FLOW RÉGIME CHANGES IN NAMIBIAN RIVERS: PATTERNS, EFFECTS AND POSSIBLE CAUSES

G Van Langenhove, B de Bruine, L Rukira, A Hatutale
Department of Water Affairs, Ministry of Agriculture, Water and Rural Development, Republic of Namibia

INTRODUCTION

Both in Nambia's ephemeral rivers in the interior and in the perennial rivers on its northern border, low flow conditions have prevailed since the beginning of the eighties. This was initially attributed to temporary conditions of low rainfall, but there has been no return to the higher flows that occurred before, also not during later periods with above average rainfall.

Because of the adverse effect on the country's water resources, investigations were carried out to assess the possible causes of the changes and to forecast the future trends in the hydrological régimes of Namibia's river systems [1].

RUNOFF RESPONSE IN NAMIBIA'S NORTHERN BORDER RIVERS

General

Almost all flow in the rivers on Namibia's northern borders originates in the upper catchments in Angola and Zambia (**Figure 1**). The rainfall pattern for these areas is highly seasonal, with a wet summer and a dry winter, like in the interior of Namibia. The total precipitation, however, is higher, more reliable and better distributed over the whole rainy season. The physical nature of the terrain is such that the river flow is, to a varying degree, not only dependent on a direct surface response, but also includes a strong delayed surface runoff component, due to major storage in the swamps and flood plains in the upper and middle parts of the drainage systems.

Okavango River

The Okavango River, of which the basin response characteristics are best known and understood, has a marked seasonal régime with a bi-modal flood distribution and a reliable minimum flow at the Botswanan border (**Figure 2**). The river starts to rise in November, first slowly as a result of local or nearby rainfall, and later more quickly as direct runoff in the Cubango tributary to reach a first peak during February/March. Flood plains and swamps delay and attenuate the concurrent flood in the Cuito tributary, which reaches the confluence later, contributing to the second and often highest peak in the Okavango River during late April. The two sub-basins contribute equally to the total annual flow, but their different nature results in the Cuito River sustaining most of the minimum flow in the Okavango River, which has never been below 80 m^3/s since monitoring started in the forties.

Kunene, Zambezi and Kwando rivers

The Kunene River to the west and the Kwando and Zambezi rivers to the east show similar hydrographs, often also with a bi-modal flood distribution, but with different flood attenuation and delays, and the patterns are more variable here. The associated physical features are the wide flood plains between Rocadas and Calueque on the Kunene River in Angola and the Barotse plains on the Zambezi River in Zambia respectively. The minimum flow in the Kunene is low and highly variable, indicating that there is no real base flow, while, before the 1995 dry season, at the Namibian border the Zambezi River appeared to have a minimum flow of 200 m^3/s, which probably includes both base flow and delayed runoff components.

Inter-seasonal effects

Because of basin storage, there is a positive inter-seasonal relation between the annual flows in all these rivers, with years with high and low floods more likely to be grouped. Because of the influence of extensive flood plains, the highest lag-one serial correlation coefficient (r = 0.51) is found for the Zambezi River.

FLOW RÉGIME CHANGES SINCE THE BEGINNING OF THE EIGHTIES

Liambezi Lake

The Liambezi Lake is at the lowest point and the centre of the drainage system of the Eastern Caprivi in the extreme north east of Namibia (**Figure 1**). During the sixties and seventies it regularly received water from the seasonal floods in the Zambezi River, either by direct overflow from the north through the Eastern Caprivi or by backwater from the confluence with the Chobe River, and/or in the Kwando River through the Linyanti Swamps. Although the Lake had been reported to be dry some time before 1950, it was considered to be perennial, and served as an important fishing source for the local population.

Since 1982, however, no further floods from any side reached the Lake, which as a result had dried completely out in 1985. Only in 1989 a backwater through the Chobe River carried some water and formed a small pool for a few months. The magnitude of this type of event used to be normal in the sixties and seventies.

