

Cahora Bassa retrospective, 1974–1997: effects of flow regulation on the Lower Zambezi River

Bryan R. Davies, Richard D. Beilfuss and Martin C. Thoms

Introduction

The Zambezi River (Fig. 1) (24–38° E, 12–20° S) is the fourth largest floodplain river in Africa (2,574 km) and the largest system flowing into the Indian Ocean (BALEK 1977, DAVIES 1986). Rising in Angola it has a catchment area of 1,570,000 km², drains the southern borders of the Democratic Republic of Congo (DRC) and traverses Botswana, Zambia, Zimbabwe, Tanzania, Malawi and Moçambique (WELCOMME 1972). The lower river enters the sea through a mosaic of alluvial grassland and swamp forest (the Marromeu Complex) some 100 km inland from the coast, and a mangrove-deltaic system with a sea frontage of about 290 km (e.g. TINLEY & SOUSA DIAS 1973). An extensive review of the basin can be found in DAVIES (1986). The river comprises three segments: *Upper* (1,078 km), from

sources to the Victoria Falls; *Middle* (853 km), between the Victoria Falls and Cahora Bassa Gorge; and *Lower* (593 km) from Cahora Bassa to the sea (e.g. DAVIES 1986).

The Lower Zambezi is a complex physical system with four macro-scale river–floodplain zones (Fig. 2) comprising narrow gorges, mobile sand-braided reaches, an anabranching, and a coastal distributary zone. The complexity is due to variations in regional geomorphology producing a series of distinct valley–floor–trough, river–floodplain associations. In the uplifted mountainous areas below Cahora Bassa and Tete, the channel is confined to a 500 m-wide narrow valley with relatively high gradients. Boulder and bedrock outcrops and high stream energies dominate the instream environment of the gorge zones. Downstream of these zones the val-

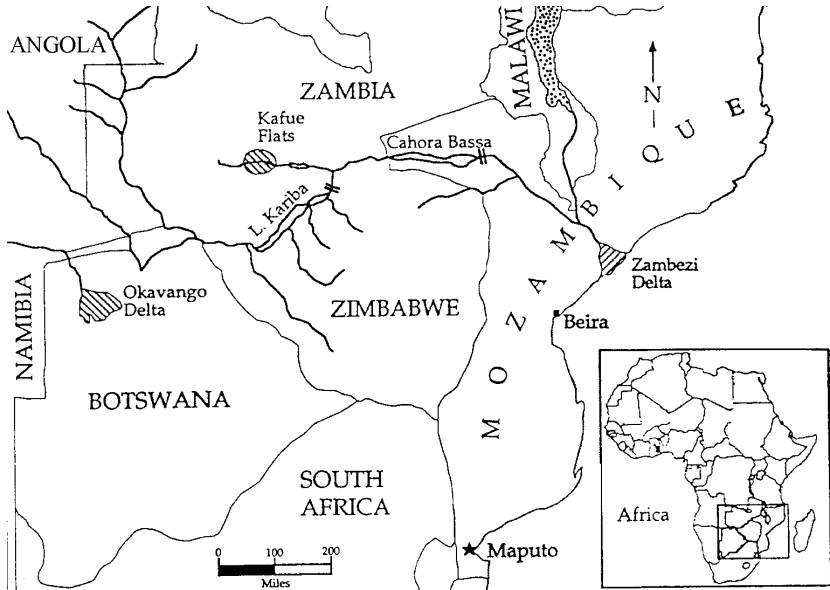


Fig. 1. The Zambezi River from its headwaters to its delta in Moçambique.

ley–floor–trough broadens to several kilometres. Because gradients are still relatively high and boundary sediments (mostly fine gravel and sand) are highly mobile, a braided sand-bed river dominates. This zone is further characterised by extremely high sediment fluxes. With further increases in the width of the valley–floor–trough and a decrease in river channel energies, large floodplains are constructed. A series of anabranch channels flow through the upstream section of these floodplains. With progressive reduction in bed gradients, the anabranches give way to a distributary channel network. In the coastal distributary zone, floodplain widths can reach several hundred kilometres.

JACKSON (e.g. 1986) describes the Zambezi as a 'sandbank' river with pronounced flood (January–April) and dry season (June–October) flows. The characteristic flood of the Middle Zambezi comprises a double peak in February and April. His-

torically, Lower Zambezi flows have occasionally exceeded $22,000 \text{ m}^2 \text{ s}^{-1}$, with average floods ranging between $8,000$ and $14,000 \text{ m}^3 \text{ s}^{-1}$ (e.g. DAVIES 1998).

