747										
	M			4 845	25.52	1.89	2.5	24.27	6	1.01	10 485	27.18	- 1.66
May	1	327.04	2 744										
	16	326.50	2 703										
	M			7 503	19.55	2.98	3	18.42	4.5	0.87	8 313	22.27	- 2.12
June	1	326.04	2 668										
	16	324.82	2 577										
	M			5 293	13.72	3.04	3	16.86	4	0.46	7 854	20.36	- 6.64
July	1	323.46	2 478										
	16	322.09	2 379										
	M			5 167	13.84	3.13	3	14.79	3.5	0.08	6 719	17.99	- 4.15
August	1	321.74	2 355										
	16	322.53	2 410										
	M			2 285	6.12	2.31	2.5	1.74	0.5		1 509	4.04	2.08
September	1	322.61	2 416										
	16	322.50	2 409										
	M			1 448	3.75	2.36	2.5	2.42	1		1 847	4.79	- 1.03
October	1	322.18	2 385										
	16	321.68	2 350										
	M			1 102	2.95	2.70	3	5.93	1.5		3 222	8.63	- 5.68
November	1	319.71	2 213										
	16	317.28	2 050										
	M			1 139	2.95	2.99	3	9.52	2.5		4 823	12.50	- 9.55
December	1	315.07	1 906										
	16	314.03	1 840										
	M			2 922	7.83	2.96	3	5.90	2		3 310	8.86	- 1.03

Annex II. (3.3) Hydrological data for the Cahora Bassa 1979–1980 (Bernacsek and Lopes, 1984).

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

1979

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood-gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	Δ Volume of reservoir (inflow-outflow) (km³)
January	1 16 M	314.52 314.24	1 870 1 859	2 316	6.20	3.00	3.5	3.73	1.5		2 516	6.74	- 0.54
February	1 16 M	314.23 316.97	1 852 1 900	3 158	7.64	0.46	1.0	2.61	1.0		1 268	3.07	4.57
March	1 16 M	316.60 319.24	2 005 2 182	5 366	14.37	1.77	2.5	1.95	0.5		1 389	3.72	10.65
April	1 16 M	321.51 323.13	2 338 2 454	3 982	10.32	2.58	3.0	0.31		0.03	1 129	2.93	7.39
May	1 16 M	324.53 325.58	2 555 2 632	3 261	8.73	2.72	3.0	0.88	0.5	0.58	1 559	4.17	4.56
June	1 16 M	326.27 326.96	2 685 2 737	3 198	8.29	4.07	5.0	2.23	1.0	0.87	2 770	7.18	1.11
July	1 16 M	326.68 325.76	2 716 2 647	3 118	8.35	4.39	5.0	3.07	1.5	0.37	3 673	9.84	- 1.48
August	1 16 M	326.13 326.01	2 674 2 665	1 616	4.33	3.76	4.5	0.96	0.5	0.59	1 984	5.31	- 0.98
September	1 16	325.76 325.38	2 647 2 619	1 401	3.63	3.57	4.0	1.68	1.0	0.56	2 239	5.80	- 2.17
October	1 16 M	324.93 324.28	2 585 2 537	1 122	3.00	4.27	4.5	1.70	1.0	0.33	2 364	6.33	- 3.32
November	1 16	323.62 323.04	2 489 2 447	1 200	3.11	3.79	4.0	1.63	1.0	0.14	2 146	5.56	- 2.45
December	1 16	322.62 322.18	2 417 2 385	1 890	5.06	4.00	4.0	7.00	2.0		4 108	11.00	- 5.94