Kwando River

Also since 1982, no significant annual floods came down in the Kwando River. The flow only showed slow oscillations between a fairly steady minimum flow of 20 m^3/s and a maximum not exceeding 30 m^3/s, less than half of the annual peaks observed before, and during 1995 the river even fell to 11 m^3/s, by far the lowest ever since monitoring started in the sixties. Initially flow was maintained in the main channels of the Kwando River along the border between Namibia and Botswana and in the upper parts of the Linyanti Swamps. Later however, channel blockages caused by accumulation of débris and vegetation developed, and at the moment most of the previous wetlands in the two countries are completely dry, with little or no prospect of returning to their previous state. Expensive emergency water supply by tanker services has become necessary to supply drinking water to the local communities, that relied on the wetlands in the area.

Zambezi, Okavango and Kunene rivers

Similar low flow events reflecting the much lower river flows were observed in the other northern border rivers.

The Zambezi River used to inundate its flood plains in the eastern half of the Eastern Caprivi almost every year before 1982, but only two or three times since then. The ratio of the average annual flows after and before 1982 is less than 0.55. During 1995 and 1996, the lowest minimum flows, since monitoring started at Katima Mulilo in the sixties, were observed, 190 and 140 m^3/s respectively. Historic low flows have also been recorded in the Okavango River during the last decade, and the Kunene River receded to near-to-zero flows several times. The low flows have brought about water supply problems, because of the low river levels in general, and a significant reduction in hydro-power generation on the Kunene River, and there has definitely been an effect on the important wetlands and eco-systems in the Eastern Caprivi and the Okavango Swamps.

RUNOFF RESPONSE IN THE RIVERS IN THE INTERIOR OF NAMIBIA

General

All rivers in the interior of Namibia are ephemeral and flow mainly or only as a direct surface runoff response during a few heavy thunder showers in the rainy season. There is little or no delayed surface or subsurface runoff and definitely no base flow, the main reasons being the erratic rainfall pattern, the high river bed losses and the physical features of many catchments, which are often characterized by impermeable surfaces, little or no top soils, the absence of vegetation and the hilly or mountainous terrain. The resulting "flash floods" run over dry river beds, and can rise two or three metres in less than thirty minutes and then recede to zero within a few hours.

Inter-seasonal effects

There is a high variability in flows, both within and between seasons, with the coefficient of variation exceeding values of 1 to 3. Unlike most other river systems throughout the world, including Namibia's northern border rivers, most flow records for the rivers in the interior give evidence of a negative inter-seasonal relation between the annual flows. The only reason that has been identified would be a vegetation persistence. Good rainy seasons result in a better vegetation cover, which increases the interception and thereby reduces the runoff potential during the next rainy season(s). Poor rainy seasons leave little vegetation, which has the opposite effect of a higher runoff potential.

FLOW RÉGIME CHANGES SINCE THE END OF THE SEVENTIES

Although the high variability and the often short length of record tend to hide such differences, most flow series show a decline in flows since the end of the seventies (**Figure 3**). For instance, the ratio of the average annual inflows into the Hardap Dam on the Fish River, which is by far the strongest river in the interior of Namibia, after and before the 1977/78 rainy season is less than 0.25. Other evidence is that the Kuiseb River has not reached the Atlantic Ocean since the sixties, which used to happen on average every third or fourth year before.

The impact on the surface water sources in the interior of the country has been adverse. Since 1980, water restrictions, augmentation by other sources and/or the implementation of emergency water supply schemes had to be resorted to several times for economically important consumers, such as the capital city of Windhoek and the country's largest irrigation scheme at the Hardap Dam.

The similarity with the trends in the northern border rivers is striking, and the fact that the drastic decrease in flows appears to have started a few years later for the latter may be another effect of the observed basin storage.

TRENDS IN HYDROLOGICAL SERIES

Systematic changes

All hydrological series display short-term random variations, but three different types of long-term changes may also be present:

- ◊ *Periodic cycles* with a fairly constant period and magnitude, caused by similar conditions affecting the precipitation patterns, and often associated with sun spots.
- ◊ *Gradual trends* caused by longer-term physical changes which may also be climatic, for instance the alleged global warming, or due to changes in vegetation or land use patterns.
- ◊ *Sudden breaks*, due to abrupt physical changes in the runoff pattern, which may have natural causes, such as tectonic movements, or may be caused by human intervention, as in the case of the construction of major impoundments.