Prior to river regulation, agriculture in the Lower Zambezi centred on floodplain recession practices in response to annual flood cycles: planting in April and harvesting prior to the main flood. In this context, Cahora Bassa, as the lowest dam on the river (Fig. 3), is the key both to the maintenance of ecological processes and to the social practices of the Lower Zambezi Valley and in this paper we concentrate on its effects on the lower river.

Cahora Bassa Dam: pre-impoundment studies

Since the 1950s, the Zambezi has, like many other African rivers, been subjected to serial hydro-power and water-supply impound-

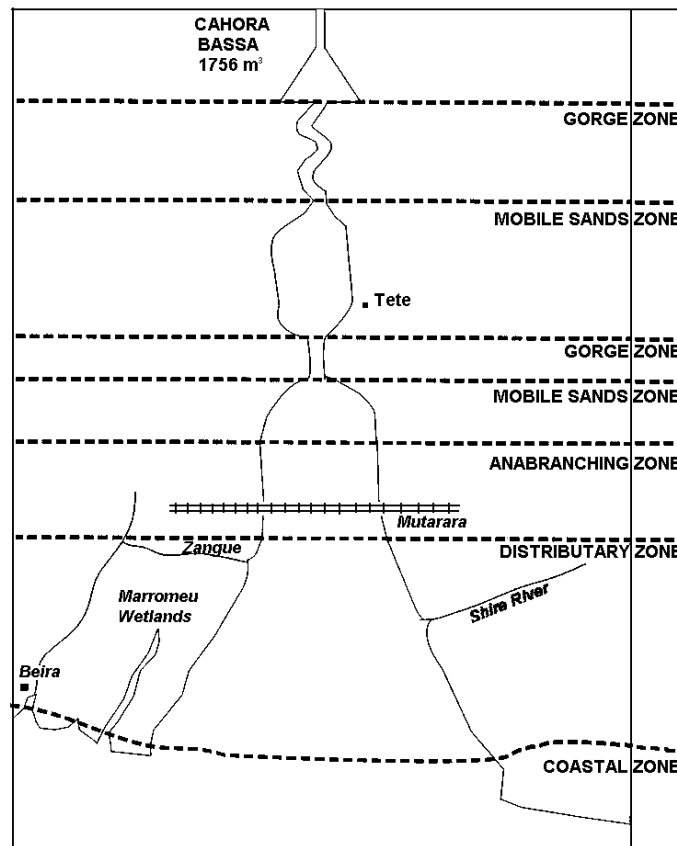


Fig. 2. Schematic river zonation of the Lower Zambezi.

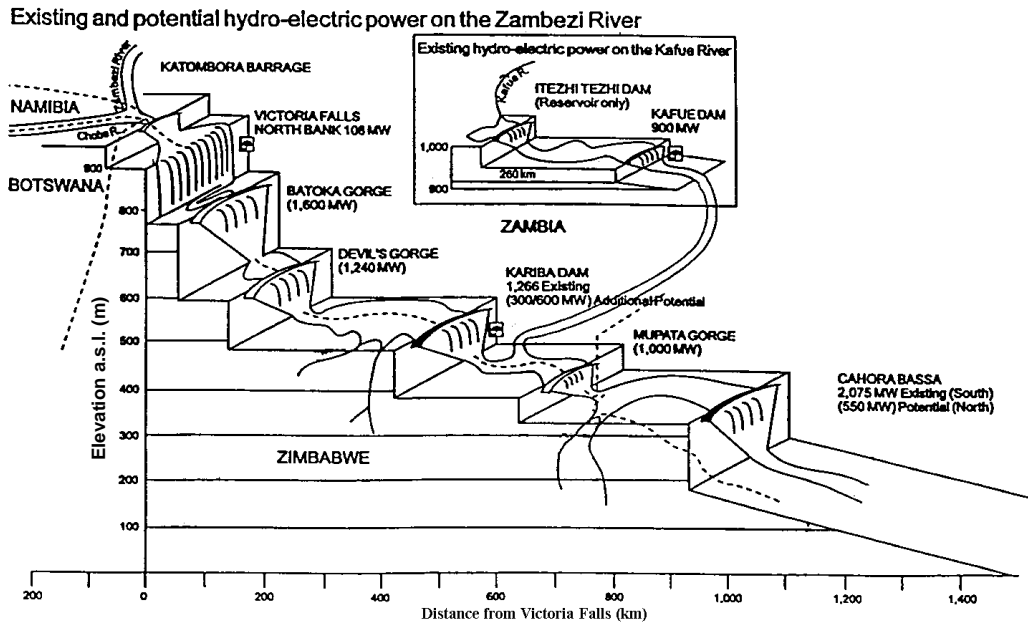


Fig. 3. Schematic diagram of the reservoirs and potential power hydro-power production of the Zambezi Basin (after CHONGUIÇA 1997).

ments. Kariba, the third largest storage area in the world (area, 5,364 km²; volume, 180.6 × 10⁹ m³) produces 1,266 MW (McCULLY 1996), while Kafue Gorge Dam in Zambia produces 900 MW (four additional power plants are being considered; Fig. 3). These structures have greatly curtailed flows into the Cahora Bassa Gorge, with a declining trend evident since 1975 (Fig. 4).

