Land-Water Linkages in Rural Watersheds Electronic Workshop

18 September – 27 October 2000

Case Study 20

The influence of a headwater wetland on downstream river flows in sub-Saharan Africa

Matthew McCartney
Centre for Ecology and Hydrology
Wallingford, Oxon OX10 8BB, UK

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, Italy

ABSTRACT

Assessment of the impact of upstream land use on downstream water resources requires an understanding of the hydrological functions of the headwater systems. This paper reports on a study conducted to provide an insight into the hydrology of dambos, a type of seasonal wetland, common in the headwaters of many major river systems in southern and central Africa, including the Zambezi, Kafue, Save, Okavango, Rufiji and Zaire.

THE STUDY

The Dambo Processes Integration Experiment, conducted between 1994 and 1998, involved detailed monitoring of a small catchment at the Grasslands Research Station near Marondera in Zimbabwe. The catchment, located on hard crystalline rocks, is representative of many in the region. It forms the headwaters of the Manyame River, which eventually discharges into the Zambezi. The catchment, area 3.33 km^2, contains a single dambo, of area 1.21 km^2 (i.e. 36% of the catchment). Average annual rainfall is 859 mm, falling predominantly during the summer (October to April). The catchment is used primarily for light cattle grazing but about 16% of the area is used for maize cultivation.

Data, which were collected over a two-year period (1995 to 1997), included catchment rainfall and stream discharge, and soil water content and groundwater levels along an instrumented transect across the catchment. Additional data on geochemical tracers (e.g. chloride and alkalinity) and isotopes (e.g. deuterium), that are naturally present in water, were also collected. The combined data sets were analysed to examine the catchment water balance, hydrological pathways and stream flow generating processes.

WHY ARE DAMBOS IMPORTANT ?

Dambos are significant elements of the landscape over much of Sub-Saharan Africa. Interspersed within miombo woodland, which extends across about 2.8 million km^2, they occupy up to 40% of the land surface in some places. They are important from both a land-use and a water resource perspective, because:

1. Many dambos retain extensive wet regions during the dry season, and this availability of water during dry periods makes them a valuable agricultural resource in arid and semi-arid regions (Scoones, 1991).

2. They are attributed a significant role in the regional hydrological cycle. It is widely believed, though not scientifically substantiated, that they act as "sponges" or reservoirs, storing water during the wet season and releasing it slowly through the dry season, thus attenuating floods and maintaining dry season river flows.

In Zimbabwe, where it is estimated that they occupy about 1.3 million ha (i.e. close to 4% of the country's area), small-scale farmers have always depended on dambos for crop production (Whitlow, 1985). However, for much of this century their disturbance, through cultivation, has been perceived to conflict with their function as a source of downstream river flow. Indeed, colonial legislation (e.g. the Water Act, 1927 and the Natural Resources Act, 1941) sought to prevent dambo cultivation in order to protect downstream water resources.

At present, detailed understanding of the hydrological processes occurring within dambo catchments is lacking. A review of hydrology in southern Africa reveals that much that has been written about their hydrological functions is based on conjecture rather than rigorous

scientific evidence (McCartney, 1998). Dambos are, therefore, worthy of scientific interest in relation to both process understanding and environmental management.

KEY STUDY FINDINGS

- The hydrology of the catchment is heavily influenced by a clay lens embedded at shallow depth within the soil profile of the dambo. The clay lens acts as a barrier, separating the below-clay and above-clay water bearing layers. The soil profile over much of the dambo may be saturated for several months in the wet season because vertical drainage is impeded by the clay and the low slope angle reduces throughflow efficiency.

- Flow from the catchment is seasonal (i.e. the stream never flows all year). The greatest discharge from the catchment occurs when the soil profile across the dambo is saturated (i.e. January to March). Frequency analysis highlights the very "flashy" nature of flow from the catchment; during 1995/96, two-thirds of the total annual discharge occurred on just 15 days out of the 269 with flow (McCartney *et al.*, 1998a).

- The stream may continue to flow well into the dry season; during 1995/96, it continued until 05/09/96, but this late season flow accounted for less than 6% of the total annual runoff. Temporal variation in stream chemistry is consistent with the interpretation that all flow from the catchment, including the dry season recession, is derived predominantly from shallow sources without significant augmentation from a deep "bedrock" aquifer.