Analysis of hydrological time series

Three of the many possible analysis methods are:

- ◊ Calculation of *serial correlation* coefficients for a range of lag periods, which is a simplified way of harmonic or spectral analysis, to detect cycles.
- ◊ *Regression analysis* of linear or more complex type to determine trends.
- ◊ Graphical or numerical *double mass curve techniques* to identify breaks.

The study of time series is often complicated by one or more of the following factors:

- ◊ The presence of random variations of the same of a greater magnitude than the effect of systematic changes.
- ◊ The shortness of the record length in comparison with the time scale of especially cycles.

◊ The possible occurrence of various changes in combination.

INVESTIGATION OF NAMIBIAN HYDROLOGICAL SERIES

The two longest available records that were investigated are:

◊ The annual Windhoek precipitations, 104 hydrological years from 1891/92 to 1994/95 (**Figure 4**)

◊ The annual Zambezi River flows for the Zambian station at Victoria Falls, 88 hydrological years from 1907/08 to 1994/95 (**Figure 5**).

Analysis of Windhoek precipitation record

The average and standard deviations of the annual precipitations are 363.0 and 144.8 mm respectively. The following inferences can be made from statistical analysis:

◊ The highest serial correlation coefficients are -0.269 (negative) and 0.260 (positive) for lags of 7 and 16 years respectively. This would indicate a very weak periodicity of approximately 15 years, which would explain less than 7 % of the annual variation.

◊ A linear trend would give correlation coefficients of -0.07 and -0.25 for the whole period and the last 33 years respectively, with a similarly low statistical weight.

◊ The average precipitation over the last 15 years has only been 306.7 mm, which is lower than the average precipitation over selected other periods, for instance the preceding 18 years with an average of 406.0 mm. Selected periods with similar low averages, however, can be found, for instance the 10 years from 1923/24 to 1932/33 with an average of 285.8 mm.

These differences have little statistical significance, and, as there is also no physical explanation, they must be attributed to random variations or statistical coincidence. Yet the two last points indicate that the annual precipitations have on average been lower during the most recent years.

Analysis of Victoria Falls flow record

The averages and the standard deviations of the annual flows are 33 600 and 12 700 Mm^3 respectively. The following inferences can be made from statistical analysis:

◊ The highest correlation coefficients are 0.509 (positive) and -0.017 (negative) for lags of 1 and 15 years respectively. The high first value confirms the inter-seasonal correlation because of basin storage, while the very low second value confirms the total absence of periodic cycles.

◊ A linear trend would give a positive correlation coefficient of 0.26 for the whole period, which is in contradiction with the concept of decreasing flows, and which has little statistical significance. A more meaningful split of the record can be made at the beginning of the sixties, giving much higher and more conclusive correlation coefficients of 0.67 and -0.56 for the two successive periods.

◊ The average flow over the last 15 years has only been 24 100 Mm^3/a, which is much lower than the average flow over the previous periods, for instance the preceding 34 years with an average of 43 900 Mm^3/a (**Figure 4**). The difference has a statistical significance of 85 %, which cannot be ignored. It is of interest to observe that the first 17 years of the record had an average flow of 23 800 Mm^3/a, which is very comparable to the recent period.

DISCUSSION AND CONCLUSION

The patterns for the other rivers on the border and in the interior of Namibia also show lower average flow magnitudes over the past 15 to 20 years. To extrapolate with confidence the apparent trend, additional physical evidence would be desirable.

The most obvious reason would be a change in general climatic conditions and the associated modified precipitation. Evidence from Namibian rainfall records, however, is not conclusive (**Figure 5**), and information on rainfall in the catchments of the border rivers is very scarce. It is of interest to note that a similar uncertainty exists for the rainfall patterns in the Sahel zone, where a sudden decline has allegedly occurred since 1968 [2].