The twelfth largest storage area in the world (volume, 63 × 10⁹ m³; area, 2,739 km²), the 171 m high Cahora Bassa Dam was completed in 1974. Power (2,040 MW) is delivered through five turbines, while eight sluice gates set at 111 m in the wall can discharge 1650 m³ s⁻¹ (OLIVIER 1970) of hypolimnetic water.

Between December 1973 and October 1974 the Lower Zambezi was surveyed seven times at thirteen sites from the Zimbabwe border to the coast at Chinde in order to assess the potential effects of Cahora Bassa on the already regulated Lower Zambezi (Lake Chiveru, Zimbabwe, 1952, Kariba, Zimbabwe/Zambia, 1958, Kafue Gorge, Zambia, 1970). The results and recom-

mendations from these studies are reported in DAVIES (1975, 1979, 1986), DAVIES et al. (1975), HALL & DAVIES (1974) and HALL et al. (1976, 1977). No post-impoundment work on the river has taken place since then.

The pre-impoundment studies of the Lower Zambezi are summarised below.

1. The Shire River (Malawi) is the only significant tributary for the total flow of the Lower Zambezi; 8% contribution.
2. No compensation flows were planned during reservoir filling (flood season of 1974–75).
3. Management had no concern for flood-related agriculture, wetland and deltaic maintenance, or fisheries of the system.
4. No cognisance was taken of the invasive plants already in the system: *Eichhornia crassipes* (water hyacinth); *Salvinia molester* (Kariba weed); *Pistia stratiotes* (Nile cabbage); *Azolla filiculoides* (water fern).

Recommendations included:

1. Reservoir filling over a minimum of 2 years.

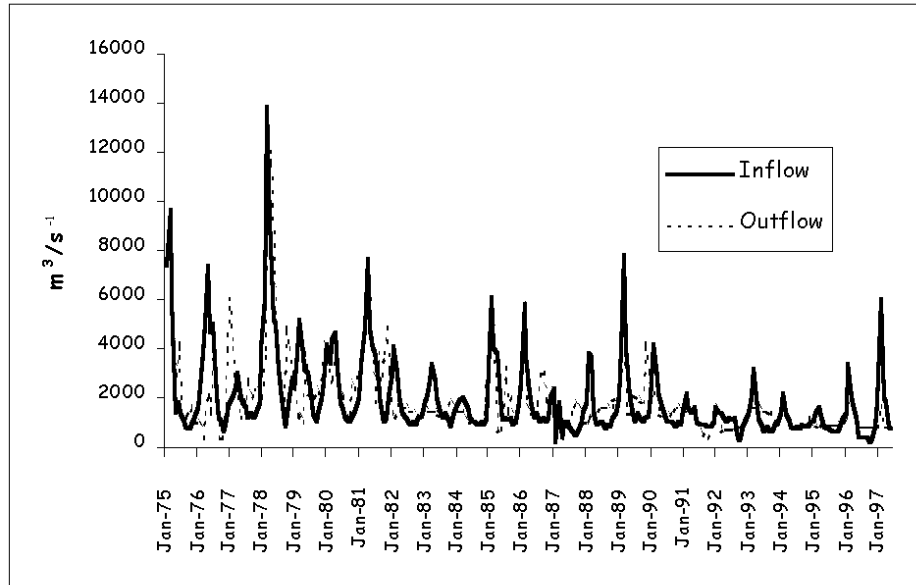


Fig. 4. Inflow to (continuous) and outflow from (broken) Lake Cahora Bassa between 1975 and 1997 (data derived from Hidroelectrica da Cahora Bassa, 1997).

2. Minimum compensation flow of $450 \text{ m}^2 \text{ s}^{-1}$ during filling (this comprised only 10% of the average annual flow) with releases to match seasonal cycles.
3. Filling from March 1975, to avoid loss of the flood.

