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THE RELATIONSHIPS BETWEEN EVAPORATION AND CERTAIN PHYSICAL PARAMETERS OF CIRCULAR PANS AND RECTANGULAR TROUGHS

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Abstract — The relationships between evaporation and certain physical parameters of circular pans and rectangular troughs are compared. These relationships have a direct influence on the economics of artificial water provision, both in terms of finances and groundwater resources utilized in providing drinking water. Rectangular troughs are more economical than circular pans.

Introduction

Evaporation is normally measured in linear units. For this reason, it is not immediately apparent just how much drinking water is lost by this means. This phenomenon has an insidious but significant effect on the economics of water provision.

The *ideal* water-point (if it is *only* to be used as a watering point by large animals) must provide maximum volume, maximum drinking space (*i.e.* perimeter length) and minimum surface area exposed to evaporation. In this discussion, the relationships between evaporation, drinking space, and volume of circular, earthen pans having a saucer-shaped cross-section and rectangular, concrete, 'V'-shaped troughs are compared. Other aspects of artificial water provision are not discussed here.

Methods

Evaporation data from six weather stations in the Lowveld region were obtained from the Weather Bureau, Department of Transport, Pretoria.

In order to determine the relationships between circular pans and rectangular troughs certain variable physical parameters of these structures were used and calculated as follows:

Circular pans

SA_p = Water surface area, πr^2 (m^2)
where r = radius

D_p = Diameter, $2\left(\frac{SA_p}{\pi}\right)$ (m)

P_p = Perimeter, πD_p or $\sqrt{\frac{SA_p}{0,07958}}$ (m)

V_p = Volume, $0,5236 d_p [3(r^2) + d_p^2]$ (m^3)
(*i.e.* volume of segment of a sphere)
where d_p = maximum depth at centre.

E_p = Daily evaporation, $0,00504\ SA_p$ (m^3)

Rectangular troughs

SA_t = Water surface area, $L_t W$ (m^2)
Where L_t = Length
W = Width

P_t = Perimeter, $2L_t + 2W$ (m)

V_t = Volume, $L_t [W(0,5d_t)]$ (m^3)
(i.e. volume of a prism)
where d_t = maximum depth at centre

E_t = Evaporation, $0,00504 SA_t$ (m^3)

Results and discussion

Mean evaporation data from six stations are summarized in Table 1. The mean daily evaporation of 5,04 mm for all stations represents 5,04 litres/m^2/day. From a 20 m diameter pan therefore, the mean daily loss equals 1 583 litres. This is sufficient water to meet the daily requirements of, for example, 1 168 impala, or 74 buffalo, or 18 elephant (based on an approximate daily consumption of 4 % of mean body mass, Young 1970).

Regardless of a water-point's shape, the greater the surface area, the greater the evaporation loss. Thus from Table 2, evaporation from pans and troughs of similar surface area is the same. It will be noted however that as a pan increases in diameter (D_p) there is an increasingly greater *difference* in drinking space between a pan and a trough (P_t-P_p), for the same surface area. Figure 1A shows that as pan perimeter increases, evaporation increases exponentially whereas in the case of a trough, the increase in evaporation is linear. The rate of evaporation increase, relative to drinking space (E/P_p) for a pan is greater than the same ratio for a trough.

An example will illustrate this phenomenon. A 5,05 m diameter pan has a similar surface area and evaporation as a 10 m long trough (Table 2). The perimeter of the pan (P_p) is 15,85 m whereas the trough's is 24 metres. The trough thus has a perimeter 1,515 times greater (P_t/P_p) than the pan's. Comparing the same parameters for a pan of 25,23 m diameter, the trough now has a perimeter 6,369 times that of the pan's, for the same evaporation loss.

Table 1

Mean evaporation data (mm) for six Lowveld stations (compiled from information obtained from the Weather Bureau, Department of Transport, Pretoria)

	Station						All stations			
Month	05961793 Skukuza n = 24 years	0681266B2 Phalaborwa n = 26 years	0723485A0 Levubu-AGR n = 18 years	05558375 Nelspruit n = 14 years	05558665 Nelspruit Friedenheim-AGR n = 10 years	06792604 Tzaneen n = 5 years	Mean annual total evaporation	Mean monthly evaporation	Mean daily evaporation	% of mean annual total evaporation
January	196,0	236,7	185,2	197,0	189,6	159,2		194,0	6,26	10,37
February	164,4	195,9	147,2	165,4	177,3	144,7		165,8	5,92	9,81
March	163,9	190,0	143,8	165,1	162,9	140,0		161,0	5,19	8,60
April	125,5	147,2	128,9	122,1	135,0	121,3		130,0	4,19	6,94
May	104,5	133,6	125,1	110,0	115,9	104,2		115,7	3,73	6,18
June	86,1	112,4	111,8	93,8	106,3	90,2		100,1	3,34	5,53
July	95,9	124,1	127,8	110,5	117,5	92,5		111,4	3,59	5,95
August	128,4	155,1	152,9	143,3	138,6	107,7		137,7	4,44	7,35
September	165,5	193,6	184,7	180,5	167,9	126,4		169,8	5,66	9,38
October	181,9	220,7	181,4	180,4	178,8	143,8		181,2	5,85	9,69
November	171,0	210,1	175,2	158,1	172,4	159,4		174,4	5,81	9,62
December	199,1	228,4	194,8	186,4	202,8	177,2		198,1	6,39	10,58
Mean annual total evaporation....	1782	2148	1859	1813	1865	1567	1839	—	—	—
Mean monthly evaporation....	148,5	179,0	154,9	151,1	155,4	130,6	—	153,3	—	—
Mean daily evaporation....	4,88	5,88	5,09	4,97	5,11	4,29	—	—	5,04	—