- Groundwater inflow from the interfluve (i.e. the surrounding catchment)into the dambo is only a small proportion of the total water input to the dambo over the year, the remainder being direct rainfall. During 1995/96, the inflow from the interfluve was estimated to be just 12% of the total, and most (80%) of this occurred during the wet season.

- Considerable volumes of water (240 +/-125 mm) are stored above the dambo clay lens at the end of the wet season. However, dry season flow typically comprises less than 12 (+/-5) % of the maximum stored within the dambo and potentially available to flow. Thus, it seems depletion of water stored within the dambo is dominated by evaporation (estimated to be 838 mm y^{-1} during 1995/96) rather than by contribution to stream flow.

- Preliminary water balance modelling (Bullock and McCartney, 1996) indicates that vegetation is a key factor in determining whether or not evaporation from the dambo exceeds that from the interfluve. In the research catchment, evaporation from the dambo was found to be greater than from that part of the interfluve covered by indigenous trees (miombo) and grass; during 1995/96, as a proportion of potential evaporation it was estimated to be 8% greater. This was attributed to the fact that the watertable remained closer to the ground surface in the dambo, thus providing more water for evaporation from the dambo than from the interfluve.

- Early in the wet season the watertable beneath the centre of the dambo responds to rainfall more slowly than that at locations upslope, because the heavier-textured and organically-rich soils of the dambo absorb greater quantities of water before water drains to the watertable. However, later in the wet season, when the watertable is either at, or very close to, the ground surface across the dambo, little or no rainfall can infiltrate into the soil and water runs rapidly across the dambo surface into the stream (saturation overland flow). Up to 70% of storm flow may be rain water that reaches the stream in this way (McCartney *et al.*, 1998b). Hence, it is postulated that dambos play a dynamic role in the production of storm flow. When the soil is not saturated they absorb and store water thus reducing flood runoff. In contrast, when they are saturated, they promote flood runoff.

CONCLUDING REMARKS

The principal results obtained in this study demonstrate that considerable volumes of water may be stored within the dambo during the wet season. However, only a very small proportion of this water supports downstream recession flows. Depletion of water stored within the dambo is dominated by evaporation rather than by contribution to stream flow. The results add to the growing body of evidence that, contrary to much that has been written in the past, many dambos do not promote dry season river flow. The results also indicate that although dambos may reduce floods at the start of the wet season, once saturated, they are important in the generation of flood runoff.

These findings have important implications for agriculture and water resource management in the region. Loss of water to evaporation rather than to downstream flow indicates that water within some dambos can be put to productive use in growing crops (particularly shallow rooted crops) with little impact on dry season river flows. The study demonstrates how better quantitative understanding of system functioning is essential for the development and implementation of fully integrated (i.e. land and water) management strategies. Further scientific study is required evaluate how dissimilarity in physiographic attributes and/or land management influences the flow response downstream of catchments containing dambos.

ACKNOWLEDGEMENTS

This work was funded by the UK Natural Environment Research Council. The study was conducted in collaboration with the University of Zimbabwe and the Zimbabwean Department of Research and Specialist Services. The author is indebted to the staff of the Horticultural Research Centre at Marondera for their assistance.

REFERENCES

Bullock, A. and McCartney, M.P. 1996. Wetland and river flow interactions in Zimbabwe. *L'hydrolgie tropicale: géoscience et outil pour le développment* (Actes de la conf? rence de Paris, mai 1995). IAHS 238, 305-321.

McCartney, M.P. 1998. *The hydrology of a headwater catchment containing a dambo*. Unpublishd PhD thesis, University of Reading. 266 pp + appendices.

McCartney, M.P., Butterworth, J. , Moriarty, P. and Owen, R.1998a. Comparison of the hydrology of two contrasting headwater catchments in Zimbabwe. In: *Hydrology, Water Resources and Ecology in Headwaters*. IAHS Publication no. 248, 515-522.

McCartney, M.P., Neal, C. and Neal, M.1998b. Use of deuterium to understand runoff generation in a headwater catchment containing a dambo. *Hydrol. Earth Syst. Sci.* 5, 65-76.

Scoones, I. 1991. Wetlands in drylands: key resources for agricultural and pastoral production in Africa. *Ambio* 20, 366-371.

Whitlow, J.R. 1985. Dambos in Zimbabwe- a review. *Zeitschrift fur Geomorphologie* 52, 63-86.