Predictions about future ecological changes that would occur should the recommendations be ignored were also made:

1. A rapid decline in coastal fisheries and shrimp industry, and artisanal river fisheries; the first two due to loss of silt and associated nutrients, the last to reduction of wetland flooding, loss of recruitment and exposure to main-channel predators.
2. Loss of mangroves and coastal erosion through flood reduction and silt loss (coastal erosion was evident during aerial surveys conducted on January 16, 1974; these were attributed to the effects of Kariba over 16 years).
3. Up to 70% reduction in sediment transport during floods, coupled to lack of scour and

upstream penetration of the estuarine salt wedge.

4. Changes in riparian and wetland vegetation structure consistent with classically regulated rivers (e.g. WARD & STANFORD 1979), and concomitant decline of large mammal and bird populations on the Marromeu Wetlands (e.g. REES 1978).
5. Spread of human disease vectors due to increased habitat (pools, lack of flushing).
6. Invasion of wetlands by alien aquatic plants.

Flow curtailment in the Lower Zambezi Valley

Lake Cahora Bassa commenced filling on December 5, 1974. It was rapidly filled in a single flood season (1974–1975) without compensation flows ($60 \text{ m}^3 \text{ day}^{-1}$ reached the river as leakage). By March 1975, an emergency flood release discharged 1.27 billion m^3 over 5 days to prevent overtopping the still incomplete wall. A discharge of $14,753 \text{ m}^3 \text{ s}^{-1}$ was achieved with a combination of eight sluice gates and emergency spillways (HUGHES & HUGHES 1992) and

flows exceeded $20,000 \text{ m}^3 \text{ s}^{-1}$ (SUSCHKA & NAPICA 1990). Ironically, this probably released a major nutrient pulse to the river, whilst stranding a large biomass of *Eichhornia* and *Salvinia*. Since 1975 two small floods have occurred: 1978, ca. $14,000 \text{ m}^3 \text{ s}^{-1}$; 1997, $16,000 \text{ m}^3 \text{ s}^{-1}$, with three additional events less than $8,000 \text{ m}^3 \text{ s}^{-1}$. There have been no unregulated spills from the dam since its closure.

Interestingly, owing to a variety of factors including Mozambique's 18-year-long civil war, the turbines have never produced full capacity and during June 1996, only 15 MW were being produced while releases from the dam were constant at $758 \text{ m}^3 \text{ s}^{-1}$.

Aerial surveys, conducted during June 1996, indicated dramatic changes in the morphology of the river–floodplain system. Morphological responses to flow regulation and the subsequent reductions in sediment loads and flows varied in the different river–floodplain zones (Fig. 5). For example, due to enhanced flow capacities in the gorges, the majority of the river channel bars had eroded. The loss of these temporary sediment storage areas resulted in a 'canal' like system with marked reduction of in-channel habitat (Fig. 5a). Whereas, in the anabranch zone, marked reductions in the magnitude and frequency of floodplain inundation have caused dominance of one main channel, whereas previously there were several active channels (Fig. 5b). Many secondary channels have become isolated from the main channel through silting of entrance points.

It is clear that many of the predictions of the original study team were correct. Particularly in the Marromeu Complex, where upstream sectors had experienced widespread encroachment by woody savanna onto the herbaceous floodplain. Meander trains and oxbows were choked, while invasion by the alien plants, *Azolla* and *Eichhornia* at least was clear. Bird and mammal life was virtually non-existent compared to the 1970s – the once enormous populations of Cape buffalo, *Syncerus cater* (over 70,000 head) had virtually disappeared. However, although altered flooding and sediment depletion could be cited for the loss of ungulates, desiccation of the region (enhanced human access), the civil

war, and poaching are more likely causes.

Connectivity of wetlands to the main channel had been disrupted with severe consequences for local artisanal fisheries and avifauna, and only one of the main channels of the Zambezi had relatively newly recruited and healthy mangrove. Aerial surveys indicated a 40% loss of mangrove (P. DUTTON, Natural Environment Consultant, Beira, personal communication), while coastal erosion was obvious. HOGUANE (1997) reported that prawn catch rates have declined by 60% between 1978 and 1995, which drop is directly correlated to falling runoff to the offshore Sofala Bank from the Zambezi.

The constancy of flow imposed by Cahora Bassa Dam can be summarised as little short of catastrophic. The dam has operated for two decades as a permanent discontinuity in the river continuum (sensu WARD & STANFORD 1983), transforming a flood-pulse driven river ecosystem, floodplain, and coastal zone, into a series of confined channels. Annual cycles of wetland/floodplain connectivity and flood pulses (sensu JUNK et al. 1989) have been broken, as have sediment and nutrient replenishment regimes.