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

1980

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBO		OUTFLOW AT CAHORA BASSA							
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood-gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	Δ Volume of reservoir (inflow-outflow) (km³)
January	1 16 M	319.97 319.58	2 232 2 202	4 346	11.64	4.67	4.0	6.44	2.0		4 127	11.05	0.59
February	1 16 M	320.41 321.73	2 261 2 354	3 370	8.44	3.72	4.0	0.40			1 645	4.12	4.32
March	1 16 M	322.30 324.48	2 395 2 550	4 454	11.93	3.76	4.0	1.51	0.5		1 969	5.27	6.66
April	1 16 M	324.89 325.18	2 583 2 605	4 594	11.90	3.98	4.0	4.39	1.0	0.52	3 429	8.88	3.02
May	1 16 M	326.06 325.91	2 670 2 658	3 571	9.56	4.00	4.0	6.25	2.0	0.70	4 095	10.97	-1.40
June	1 16 M	325.45 324.71	2 624 2 569	1 823	4.73	3.09	3.5	3.27	1.0	0.31	2 516	6.68	-1.95
July	1 16 M	324.76 324.51	2 573 2 554	1 690	4.53	2.49	3.0	2.98	1.0		2 044	5.47	-0.94
August	1 16 M	324.39 324.30	2 547 2 539	1 352	3.62	2.18	3.0	2.03	1.0		1 567	4.20	-0.58
Septembre	1 16 M	329.17 323.96	2 530 2 513	1 104	2.86	1.95	3.0	2.34	1.0		1 656	4.29	-1.43
October	1 16 M	323.60 322.97	2 488 2 443	1 227	3.29	6.26	4.5	2.53	1.0		2 536	6.79	-3.50
November	1 16 M	322.16 321.63	2 384 2 347	1 301	3.37	4.55	6.5	1.54	1.0		2 350	6.09	-2.72
December	1 16 M	321.00 320.26	2 803 2 251	1 736	4.65	0.56	1.5	6.31	2.0		2 566	6.87	-2.22

Annex II. (3.4) Hydrological data for the Cahora Bassa 1981–1982 (Bernacsek and Lopes, 1984).

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

1981

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBC		OUTFLOW AT CAHORA BASSA							Δ Volume of reservoir (inflow-outflow) (km³)
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	
January	1	320.02	2 233										
	16	319.53	2 200										
	M			2 358	6.32	0.10	1.0	8.29	2.0		3 131	8.39	-2.07
February	1	319.08	2 171										
	16	319.92	2 228										
	M			6 056	14.65	1.84	2.5	6.58	2.0		3 482	8.42	6.23
March	1	321.83	2 361										
	16	322.66	2 420										
	M			7 354	19.70	2.76	3 0	12.07	3.0		5 537	14.83	4.87
April	1	323.83	2 505										
	16	325.06	2 595										
	M			4 057	10.51	0.28	1.0	4.15	1.0	0.04	1 728	4.47	6.04
May	1	326.16	2 670										
	16	327.00	2 741										
	M			3 998	10.71	0.09	1.0	7.32	1.5	0.95	3 119	8.35	2.36
June	1	327.03	2 743										
	16	326.96	2 737	3 669	9.51	0.08	1.0	9.31	2.5	0.94	3 985	10.33	-0.82
July	1	326.73	2 720										
	16	325.74	2 646										
	M			2 066	5.53	0.09	1.0	8.40	2.5	0.57	3 382	9.06	-3.53
August	1	325.41	2 621										
	16	325.03	2 593										
	M			1 687	4.52	0.10	1.0	6.21	2.0		2 356	6.31	-1.79
September	1	324.72	2 570										
	16	324.27	2 537										
	M			1 412	3.67	0.09	1.0	6.50	2.0		2 543	6.59	-2.92
October	1	323.56	2 485										
	16	322.80	2 430										
	M			1 245	3.33	0.77	1.5	6.38	2.0		2 668	7.15	-3.82
November	1	321.99	2 373										
	16	321.33	2 325										
	M			1 302	3.38	3.76	4.0	6.42	2.0		3 927	10.18	-6.80
December	1	318.99	2 165										
	16	316.69	2 012										
	M			1 405	3.76	7.72	2.5	10.86	3.0		4 881	13.07	-9.31

