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Water abstraction from dambos using treadle pumps

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DAMBOS ARE SEASONALLY saturated wetlands, located in the valley bottoms of many headwater catchments throughout sub-Saharan Africa. They are important for the food security of many rural people because they provide a water reserve that can be used in the dry season and during times of drought. In Zambia and other countries in southern Africa, rapid population growth has led to increased utilisation of dambos by small-holder farmers. Increasingly, simple technologies, such as treadle pumps, are being used to facilitate irrigation.

Treadle pumps are manual pumps (operated by the legs) to lift water from rivers and shallow wells. Developed in Bangladesh, they are increasingly obtainable in sub-Saharan Africa. For example, in Zambia it is estimated that there are now approximately 2,500 treadle pumps being used by farmers to irrigate vegetables in dambo gardens. There are two principal designs of pump. "Suction" pumps, used to extract water from rivers or shallow sources, typically produce an average discharge in the range 1 to 2 ls^{-1}, based on sustainable pumping over the day for one operator. "Pressure" pumps, designed to extract water from deeper sources (total pumping pressures up to 14 m) have lower discharges, usually 0.3 to 1 ls^{-1} (Kay and Brabben, 2000).

There is concern that over exploitation of dambos may result in negative environmental effects and that water may be the limiting factor in the extent to which dambos can be utilised. This paper provides a "rule of thumb" for estimating the inflow of water into dambos and presents a simple method for estimating an upper limit to the number of treadle pumps that can safely be used on a dambo.

Figure 1: Conceptualisation of the hydrological fluxes that comprise a dambo water budget

Dambo water budget

There have been very few detailed studies of the water balance of catchments containing dambos (Figure 1). The relative importance of water entering from the surrounding uplands (interfluves) remains a key unknown. In the literature, it has often been stated that dambos receive much of their water as seepage from the surrounding interfluve assisted by rainfall, or that surface runoff and subsurface flow from the interfluves contribute most of the dambo groundwater (e.g. Acres *et al*., 1985). However, no studies present supporting data and the relative importance of the interfluve in providing water to a dambo has been called into question. Balek (1977) notes that dambos "*are recharged mostly by precipitation, since the subsurface inflow into them is relatively small*". It has also been shown that dambo water tables fluctuate in sympathy with rainfall fluctuations, supporting the general hypothesis that direct precipitation is the major input into the dambo (Whitlow, 1985). Of course, to a large degree the relative importance of direct precipitation in the water budget of a dambo will be a function of the areal extent of the dambo relative to the rest of the catchment. This fact has long been recognised:

"*The more extensive this adjacent high ground is the more persistent will the vlei [dambo] be, that is to say that it remains wet longer after the rain stops and retains its moist condition better in a series of drought years.*" (Rattray *et al*., 1953).

In the current project, the few studies of dambo hydrology in which sufficient data have been obtained to estimate the annual water budget of dambos, were re-visited and estimates made of the contribution of water into the dambo from the interfluve (Table 1). The evaporation term is the greatest source of possible error in these water balances.

Figure 2 shows, for the four catchments, the flow into the dambo from the interfluve as a proportion of the total inputs into the dambo. Regression was used to estimate the line of best fit through the points:

$$I_F = 0.08\ DAMBO^{-0.68} \qquad R^2 = 0.91 \qquad N = 4 \qquad (1)$$

where: I_F is the proportion of the total annual input into the dambo that originates on the interfluve. DAMBO is the proportion of the catchment area that is dambo.

The R^2 value is surprisingly high, particularly given the diverse nature and climate of the catchments. The high correlation may partly be a direct consequence of the limited data available to derive the relationship, and an indirect consequence of the assumptions made in computing the water balances of each catchment. Nevertheless, the result confirms the importance of the contributing interfluve area on the annual input of water to the dambo. Although it does not allow for antecedent conditions within the catchment (i.e. in particular the elevation of the water table beneath the interfluve at the start of the wet season), nor the distribution of rainfall within the year, this relationship provides a crude "rule of thumb" for estimating the annual flow from the interfluve to the dambo.

$$Since\ I_F = \frac{Q_I}{(Q_I + P.A.1000)} \quad then\ Q_I = \frac{I_F.P.A.1000}{(1 - I_F)} \qquad (2)$$

where: Q_I is the annual inflow to the dambo that originates on the interfluve (m^3)

P is the annual rainfall onto the dambo (mm)

A is the area of the dambo (km^2).

In terms of agricultural utilisation of dambos, the fluxes from the interfluve into the dambo will be of greatest benefit if maintained into the dry season. Neither Balek and Perry (1973), nor Faulkner and Lambert (1991), provide estimates of seasonal changes in storage within the dambos, so it is only possible to estimate the annual, and not the seasonal, fluxes from the interfluve to these dambos. However, the data obtained from the Grasslands Research Catchment (GRC) in Zimbabwe indicate that the flux from the interfluve occurred predominantly during the wet season, and decreased substantially as the water-levels beneath the interfluve dropped, early in the dry season. About 20% of the flow from the interfluve into the dambo occurred during the dry season and this was approximately 11% of the estimated total water stored in the dambo (i.e. above the clay lens that effectively comprises the hydrological base of the dambo) during the dry season (McCartney, 1998). The flow from the interfluve is important in maintaining the dry season water table within the dambo.