Rehabilitation

Variability is a key component of healthy riverine ecosystems. Flow regulation has radically reduced the spatial and temporal dynamics of the river. Whilst one may not be able to rehabilitate the entire river to its original 'pre-regulated state', the condition of several key ecological functions would be improved with prescribed flood events. Releases of water from the dam to ensure significant floodplain inundation would ensure the reinstatement of some ecological functioning (e.g. BEILFUSS & DAVIES 1998).

Rehabilitation techniques are available (e.g. GORE & PETTS 1989), but most of them, developed outside southern Africa, require highly technical approaches and are expensive with regard to trained personnel (see e.g. KING & THARME 1994). The result has been the development of a holistic ecosystems approach to environmental water allocations. Here, ideal flood and low flows, seasonal patterns of sedi-

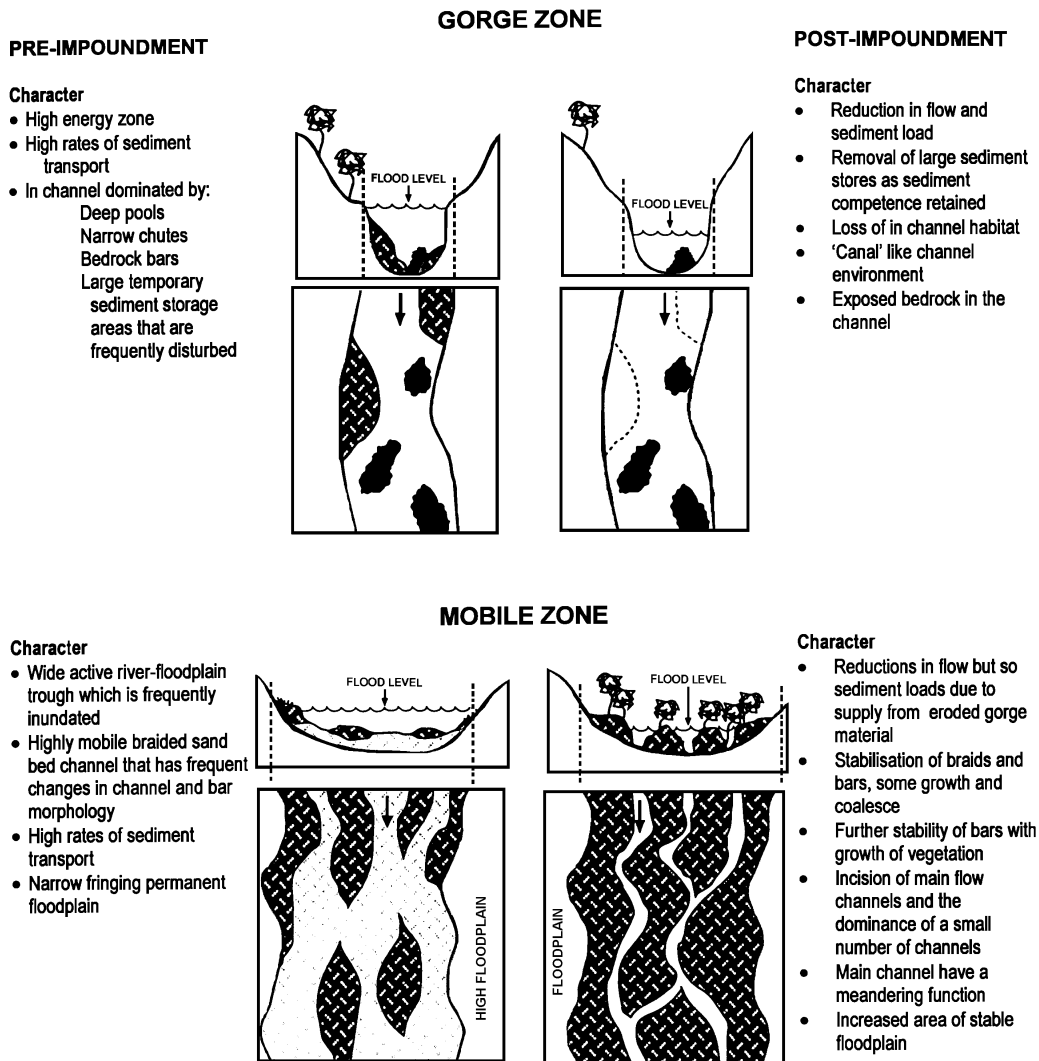


Fig. 5a. Geomorphological changes in the Lower Zambezi Valley wrought flow curtailment from Cahora Bassa Dam: the gorge and mobile zones.

ment transport, desired water quality states, and minimum requirements for fish-spawning cues can be generated for a particular river or river zone in relation to an identified water project using system- and site-specific knowledge, and the best available expert opinion.