There is no other substantiated explanation for the observed variations in river flow régime. A recent speculation has been the possible change of land use and vegetation, which could have been different causes:

◊ In the upper catchments of the border rivers, there could have been intensified agricultural development, from which less dense vegetation and runoff interception would result, during the 30 or 40 years before the start of armed conflicts in that area.

◊ In the interior of Namibia, there may have been serious overgrazing, with similar result, during the same period, before the development of more sound farming practices and the proliferation of medium size dams in the catchments.

A reliable extrapolation of the observed trend is not possible, but the discussed flow record for Victoria Falls indicate that similar periods of low flows have occurred in the past, and that the present situation is not exceptional and may continue for an indefinite period.

ACKNOWLEGEMENTS

The kind willingness of the Zambian Department of Water Affairs to make the Victoria Falls flow data available, as well as the permission and support of the Namibian Department of Water Affairs to prepare and present this paper are appreciated.

REFERENCES

(1) Mostert A C, Van Langenhove G. Preliminary assessment of the Linyanti River. Internal report 11/6/3/1, Department of Water Affairs, Windhoek, August 1994.

(2) Demarée G R. An indication of climatic change as seen from the rainfall data of a Mauritanian station. Theor. Appl. Climatol. 42, 1990, pp 139-147.

FIGURE 1 : NAMIBIA'S NORTHERN BORDER RIVERS

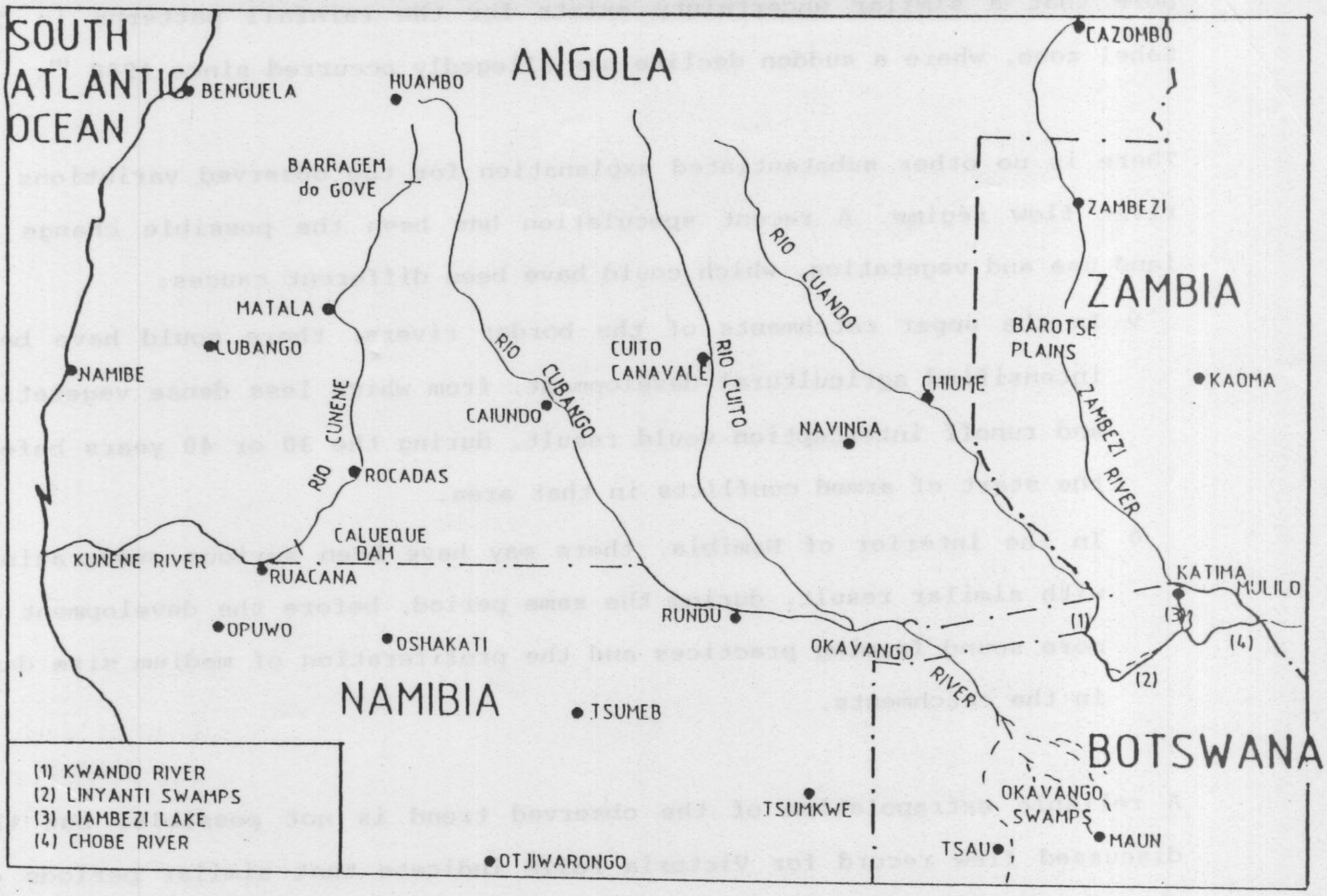

FIGURE 2 : TYPICAL OKAVANGO FLOW HYDROGRAPH

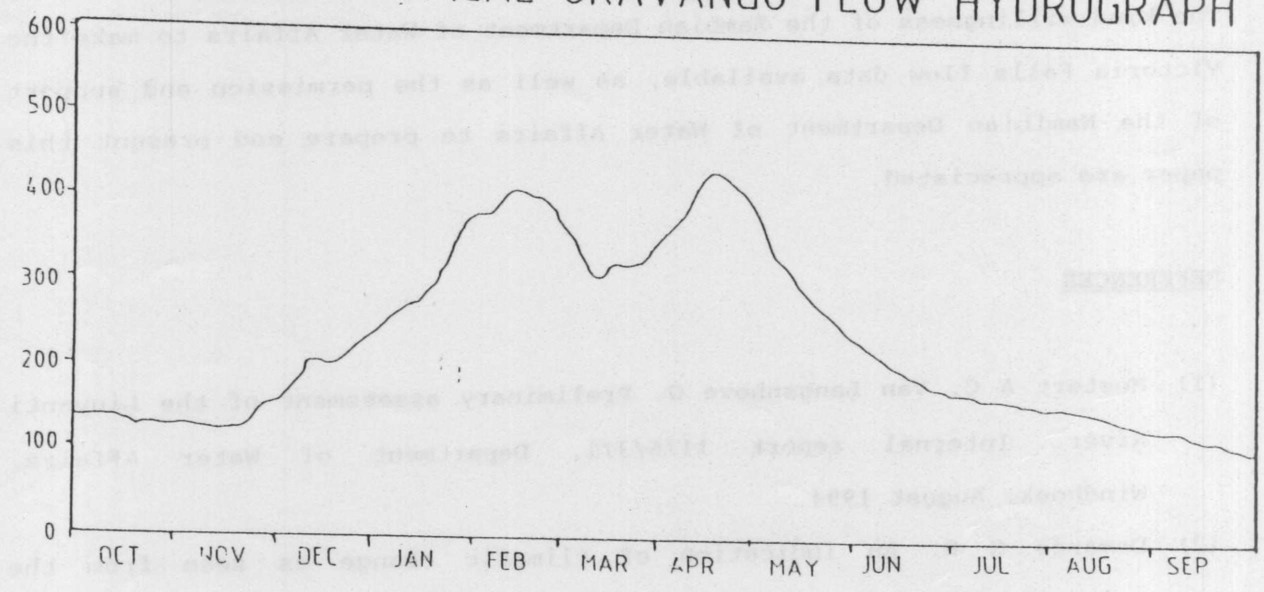

FIGURE 3: ANNUAL INFLOWS FOR HARDAP DAM

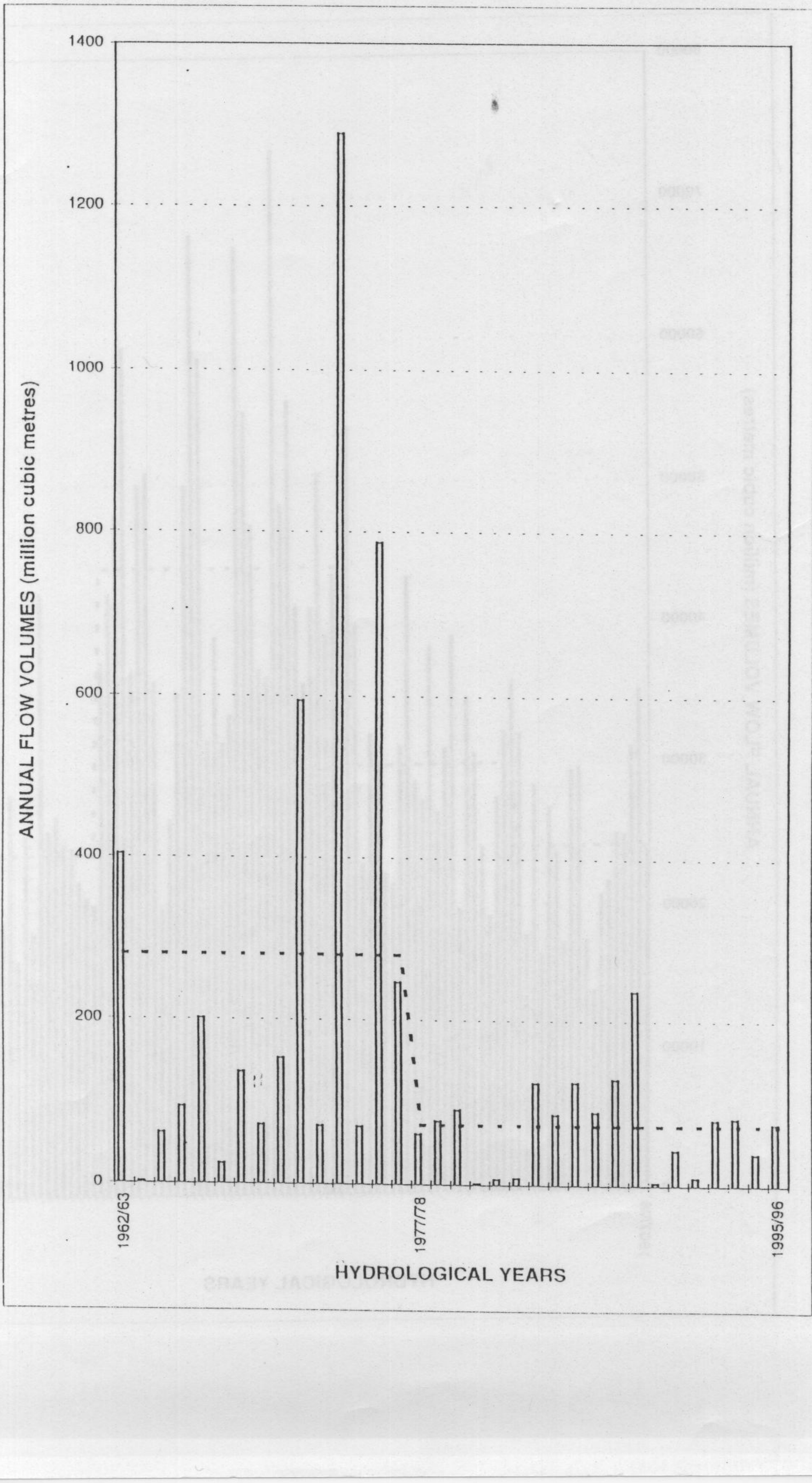

FIGURE 4: ANNUAL FLOWS FOR VICTORIA FALLS