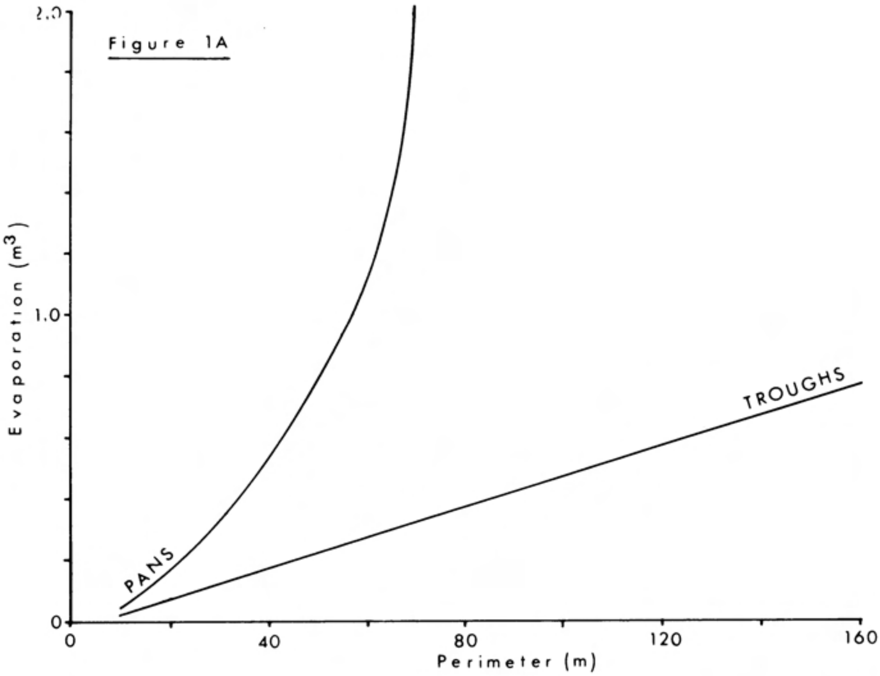
Table 2

The relationships between circular pans and rectangular troughs each having similar surface areas and evaporation rates

Circular pans[1]			Pans & troughs		Rectangular troughs[2]		
D_p	P_p	V_p	SA	E	L_t	P_t	V_t
m	m	m^3	m^2	m^3	m	m	m^3
2,52	7,93	0,315	5	0,025	2,5	9	1,050
3,57	11,21	0,892	10	0,050	5,0	14	2,100
4,37	13,73	1,638	15	0,076	7,5	19	3,150
5,05	15,85	2,533	20	0,101	10,0	24	4,200
5,64	17,72	3,543	25	0,126	12,5	29	5,250
7,98	25,07	10,02	50	0,252	25,0	54	10,50
11,28	35,45	28,25	100	0,504	50,0	104	21,00
25,23	79,27	316,6	500	2,520	250,0	504	105,0
35,68	112,10	895,0	1000	5,040	500,0	1004	210,0

[1] In all cases $d_p = 0,05\ D_p$

[2] In all cases $d_t = 0,42$ m and W = 2 m



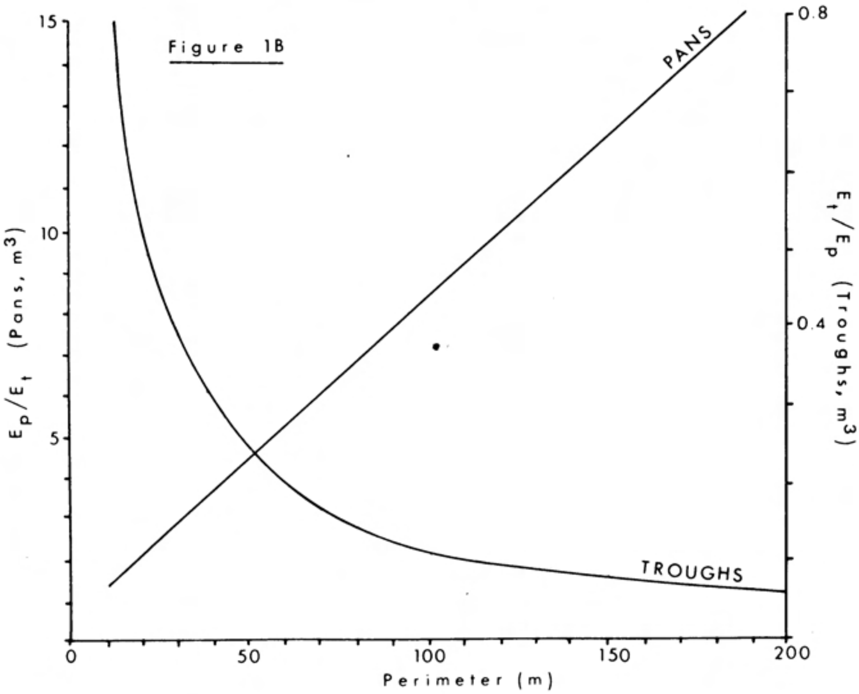


Fig 1. A-B Evaporation and perimeter relationships between pans and troughs (see text for explanation).