In a rule-of-thumb approach, WILSON (1997) calculated that some 49 km³ are available annually from Lake Cahora Bassa without loss of power production. Further, with correct intra-

annual variability, a drop in present dry season flows from the reservoir by 3 km³ month⁻¹ could stimulate prawn production by some \$30 million year⁻¹ (HOGUANE 1997). Such flow variations would have to be coupled to an exhaustive social programme, for the newly formed islands and stabilised margins of the lower river now have large human populations (T. SCUDDER, Caltech, personal communication).

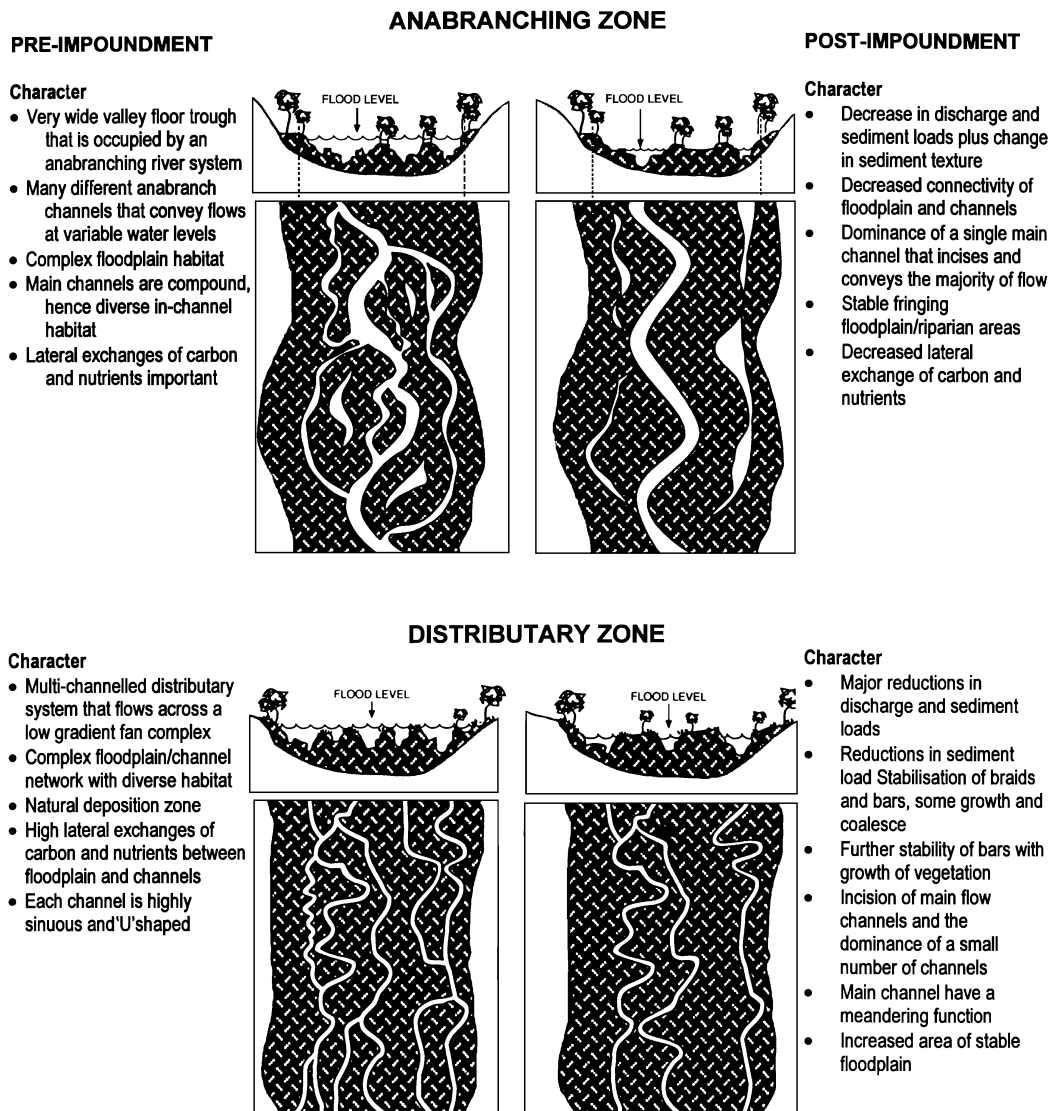


Fig. 5b. Geomorphological changes in the Lower Zambezi Valley wrought flow curtailment from Cahora Bassa Dam: anabranching and distributary zones.