HYDROLOGICAL DATA FOR CAHORA BASSA RESERVOIR

January to August 1982

Month	Day	Reservoir water level (m.a.s.l.)	Reservoir surface area (km²)	INFLOW AT ZUMBC		OUTFLOW AT CAHORA BASSA							Δ Volume of reservoir (inflow-outflow) (km³)
						Turbines		Floodgates		Spillgates	Total		
				Mean monthly rate (m³/sec)	Total monthly volume (km³)	Total monthly volume (km³)	Mean No. of turbines operating	Total monthly volume (km³)	Mean No. of flood gates operating	Total monthly volume (km³)	Mean monthly rate (m³/sec)	Total monthly volume (km³)	
January	1	314.36	1 862										
	16	312.97	1 275										
	M			2 365	6.34	0.10	1.0	7.72	2.0		2 921	7.82	-1.48
February	1	313.55	1 811										
	16	314.77	1 887										
	M			4 030	9.75	0.08	1.0	3.65	1.0		1 542	3.73	6.02
March	1	316.70	2 012										
	16	317.30	2 051										
	M			2 082	5.58	0.09	1.0	3.59	1.5		1 373	3.68	1.90
April	1	317.63	2 073										
	16	317.50	2 064										
	M			1 290	3.34	0.09	1.0	4.00	1.0		1 576	4.09	-0.75
May	1	317.27	2 049										
	16	316.99	2 031										
	M			1 207	3.23		2.0	3.39	1.0		1 812	4.85	-1.62
June	1	316.47	1 997										
	16	316.29	1 986										
	M			1 196	3.10	2.06	3.0	2.05	1.0		1 586	4.11	-1.01
July	1	315.96	1 959										
	16	315.45	1 963										
	M			1 222	3.27	2.14	3.0	2.28	1.0		1 651	4.42	-1.15
August	1	315.37	1 925										
	16	315.07	1 906										
	M			1 161	3.11	0.79	2.0	3.49	1.0		1 596	4.28	-1.17

Annex II. (4) Total volume, surface area and mean depth of the Cahora Bassa reservoir at various water levels (Bernacsek and Lopes, 1984).

SURFACE AREAS (km^2) OF CAHORA BASSA RESERVOIR FOR WATER LEVEL:
295.0 to 331 m.a.s.l. (FROM HYDROLOGY DEPT. OF HCB)

Surface area = $0.65738\ (\text{level} - 256.5)^{1.95873}$ as in equation format $y = a\ (x-b)^c$