When volumes are compared, it can be seen from Table 1 that up to a pan diameter of 7,98 m and a trough length of 25 m, the trough's capacity exceeds the pan's. Beyond these dimensions, the pan's volume exceeds the trough's by a progressively greater margin. In practical terms however, this is not important. A 15 m long trough will hold 6 300 litres. This is enough water to meet the daily requirements of 4 667 impala, or 295 buffalo, or 71 elephant (Young 1970). Greater storage capacity than this is unnecessary and results in a waste of water by evaporation.

Generally then, it is apparent that as pan diameter increases, drinking space also increases, though at a progressively decreasing rate, relative to its surface area (P_p/SA). In the case of a trough, there is more drinking space for the same surface area as a pan (in all cases $P_t/SA > 1 m/m^2$), even for a hypothetical trough 500 m long. Assuming that an arbitrary figure of 0,5-1,0 m^2 water surface is necessary for most herbivores in order to drink, larger pans provide a surface area far in excess of this requirement as only a peripheral band approximately one metre wide is normally utilized. The inner 'core' of the pan thus provides no drinking space, exposing water to evaporation.

Table 3

The relationship between circular pans and rectangular troughs each having similar perimeters.

CIRCULAR PANS[1]				PANS & TROUGHS	RECTANGULAR TROUGHS[2]			
D_p	SA_p	V_p	E_p	P	L_t	SA_t	V_t	E_t
m	m^2	m^3	m^3	m^3	m	m^2	m^3	m^3
3,18	7,96	0,632	0,041	10	3,0	6	1,260	0,030
3,82	11,46	1,098	0,058	12	4,0	8	1,680	0,040
4,78	17,91	2,149	0,090	15	5,5	11	2,310	0,055
6,37	31,83	5,099	0,160	20	8,0	16	3,360	0,081
7,96	49,74	9,917	0,251	25	10,5	21	4,410	0,106
9,55	71,62	17,16	0,361	30	13,0	26	5,460	0,131
10,82	91,95	24,96	0,463	34	15,0	30	6,300	0,151
14,01	154,2	54,18	0,777	44	20,0	40	8,400	0,202
15,92	199,0	79,53	1,003	50	23,0	46	9,660	0,232
23,87	447,6	268,0	2,226	75	35,5	71	14,91	0,358
31,83	795,8	635,1	4,011	100	48,0	96	20,16	0,484
47,75	1790,8	214,8	9,026	150	73,0	146	30,66	0,736
63,66	3182,9	5082,7	16,042	200	98,0	196	41,16	0,988

[1] In all cases $d_p = 0{,}05\ D_p$
[2] In all cases $d_t = 0{,}42$ m and W = 2 m

Comparing pans and troughs with similar perimeters (Table 3) it will be seen that evaporation from a pan increases exponentially as perimeter increases whereas from a trough the increase is linear (Figure 1A). Conversely, the trough to pan evaporation ratio (E_t/E_p) decreases exponentially as perimeter increases, whereas the E_p/E_t ratio for pans is linear (Figure 1B). In other words, as perimeters increase, progressively less water is lost to evaporation per metre drinking space from a trough, whereas exponentially more water is lost per metre from a pan.

In practical terms then, a 15 m long trough with a 34 m perimeter will lose 0,151 m^3 daily, whereas a pan with a similar perimeter (10,82 m diameter) will lose 0,463 m^3 daily. Over a period of one year the trough will lose 55,115 m^3 and the pan 169,00 m^3, a difference of 3,1 times. In addition to this, it must also be remembered that unless constructed of impervious material or sealed artificially, earthen pans also lose water *via* seepage, though this would be difficult to quantify. An additional problem with pans is the turbidity of the water — pans of 10 m diameter or less are frequently churned into a watery mud by certain ungulate species. Most species on the other hand prefer clean water to drink (Weir & Davison 1965; Young 1970; Jarman 1972). By increasing pan diameter, say to 25 m, this problem is reduced to some degree. Such a pan will, however, lose an annual total of 919,8 m^3 of water *via* evaporation, 16,7 times greater than the loss from the 15 m long trough.

Conclusion

As pans and troughs increase in size, so do the differences in their perimeters, evaporation, and volumes. This phenomenon has a direct influence on the economics of artificial water supply. Rectangular troughs are more economical than pans when artificially providing drinking water for wildlife.

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