The name Cahora Bassa is derived from Sena “a caho” – finished/are done – “ma bassa” work/service – and stems from workers who ferried goods and people the nearly 600 km to Cahora Bassa rapids from the Indian Ocean. Perhaps the work is now just beginning: “N’yatoma bassa” – work begins.

Acknowledgements

The first two authors would like to acknowledge the support of KEN WILSON of the Ford Foundation, Johannesburg, LUIS COVANE of Arquivos do Patrimonial Cultural, Maputo, and friends and colleagues who attended the Songo Workshop on the Sustainable Utilisation of the Cahora Bassa Dam and the

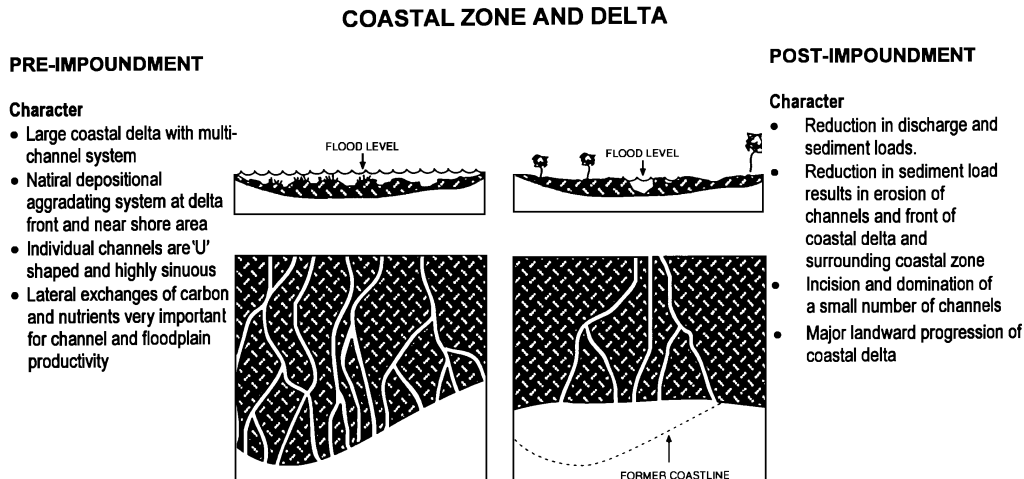


Fig. 5c. Geomorphological changes in the Lower Zambezi Valley wrought flow curtailment from Cahora Bassa Dam: the coastal zone and delta.

Valley of the Lower Zambezi. Funding for the aerial surveys was provided by the Foundation for Wildlife Conservation and Fondation Tour du Valat. HOWARD WALKER of Dulstroom is warmly thanked for his hospitality, philanthropy and precision flying.

References

- BALEK, 1977: *Hydrology and Water Resources in Tropical Africa. Developments in Water Science*, 8. – Elsevier Amsterdam, 208 pp.
- BEILFUSS, R. D. & DAVIES, B. R., 1998: Prescribed flooding and Wetland Rehabilitation in the Zambezi Delta, Mozambique. – In: STREEVER, W. (ed.): *International Perspectives on Wetland Rehabilitation*. – Kluwer Publ., Dordrecht.
- CHONGUIÇA, E., 1998: Uma abordagem sistémica para a gestão integrada de bacias hidrográficas (enfoque hidrogeomorfológico). – Paper to the *Workshop on The Sustainable Utilisation of the Cahora Bassa Dam and the Valley of the Lower Zambezi, Songo, 29 September–October 2, 1997*, 14 pp.
- DAVIES, B. R., 1975: Cahora Bassa hazards. – *Nature Lond.* 254: 477–478.
- DAVIES, B. R., 1979: Stream regulation in Africa: A Review. – In: WARD, J. V. & STANFORD, J. A. (eds): *The Ecology of Regulated Streams* 113–142. – Plenum Press, New York, 398 pp.
- DAVIES, B. R., 1986: The Zambezi River System. – In: DAVIES, B. R. & WALKER, K. F. (eds): *The Ecology of River Systems. Monogr. Biol.* 60: 225–267. – Dr. W. Junk, Dordrecht.
- DAVIES, B. R. (ed.), 1998: *The Sustainable Utilisation of the Cahora Bassa Dam and the Valley of the Lower Zambezi*. – Proceedings of the Cahora Bassa Workshop, Songo, 29 September – October 02, 1997. – Arquivos do Património Cultural, Maputo, 48 pp.
- DAVIES, B. R., HALL, A. & JACKSON, P. B. N., 1975: Some ecological aspects of the Cahora Bassa Dam. – *Biol. Conserv.* 8: 189–201.
- GORE, J. A. & PETTS, G. E., (eds), 1989: *Alternatives in Regulated River Management*. – CRC Press Inc., Boca Raton, Florida, USA, 344 pp.
- HALL, A. & DAVIES, B. R., 1974: Cabora Bassa: Apreciação global do seu impacto no Vale do Zambeze. – *Rev. Mens Econ. Moçamb., Lourenço Marques* 11: 15–25.
- HALL, A., DAVIES, B. R. & VALENTE, I. C. B. M., 1976: Cabora Bassa. Some preliminary physico-chemical and zooplankton pre-impoundment survey results. – *Hydrobiologia* 50: 17–25.
- HALL, A., VALENTE, I. C. B. M. & DAVIES, B. R., 1977: The Zambezi River in Moçambique: the physico-chemical status of the middle and lower Zambezi prior to the closure of the Cabora Bassa Dam. – *Freshwater Biol.* 7: 187–206.
- HOGUANE, A. M., 1997: Shrimp abundance and river runoff in Sofala Bank – the role of the Zambezi. – *Workshop on The Sustainable Utilisation of the Cahora Bassa Dam and the Valley of the Lower Zambezi, Songo, September 29 – October 02, 1997*, 16.
- HUGHES, R. H. & HUGHES, J. S., 1992: *A Directory of African Wetlands* 657–688. – World Conservation Union, Gland, Switzerland and Cambridge, UK/UNEP, Nairobi, Kenya/WCMC, Cambridge, UK.
- JACKSON, P. B. N., 1986: Fish of the Zambezi system. – In: DAVIES, B. R. & WALKER, K. F. (eds): *The Ecology of River Systems. Monogr. Biol.* 60: 269–288. – Dr. W. Junk, Dordrecht.