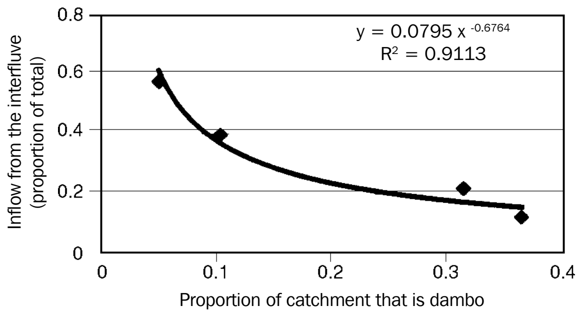

Figure 2: Comparison of the inflow to the dambo from the interfluve for catchments with different proportions of dambo

Assessing "safe" treadle pump withdrawals from dambos

Water resources can limit economic growth in small-scale irrigation. A few farmers pumping from a small stream or

Table 1: Comparison of dambo water balances derived from different catchment studies (source: McCartney, 1998).

	Catchment			
	Luano A Zambia	**Luano J Zambia**	**Chizengeni Zimbabwe**	**Grasslands Research Catchment, Zimbabwe**
Researchers	Balek and Perry (1973)	Balek and Perry (1973)	Faulkner and Lambert (1991)	McCartney (1998)
Catchment area (km^2)	1.43	1.28	2.74	3.33
Area of interfluve (km^2)	1.28	1.22	1.88	2.12
Area of dambo (km^2)	0.15	0.06	0.86	1.21
Area of dambo (%)	10.3	4.9	31.3	36.3
Water balance of the dambo				
Hydrological Year (01/10 to 30/09)	1967/68	1967/68	1985/86	1995/96
Rainfall (Mm^3)	0.190 (1269)	0.079 (1320)	0.793 (922)	1.31 (1085)
Outflow from dambo (Mm^3)	0.239	0.156	0.195	0.330
Dambo evaporation (Mm^3)	0. 076 (508)	0.030 (508)	0.662 (770)	1.014 (838)
Increase in dambo storage (Mm^3)	0.0	0.0	0.156 (181)	0.151 (125)
Inflow from the interfluve (Mm^3)	0.125	0.107	0.221	0.185
(% of total inputs to dambo)	39.7	57.5	22.0	12.4

Numbers in brackets are equivalent volumes in mm shallow groundwater may not cause much of a problem, but large numbers of farmers operating in the same area can result in over exploitation of the resource to the detriment of everyone, including people living downstream. It is therefore necessary to estimate the maximum number of treadle pumps that can be safely used on a dambo.

Assuming an average abstraction rate of 1.5 ls^{-1} and an irrigation time of 20 hours per week, then average water abstraction is 108 m^3 per pump per week. For a crop water requirement of 25 mm a week, typical of the dry season in southern Africa, this equates to an irrigation area of 0.43 ha. In Zambia and Zimbabwe plot sizes usually vary from 0.25 ha to 0.4 ha. Assuming 20 weeks of irrigation in the dry season (April to September) then average total abstraction for a pump is 2,160 m^3, to provide 500 mm of evapotranspiration over 0.4 ha.

Assuming that the amount of water abstracted for dry season irrigation should not exceed the average annual dry season inflow to the dambo, then it is possible, using equations 1 and 2, to estimate the maximum number of treadle pumps that can be safely used on a particular dambo. The results obtained for the research catchments (Table 2) indicate, not unreasonably, that the smaller the proportion of a catchment that comprises dambo and/or the higher the average annual rainfall, the greater the fraction of the dambo that can be safely irrigated with treadle pumps. This seems intuitively more rational than the suggestion that for all catchments a safe limit on the extent of irrigated cultivation on a dambo is 10% of the catchment or 30% of the dambo, whichever is the smaller (Faulkner and Lambert, 1991).

The proposed upper limit on abstraction (i.e. no more than the average dry season inflow) is rather arbitrary, but is cautious, since it makes no allowance for water stored within the dambo at the end of the wet season. Of course, if the maximum numbers of pumps suggested were installed, in years with below average rainfall, abstractions would exceed the dry season inflow and "wet season water" would effectively be removed from the dambo.

The specific yield (i.e. storativity) of the dambo soils at GRC (i.e. above the clay lens) averaged approximately 0.1 (McCartney, 1998). Therefore, treadle pump irrigation of the proposed maximum 7.2 ha in the dry season of 1996 (when actual evapotranspiration equalled 314 mm) would equate to an increased drop in the water table over the dambo of approximately 11 cm.

Concluding remarks

Dambos provide substantial opportunities for irrigated agriculture for small-holder farmers in sub-Saharan Africa. The methodology described in this paper is simple to use and provides a reasonable first estimate, in a water resource context, of the maximum number of treadle pumps that can safely be used on a dambo. In any particular situation consideration should be given to other environmental and socio-economic factors that might further limit the maximum number of treadle pumps that can be used.

Acknowledgements

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Table 2: Estimate of the maximum number of treadle pumps that can be used on a dambo

	Catchment			
	Luano A Zambia	**Luano J Zambia**	**Chizengeni Zimbabwe**	**Grasslands Research Catchment, Zimbabwe**
Catchment area (km^2)	1.43	1.28	2.74	3.33
Dambo area (km^2)	0.15	0.06	0.86	1.21
DAMBO	0.104	0.047	0.313	0.363
Average annual rainfall (mm)	1270	1270	900	860
I_F	0.367	0.629	0.174	0.157
Q_I (annual) (m^3)	110,448	129,191	163,046	193,801
Q_I (dry season) (m^3)*	22,090	25,838	32,609	38,760
Maximum number of treadle pumps+	10	12	15	18
Maximum area irrigated (ha) ^	4 (27)	4.8 (80)	6 (7)	7.2 (6)

* Assuming that 20% of the inflow occurs in the dry season, as was observed at GRC
+ Limiting the maximum number to that which would extract the average dry season inflow
^ Nos. in brackets is the percentage area of the dambo that can be irrigated safely

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