Level	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
295	838	842	847	851	855	860	864	868	873	877
6	881	886	890	894	899	903	908	912	917	921
7	926	930	934	939	944	948	953	957	962	966
8	971	975	980	985	989	994	998	1 003	1 008	1 012
9	1 017	1 022	1 027	1 031	1 036	1 041	1 045	1 050	1 055	1 060
300	1 065	1 069	1 074	1 079	1 084	1 089	1 094	1 098	1 103	1 108
1	1 113	1 118	1 123	1 128	1 133	1 138	1 143	1 148	1 153	1 158
2	1 163	1 168	1 173	1 178	1 183	1 188	1 193	1 198	1 203	1 208
3	1 213	1 218	1 223	1 229	1 234	1 239	1 244	1 249	1 254	1 260
4	1 265	1 270	1 275	1 280	1 286	1 291	1 296	1 302	1 307	1 312
305	1 317	1 323	1 328	1 333	1 339	1 344	1 350	1 355	1 360	1 366
6	1 371	1 377	1 382	1 387	1 393	1 398	1 404	1 409	1 415	1 420
7	1 426	1 431	1 437	1 443	1 448	1 454	1 459	1 465	1 471	1 476
8	1 482	1 487	1 493	1 499	1 502	1 510	1 516	1 521	1 527	1 533
9	1 539	1 544	1 550	1 556	1 562	1 567	1 573	1 579	1 585	1 591
310	1 597	1 602	1 608	1 614	1 620	1 626	1 632	1 638	1 644	1 650
1	1 656	1 662	1 667	1 673	1 679	1 685	1 691	1 697	1 704	1 710
2	1 716	1 722	1 728	1 734	1 740	1 746	1 752	1 758	1 764	1 771
3	1 777	1 783	1 789	1 795	1 801	1 808	1 814	1 820	1 826	1 833
4	1 839	1 845	1 851	1 858	1 864	1 870	1 877	1 883	1 889	1 896
315	1 902	1 908	1 915	1 921	1 928	1 934	1 940	1 947	1 953	1 960
6	1 966	1 973	1 979	1 986	1 992	1 999	2 005	2 012	2 018	2 025
7	2 031	2 038	2 045	2 051	2 958	2 064	2 071	2 078	2 084	2 091
8	2 098	2 104	2 111	2 118	2 124	2 131	2 138	2 145	2 151	2 158
9	2 165	2 172	2 179	2 165	2 192	2 199	2 206	2 213	2 220	2 227
320	2 233	2 240	2 247	2 254	2 261	2 268	2 275	2 282	2 289	2 296
1	2 303	2 310	2 317	2 324	2 331	2 338	2 345	2 352	2 359	2 366
2	2 373	2 380	2 387	2 395	2 402	2 409	2 416	2 423	2 430	2 438
3	2 445	2 452	2 459	2 466	2 474	2 481	2 488	2 495	2 503	2 510
4	2 517	2 525	2 532	2 539	2 547	2 554	2 561	2 569	2 576	2 583
325	2 591	2 598	2 606	2 613	2 621	2 628	2 635	2 643	2 650	2 658
6	2 665	2 673	2 680	2 688	2 696	2 703	2 711	2 718	2 726	2 733
7	2 741	2 749	2 756	2 764	2 772	2 779	2 787	2 795	2 802	2 810
8	2 818	2 825	2 833	2 841	2 849	2 856	2 864	2 872	2 880	2 888
9	2 895	2 903	2 911	2 919	2 917	2 935	2 943	2 950	2 958	2 966
330	2 974	2 982	2 990	2 998	3 006	3 014	3 022	3 030	3 032	3 046
1	3 054									

TOTAL VOLUME (DEAD PLUS LIVE STORAGE), SURFACE AREA AND MEAN DEPTH OF CAHORA BASSA RESERVOIR AT VARIOUS WATER LEVELS. DEAD STORAGE VOLUME IS 4 000 km^3 AT 295.00 m.a.s.l.

Water level (m.a.s.l.)	Total volume (km^3)	Surface area (km^2)	Mean depth (m)	Water level (m.a.s.l.)	Total volume (km^3)	Surface area (km^2)	Mean depth (m)
295.00	4 000*	838	4.77	314.00	28 500	1 839	15.50
296.00	4 865*	881	5.52	315.00	30 500	1 902	16.04
297.00	5 875	926	6.34	316.00	32 640*	1 966	16.60
298.00	6 875	971	7.08	317.00	34 250	2 031	16.86
299.00	7 875	1 071	7.35	318.00	36 250	2 098	17.28
300.00	8 750	1 065	8.22	319.00	38 000	2 165	17.55
301.00	9 840*	1 113	8.84	320.00	40 000	2 233	17.91
302.00	10 875	1 163	9.35	321.00	43 320*	2 303	18.81
303.00	12 000	1 213	9.89	322.00	44 750	2 373	18.86
304.00	13 125	1 265	10.38	323.00	47 125	2 445	19.27
305.00	14 375	1 317	10.91	324.00	49 500	2 517	19.67
306.00	16 060*	1 371	11.71	325.00	52 500	2 591	20.26
307.00	17 250	1 426	12.10	326.00	55 750*	2 665	20.92
308.00	18 750	1 482	12.65	327.00	59 000	2 741	21.52
309.00	20 250	1 539	13.16	328.00	61 500	2 818	21.82
310.00	21 750	1 597	13.62	329.00	64 250	2 895	22.19
311.00	23 640*	1 656	14.28	330.00	67 000	2 974	22.53
312.00	25 250	1 716	14.71	330.50	68 000	3 014	22.56
313.00	26 875	1 777	15.12	331.00	70 010*	3 054	22.92