- JUNK, W. J., BAYLEY, P. B. & SPARKS, R., 1989. The flood pulse concept in river floodplain systems. – In: DODGE, D. P. (ed.): *Proceedings of the International Large River Symposium. Can. Spec. Publ. Aquat. Sci.* **106**: 110–127.
- KING, J. M. & THARME, R., 1994: *Assessment of the Instream Flow Incremental Methodology and Initial Development of Alternative Instream Flow Methodologies for South Africa*. – Final Contract Report to the South African Water Research Commission., Pretoria, South Africa, WRC #259/1/94, 590 pp.
- MCCULLY, P., 1996: *Silenced Rivers: The Ecology and Politics of Large Dams* – Zed Books, London and New Jersey, 350 pp.
- OLIVIER, H., 1970: *Great Dams of Southern Africa*. – Purnell Publ., Cape Town.
- REES, W. A., 1978: The ecology of the Kafue Lechwe: As affected by the Kafue Gorge Hydro-electric Scheme. – *J. Appl. Ecol.* **15**: 205–217.
- SUSCHKA, J. & NAPICA, P., 1990: Ten years after the completion of Cahora Bassa Dam. – In: *The impact of large water projects on the environment. Proceedings of an International Symposium, 21–31 October, 1986*: 171–203. – UNEP and UNESCO, Paris.
- TINLEY, K. L. & SOUSA DIAS, A. H. D., 1973: Wildlife reconnaissance of the MidZambezi Valley in Moçambique before the formation of the Cabora Bassa Dam. – *Vet. Moçamb. Lourenço Marques* **6**: 103–131.
- WARD, J. V. & STANFORD, J. A. (eds), 1979: *The Ecology of Regulated Streams* – Plenum Press, New York and London, 398 pp.
- WARD, J. V. & J. A. STANFORD, 1983: The serial discontinuity concept of lotic systems. – In: FONTEIN, T. D. & BARTELL, S. M. (eds): *Dynamics of Lotic Ecosystems*: 29–42. – Ann Arbor Science Publ. Michigan.
- WELCOMME, R. L., 1972: *The Inland Waters of Africa*. – UN/FAO. CIFA Technical Paper, 1. 117 pp.
- WILSON, K., 1997: Preliminary estimates of the potential for modifying water discharges from Cahora Bassa to ameliorate environmental impact and maximize socioeconomic benefits in the Zambezi Basin. – *Workshop on the Sustainable Utilisation of the Cahora Bassa Dam and the Valley of the Lower Zambezi, Songo, 29 September – October 2, 1997*, 4 pp.

Author's addresses:

- B. R. DAVIES, Freshwater Research Unit, Zoology Department, University of Cape Town, Rondebosch, South Africa, 7701.
- R. D. BEILFUSS, International Crane Foundation, PO Box 447, Baraboo, Wisconsin, USA, 53913.
- M. C. THOMS, CRC for Freshwater Ecology, University of Canberra, ACT 2601, Australia.